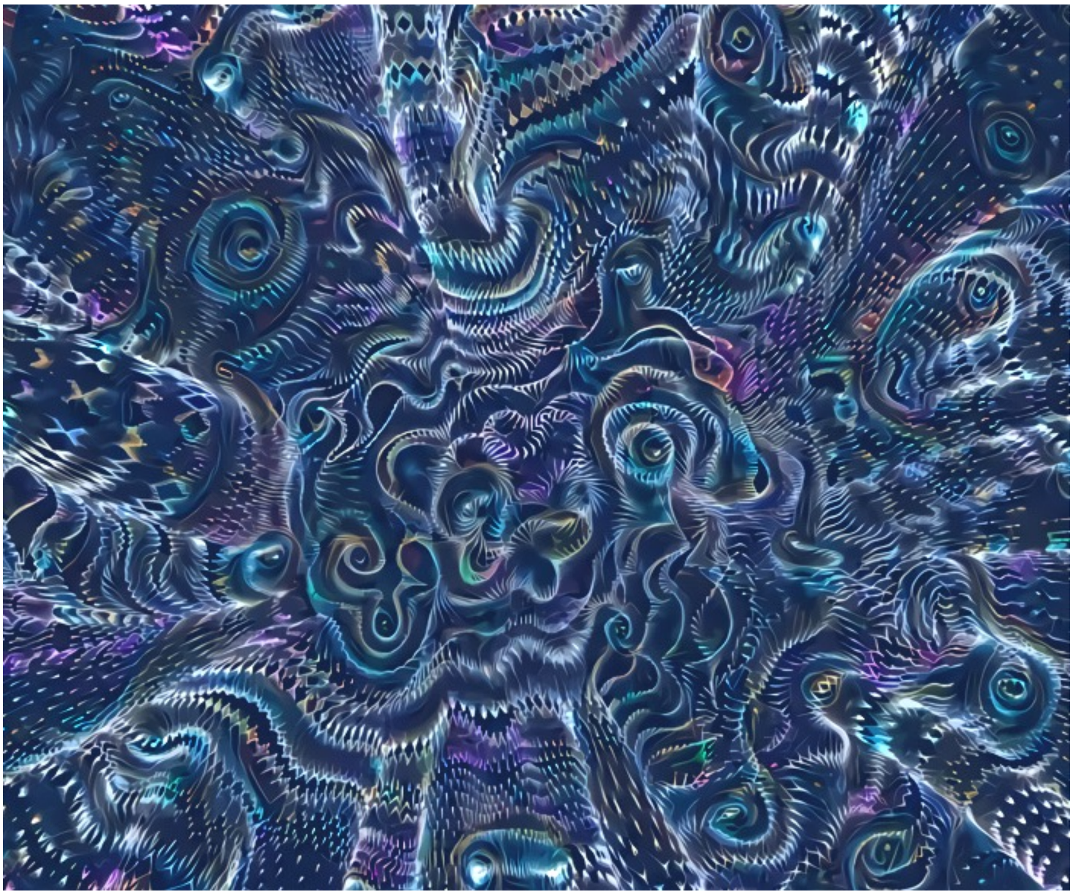
European Commission

Fixed and Mobile Convergence in Europe

Quality Measurements for 5G and Network Densification



FINAL REPORT

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Digital Single Market

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Abstract

High performance and reliable networks will be the core of Europe's Digital Single Market (DSM). Increasingly, convergence of fixed and mobile networks (FMC) will form their basic foundation, essential for the next generation of 5G networks, to support broadband services, both fixed and mobile. This study examines FMC from the perspective of increasing European broadband connectivity through dense small cell networks. Analysis focuses on the practical side of 5G networking in terms of assuring quality of service and encouraging EU-wide coverage through regulatory obligations for mobile broadband. The study examines not just the quality of service indicators that regulatory monitoring of their services will need but the whole framework necessary to introduce such a major transformation. Thus, the report is aimed at future design of practical 5G ecosystems for vertical industry applications. It examines architecture of small cell dense networks and their domination by backhaul. A series of proposals for improving network quality indicators to assure high performance, with reliable and resilient operation are presented. The scope of network quality of experience (QoE) for the end-user, is extended to fit the reality of today's digital society. Finally, the study proposes a phased implementation plan for the EU.

Résumé

Des réseaux performants et fiables seront au cœur du marché unique numérique européen (DSM). De plus en plus, la convergence des réseaux fixes et mobiles (FMC) constituera leur base fondamentale, essentielle pour la prochaine génération de réseaux 5G. Cette étude examine FMC du point de vue de l'augmentation de la connectivité à travers des réseaux de petites cellules denses. L'analyse se concentre sur le côté pratique de la mise en réseau 5G en termes d'assurance de la qualité de service et de promotion de la couverture à l'échelle de l'UE par des obligations réglementaires pour les services à large bande. L'étude propose tout le cadre nécessaire pour introduire une telle transformation majeure. Ainsi, le rapport est ciblé sur la conception des futures d'écosystèmes 5G pratiques, pour des applications industrielles verticales, par l'exploitation des réseaux denses à petites cellules. Une série de propositions visant à améliorer les indicateurs de qualité du réseau sont présentées pour assurer un fonctionnement fiable et résilient. L'étude examine les indicateurs de la qualité d'expérience (QoE) pour l'utilisateur final dans un contexte de la réalité de la société numérique d'aujourd'hui. En conclusion, l'étude propose un plan de mise en œuvre progressive pour l'UE.

Executive Summary

This study was commissioned by DG Connect, Unit F4, Digital Economy and Skills, and Unit B4, Radio Spectrum Policy Unit, and was conducted during 2017, analysing material from surveys with national regulatory authorities (NRAs), technical standards and relevant literature. The objectives of the study were to:

1. Analyse the evolution of fixed-mobile convergence (at service, infrastructure and market levels) in Europe identifying future trends that can improve connectivity;
2. Complement the EU Integrated Platform: *Mapping of Broadband Services in Europe*;
3. Provide a clear understanding of differences in network coverage measurement among the Member States and elsewhere; and,
4. Assess the technical, political and economic obstacles that prevent the definition of common coverage measurements.

To address these objectives, the study was divided into six tasks:

1. Investigating the issues of fixed-mobile convergence (FMC) and fixed-mobile substitution (FMS);
2. Analysing the potential role of fixed networks in the densification of 4G and 5G mobile networks;
3. Assessing the impacts of coverage obligations in cellular licences on connectivity;
4. Exploring EU Member States' use of quality of service (QoS) indicators;
5. Evaluating the possibility of moving toward a common set of QoS indicators; and,
6. Identifying how that might be accomplished.

The subject matter is detailed, fairly technical and so quite dense, supported by extensive research. Hence the Final Report provides a Main Findings chapter as well as a more detailed Methodological Section in addition to this Executive Summary. We were also asked to indicate where the European Electronic Communications Code (EECC) relevant Articles are already supportive of the implementation of the recommendations suggested by the study and what further future actions would be needed to move towards the recommended common approach on network quality and coverage.

This Executive Summary presents the key findings and recommendations.

Key Findings

The key findings from the study that may impact future EU policies are summarized below:

- The greatest challenges for the Digital Single Market (DSM) will not just be politico-economic but increasingly technical, as we become more dependent on networks, especially radio networks. As our dependence rises, so the more reliable and ubiquitous our networks will have to become. Consequently, the study presents a pragmatic, but quite ambitious, approach to making decisions on quality standards for networks.
- The main policy aim should be to make the next, and far more advanced, generation of networks into a viable and dependable reality for the DSM. That requires ensuring appropriate levels of operational quality, reliability and affordability that match technology challenges to social needs, to guarantee that the promised advances work in practice every minute of every day, everywhere.
- This ambitious approach is essential because we are now at a key point in planning delivery of the digital infrastructure that consumers and business will need over

the next decade. This study provides the evidence necessary to take decisions on making implementation of the DSM a reality.

- Moreover, the possibility of agreement on this topic among the Member States, which is essential to its success, is at a critical, positive moment. It could be possible to reach agreement with the key stakeholders and the NRAs, essentially through their consultative bodies, such as BEREC, on the quality measures necessary, in terms of indicators, metrics methods and benchmark values.
- A further major EU policy initiative is the European Electronic Communications Code (EECC). Its potential impacts are mentioned, where appropriate, throughout the report.

Fixed-mobile convergence will impact the forms of network densification

- Convergence of fixed and mobile communications is, and will be, an important trend in the development of EU communications over the long term. The complementarity of the two technology families is likely to be essential to progress further with 5G. The existing fixed infrastructure could supply backhaul for mobile infrastructures in some locations to save investment and speed up deployment and densification of an integrated or converged infrastructure. But there are geographic, economic, technical and regulatory limits on how much the existing fixed infrastructure can be repurposed.
- FMC should be understood as affecting much more than the physical network level. Its impact is layered, affecting the whole constellation of market, services, base stations and access points, down to the level of terminal devices. Whether fixed and mobile technologies are complementary, or substitutes, is determined by the combination of market pricing, service bundles offered, and by the human interfaces. Over-the-top (OTT) services have recently joined the fixed-mobile substitution process, particularly with Voice over IP (VoIP), a close substitute for traditional telephony (e.g. Skype for home use) or a managed business service such as Vonage.
- The integration of Wi-Fi and mobile cellular is also essential, as Wi-Fi can serve stationary or nomadic users at much lower cost than mobile cellular, while mobile remains necessary at speed, for wide area coverage and for hand-offs during a mobile communications session. But cellular/ Wi-Fi integration must not impair the end user’s right – and ability – to choose which local networks to use for data traffic offloads, and when to allocate data traffic to cellular and when to allocate it to local area networks.
- On the fibre optic backhaul side, some MNOs and ISPs – particularly those that are not subsidiaries of converged network operators – want the incumbent players to be more open and flexible on price and availability of “dark fibre” for mobile backhaul and broadband FTTH. They have asked regulators to investigate if the dark fibre owner/operators will have Significant Market Power over this product. Ensuring an open competitive market in wholesale access to mobile and fixed infrastructure – especially for backhaul – will encourage the proliferation of small cells. It could imply the unbundling and sharing of all elements of mobile networks, as well as fixed networks for use by new entrants. It would apply to existing infrastructure, or to novel 5G dense small cell infrastructure support, that could be shared with other new entrants and so lower the barriers to market entry. As stated in the explanatory note to the 2014 Commission Recommendation on relevant markets, NRAs may consider competitive problems within the fibre backhaul market in the context of the analysis of the high-quality access market. Typically, that is regulated. This does not, however, exclude the possibility of NRAs identifying

specific competitive problems on the basis of their national conditions. Thus, they may define a separate market for passive access to backhaul infrastructure, provided it meets the required three criteria test; no NRA has done this so far.

Coverage obligations can be effective for increasing connectivity

- Coverage obligations can be an effective tool to increase coverage. But their design requires careful definition, with constant attention through enforcement by frequent measurements. Field monitoring should fall under the aegis of the NRA, with active verification by the NRA, even if outside bodies are contracted for this.
- Twenty-six of the 28 EU Member States have imposed coverage obligations in one or more mobile frequency bands. These obligations are more common in the lower bands, especially 800 MHz and below. They often concern both voice and data services. Data-only coverage obligations have become more common recently, especially in bands designated for LTE, i.e. 700, 800, 1800, and 2600 MHz. Obligations often specify a minimum population coverage or, less often, minimum area coverage – or some combination of the two. Obligations are often stricter in the bands below 1 GHz, less stringent in the 2.1 and 2.6 MHz bands, as the latter may aim at preventing spectrum hoarding rather than maximising access.
- Confirmation of coverage usually involves two steps: (1) a self-declaration from operators in which they provide evidence of coverage, typically calculations of outdoor signal strength using network planning data; (2) NRAs or subcontractors may then follow up with spot checks to confirm.
- Signal strength, usually received, is the most common metric used to define voice coverage, while for data, it is the minimum downlink data transfer rate. For LTE, threshold data rates typically range from 1 to 30 Mbps. If specified, the obligation usually concerns outdoor coverage. If indoor coverage is included, it often involves some assumptions about wall attenuation (e.g. 10-12 dB attenuation to estimate indoor signal strength).
- Although there are many similarities between the MS they also differ substantially in terms of how these obligations are specified, e.g. on time limits, whether different spectrum blocks and/or incumbents and new entrants have different obligations, whether several bands can be used, and so on. In several MS, the regulators define a list of areas to be covered to a certain extent by a certain date.
- While mobile connectivity and coverage depend on many factors, most of which vary from one MS to another and over time, evidence suggests that coverage obligations can increase public access to broadband services if the obligations are suitably designed. The obligations should be specified to address policy needs, be specific (yet simple) enough, well timed, and include (legislative and economic) incentives for build-out in targeted areas. Vague obligations with deadlines far in the future and no prospects of operator cost recovery should be avoided to achieve the objective of rapid improvement of coverage.
- Nevertheless, from our interviews and surveys with NRAs, many MS are reluctant to consider harmonising their mobile coverage obligations. The diversity and specificity of local conditions (including different population distributions and agreements with neighbouring states, some of them outside the EU) produce different policy objectives and targets, which in turn demand different policy interventions, including different ways to specify coverage obligations. The prevailing opinion among the NRAs is that these matters should be left to the individual MS. Enforcement procedures in cases of non-compliance (fines, revocation of licences, and so on) should also remain national prerogatives.
- However, the value of sharing knowledge and best practice among the Member States is also recognized, and is already taking place to some extent. This should

be encouraged and supported by the EU, in particular for the issues regarding coverage along major transport paths, indoors and in remote and otherwise underserved areas.

- Our research also indicates that European harmonization and standardization of definitions and measurement of coverage and its related indicators could have important benefits. These include economies of scale in the enforcement activities of NRAs, greater certainty in interpretation of policy objectives and improved comparability across Europe. These benefits are generally recognized by the NRAs, although some also point to difficulties and costs of implementing harmonized measurements. Recommendations below examine this further.

Member States' use of QoS/QoE indicators is varied but with similar trends

- The EU Member States realize that the performance of their telecommunications networks and services needs to be monitored using quality indicators. However, today's quality indicators have accumulated gradually, largely in response to regional initiatives, with little planning or foresight. QoS/QoE measurement obligations, minimum performance levels and reporting requirements are scattered across many types of regulatory instruments, from regional directives and national laws to mobile licences, universal service and interconnection agreements, leased line contracts, etc.
- The 28 MS now require the regular measurement and reporting of at least 858 QoS/QoE indicators, an average of more than 30 per country. But averaging hides the fact that some Member State's rely extensively on QoS/QoE measurements while others hardly use them. Only about a quarter of the indicators have preset target values, and these are mainly aimed at universal service providers.
- Although the purpose (and sometimes the indicators' definitions) may have been established by European Directives, the MS determine how measurements are made, by whom, how often, and with what target values. ETSI standards are often the basis for their decisions. But implementation varies and this diversity has become an impediment to the formation of the DSM. Measurement-based indicators are essential for the DSM, not just theoretical estimates.
- Fundamentally, there is a major disparity today in the standards for quality assurance for future networks, as they are a fairly random selection. Moreover, the draft European Electronic Communication Code (EECC) notes that expanding the availability and speed of broadband has been one of Europe's main policy ICT goals. But in the future, improving network reliability, security and sustainability, with performance metrics such as reducing latency will also be important.
- In consequence, modernising the selection of indicators is needed to prepare for more challenging future use cases, as fixed and mobile networks converge in 5G, with stricter performance requirements. And optimistically, the fact that ETSI standards are widely used as guides, and there is growing acceptance of crowd-sourced data speed measurements as being a useful tool, suggest that further convergence in methods and metrics is most likely.

Flexibility and willingness to change are now apparent for QoS measurement

- The study began with the impression that QoS measurement obligations were more or less static among the NRAs and, therefore, they might be difficult to change. However, that is not the case: there is evidence of widespread flexibility and a strong inclination to improve quality standards across all MS.
- Moreover, we also found that this field is more dynamic than is generally recognized, with many NRAs making in-depth reviews every few years and

modifying their QoS monitoring agendas. Some benchmarks are updated, while others are retired. Consequently, it would be a mistake to assume that a country's specific strategy is set in stone and can never change.

- Hence the study's findings suggest NRAs may well be willing to agree on a common set of quality indicators, definitions and methods of measurement and acceptable ranges of benchmark values. This optimism is based on an analysis of QoS rules in the 28 MS which shows that differences generally have logical explanations so discussion and negotiation can narrow the differences. Many apparent differences among national implementations are superficial – arising more from language differences than anything else – although there are also some substantive differences that could be harder to overcome: specifically, some countries prefer a "market led" approach while others prefer a "regulator led" approach. The former tends to impose few QoS reporting obligations while the latter tend to impose many (up to ten times as many).
- Most Member States have adopted and modified their QoS regulations in waves, responding to regional policy initiatives (Directive 98/10/EC, voice telephony and universal service in a competitive environment; the Universal Service Directive 2002/22/EC; and Directive 2009/136/EC, amending the 2002 Directive). They have generally accepted regional guidance as long as the harmonization of details could be considered voluntary. The clearest example is in measurements of call-handling by emergency "112" phone-in centres. This is the only group of QoS parameter measurements implemented similarly in every Member State, and the principles are voluntary.
- In the light of the above acceptance by Member States of Regional policy, we may expect that quality measures (both metrics and measurement methodology) will be adopted and implemented in a consistent and detailed manner across the Union, if a Regulation on quality levels and indicators is set out by the EU.
- The draft EECC code tasks BEREC with devising guidelines for harmonising QoS indicators and measurements and we support that solution.
- A future approach may be that, while the Commission suggests metrics and methods through BEREC, NRAs may then decide if they are appropriate. In this way, the NRAs would be empowered to propose measurement methods that the Commission could evaluate jointly with the NRA to reach agreement. For instance, the growing acceptance of crowdsourced data and link testing by end users is an important area of convergence, even though the websites use different software. Adaptations of M-Lab, Ookla and Austria's NetzTest are the basis of several websites sponsored by the NRAs. Also in this context, ETSI standards provide much commonality, on measurement methodologies, definitions, descriptions, statistical analysis and sampling techniques.
- In summary, all Member States realise that they require their telecommunications networks and services to be monitored regularly and the measured values of these indicators to be reported consistently. They seem willing to accept regional guidance by EU Regulation on national technical implementation (quality measures in terms of metrics and methodology) as long as the detailed governance aspects (e.g. fines for non-compliance) can be considered at national level. Many of the differences among Member States in the choice and use of QoS/QoE indicators thus seem surmountable.

The recommendations below specify the steps necessary to achieve greater regional policy coherence.

Recommendations

The way forward is examined, first, in terms of broader policy perspectives and, second, in terms of specific regulatory actions needed to implement the DSM.

Broad Policy Recommendations

- An institutional framework is needed to bring together NRAs, standards development organizations, operators, software and equipment suppliers, and user communities. Through such an initiative, the EU with BEREC can collectively organize the current random mix of indicators for QoS, QoE and network performance (NP) indicators, removing any that are redundant or obsolete and coherently assembling those that are left to form "key quality indicators" (KQIs) for the DSM.
- To promote this common approach on network quality and coverage, the European Commission is in the best position to trigger the consensual action needed. This process should be guided by a forum of stakeholders, led by the NRAs and BEREC with the aim of seeding a new generation of indicators to support innovative applications based on ubiquitous, affordable, high performance broadband including future 5G networks.
- Sharing of network quality assurance experiences among Member States, with knowledge gained and best practice, is important. It is already taking place to some extent, e.g. via BEREC and through the *Mapping of Broadband Services in Europe* project. It should be supported by the European Commission.
- Broadly speaking, there is no international example outside the EU that offers a model for the EU to follow in terms of QoS/QoE metrics, coverage obligations, measurement methods or enforcement practices. The most useful example beyond the EU is Canada, which has focused attention on the detail of reliability of QoS and QoE for the consumer in terms of continuity of service. From its history of maintaining high quality services in difficult geographic and climate conditions, its regulation focuses on QoS for fixed line and mobile operators, who often have to share a legacy infrastructure from the competing incumbent. The incumbent and competing operators must publicly report their quality achievements and failures, including the penalties paid for transgressions, on online consumer websites.

Regulatory Measures and Reforms to Implement the DSM

These inputs to policy as recommendations are far reaching. Therefore, we first suggest a framework within which they could be organized and implemented. Their basis is in collective EU-wide agreements reached in collaboration with all stakeholders.

1. A European expert group on quality indicators is needed to produce collective decisions about which quality indicators to adopt as a common core set. This would also require an implementation plan. The move towards new levels of quality could not happen at once or in a short period, so a phased introduction, with three phases is probably required. The selected key quality indicators (KQIs) would be based on the QoE/QoS parameters. Such a Europe-wide initiative could be based on BEREC's working group model led by NRAs for its many regulatory initiatives (as proposed in Articles 5 and 22 of the EECC). The successful COCOM expert groups, such as the emergency number 112 group and the new COCOM 5G group demonstrate the appropriateness of such structuring for the BEREC-led initiative. The working group would meet frequently (monthly or more as required) and take ownership of three activities: indicator selection, planning of the implementation task, and overseeing the take-up of indicators across the EU in a phased rollout.

It is recommended that, while BEREC with the NRAs lead this process, other key stakeholders are included – the relevant SDOs, network operators, suppliers, user groups for citizens and industry sectors. The principle task would be to examine the key quality indicators and form the KQI selection, with choice of the specific methods of measurement, that all MS are encouraged to implement. A set of higher-level composite KQIs, incorporating QoS and NP parameters, needs to be designed to simplify understanding of the performance of complex converged heterogeneous networks for end-users and NRAs alike. It would create a series of composite indicators for KQIs that move towards QoE for the end-user. There would also be a need for standardised reporting formats for the indicator's monitored results, identified with numbered clauses from any SDO definitions, to avoid translation divergences in the various MS languages. The final list of key quality indicators (KQIs), and their measurement, could be the subject of an EU Regulation, for reasons of ensuring the commonality of implementation based on BEREC guidelines for a consistent implementation. The current disparities in measurement methods and metrics result from the past use of Directives, which indicates the need for this more robust approach.

To build a complete European framework for networking quality, the expert group would also decide on actions to realise the following:

2. A common platform for measurement – a quality monitoring system for Europe's networks via a shared platform for NRAs to observe key quality indicators may become necessary. Facilities for embedded instrumentation of networks might be set up individually, for each NRA. More advantageous would be a shared EU-level measurement platform, used by all NRAs. That would also bring coherence and harmonization to parameters, measurement methods and data formats. It would support the transnational/internetworking aspects of quality monitoring and bring consistency to parameters, measurement methods and data formats. This has already been proposed by BEREC.

3. Financing the common measurement platform – in order to monitor network operator quality and performance, NRAs may need their own facilities for measuring quality in the future. That would require additions to NRA budgets. Consequently, the cost to NRAs of the measurement process may become a deciding factor in choices of parameters and methods. A shared platform possibly funded at European level may therefore be necessary to seed the initiatives that will ensure consistent adoption of new networking quality levels in all MS with optimal measurement methods in order to protect the DSM. In the area of broadband mapping, to verify the QoS implementation across the EU, funding at EU level may also be needed for a common platform, which would support EU harmonisation of methods and metrics, while recognising the role of NRAs and BEREC. That may also provide a basis for international standardisation of mapping indicators.

4. A European KQI database of quality measures for consumers – to provide constantly updated information of the quality from the various operators, a European database could be attached to the measurement platform for KQIs (it could also leverage existing major repositories of QoS/QoE measurements, if there are suitably compatible information types and formats, or low effort extract and transform processes). This should show the results in an easily understood form for consumers. It could also highlight two key comparative metrics:

- Which operators and networks are most reliable and where for a given performance.
- The public record of transgressions by operators against their services commitments and licence obligations.

5. Widen the parameters to meet the DSM economy's needs – Europe's current inventory of mandated QoS indicators needs modernization. It is still skewed toward voice telephony and includes standards whose continuing relevance is questionable. More importantly, it does not recognize certain themes as part of the DSM quality agenda that will be of increasing importance in the years ahead. Action is needed to:

- Modernize the selection of indicators and prepare for more challenging use cases as fixed and mobile networks converge and stricter performance requirements are needed for the array of high value applications envisioned for 5G networks.
- Work towards a higher level of composite indicators, for end-users and NRAs to simplify understanding of the quality and performance of complex converged networks.

A wider comprehensive quality parameter set for the DSM should include:

- **Benchmark parameters for reliability and resilience** – Bulgaria, Finland and Sweden have benchmarks for network resilience aimed at reducing the possibility of physical disruption from bad weather or the loss of mains power causing loss of service. While reliability appears on our comprehensive list of QoS indicators, it does not appear on the lists of widely mandated indicators because most European countries do not have minimum reliability requirements for public networks. International standards, e.g. from the ITU and ENISA, exist on this topic. Uniform minimum standards for continuity of service throughout Europe will be increasingly important as society's dependence on network services grows.
- **Energy efficiency and pollution reduction** – Telecommunications can reduce greenhouse gas emissions from travel and industry, but the industry's own carbon footprint is steadily expanding. With denser 5G networks, energy density could rise in proportion. Standards for energy consumption should be adopted, as well as for equipment recycling, e.g. with ITU/IEC standards.
- **Network security** – A review of suitable network security standards for EU-level adoption should be pursued, probably within a framework such as ISO.27001, co-ordinated with European and national cybersecurity agencies; ETSI is active here.
- **Privacy and identity protection** – Privacy and identity protection should be recognized as essential parts of network QoS in a web-based society.
- **Health and safety rules** – the biological effects of radio frequency energy are still poorly understood even after a century of widespread human exposure. As we move to higher frequency bands in the centimetric and millimetric ranges, where the energy content of signals is greater and molecular resonance effects become significant, new safety standards will be necessary. These should be formed into a coherent standards policy, with maximum levels of exposure clearly defined.

Several of these parameters are mentioned in the proposed EECC.

6. A regional model for mobile coverage obligations – To reach optimum levels of ubiquitous broadband access, a variety of forms of public support and funding may be necessary. NRA intervention in various ways will also be needed. Relevant tools might include coverage obligations, rules for network sharing that protect competition, etc. Some of these are pointed to in the EECC, e.g. Articles 30 (with 18 and 19), 45 that sets general objectives and obligations of coverage, and art.47 (3) intended to promote convergence in the criteria used to frame such coverage obligations (e.g. methods for designing coverage obligations) – but not to harmonize coverage conditions. Such interventions will only be effective if suitably designed (the obligations should address policy needs, have a suitable level of detail specified, with an appropriate time-frame and include legislative and economic incentives for rollout in targeted areas, etc., see above). We therefore recommend that a *regional model for mobile coverage obligations is produced as an EU guide*, including principles for enforcement. Its design guidelines should be based on best practice for quality indicators, offering definition of metrics and acceptable parameter levels with measurement methods, as well as what to consider in the design of coverage obligations. However, obligations and enforcement procedures for broadband coverage obligations would remain national prerogatives for NRAs, and national administrations, orchestrated by BEREC.

Résumé analytique

Cette étude a été commandée par DG CONNECT, Unité F4, Economie Numérique et Compétences, et Unité B4, politiques du spectre radio. L'étude a été réalisée en 2017, en analysant les données des enquêtes avec les autorités réglementaires nationales, les normes techniques et la littérature pertinente.

Les objectifs de l'étude étaient les suivants:

1. 1.Analyser la convergence fixe-mobile en Europe (au niveau de l'infrastructure, de service et du marché) au fil du temps et détecter les tendances futures qui peuvent améliorer la connectivité en Europe;
2. Supporter la plate-forme intégrée de l'UE sur la cartographie des services à large bande en Europe;
3. Donner une exposition claire de la mesure des différences de couverture en mobile large bande entre les États membres, et d'ailleurs dans le monde;
4. Evaluer les obstacles politiques et économiques qui empêchent la définition des mesures de couverture.

Pour répondre à ces objectifs, l'étude a été divisée en six tâches:

1. Etudier les problèmes de la convergence fixe-mobile (FMC) et de la substitution fixe-mobile (FMS);
2. Analyser le rôle possible des réseaux fixes dans la densification des réseaux mobiles 4G et 5G;
3. Evaluer les incidences des obligations de couverture dans les licences cellulaires sur la connectivité;
4. Explorer l'utilisation par les États membres de l'UE des indicateurs de qualité de service (QoS);
5. Compléter l'évaluation de la possibilité d'adopter un ensemble commun d'indicateurs de qualité de service et de l'expérience utilisateur;
6. Identifier les actions nécessaires pour adopter les indicateurs de qualité (KQIs) à travers l'UE.

Le sujet est détaillé, assez technique et donc assez dense, et fait l'objet de recherches approfondies. Donc ce rapport final fournit cette section des conclusions essentielles, suivi par une section des résultats principales ('Main Findings') ainsi qu'une section méthodologique plus détaillée. On nous a également demandé d'indiquer où des articles pertinents du Code européen des communications électroniques (EECC) sont favorables à la mise en œuvre des recommandations suggérées par l'étude.

Ce résumé analytique présente les principaux résultats et recommandations.

Principales constatations

Les principales constatations de l'étude qui peuvent avoir des répercussions politiques de réseaux futures de l'UE sont résumés ci-dessous:

- Les plus grands défis pour le marché unique numérique (Digital Single Market, DSM) ne seront pas seulement politico-économiques, mais de plus en plus techniques, car nous devenons plus dépendants des réseaux, notamment les réseaux de communications sans fil. Comme notre dépendance augmente, donc la plus fiable nos réseaux ubiquitaires devra devenir.

- Le principal objectif devrait être de faire de la prochaine, et beaucoup plus avancée, génération de réseaux en une réalité fiable et viable pour le DSM. Cela exige l'assurance des niveaux appropriés de qualité opérationnelle, en fiabilité et économie, alignent les défis technologiques avec les besoins sociaux, afin de garantir que le progrès promis marche parfaitement, chaque minute de chaque jour, partout.
- Cette approche ambitieuse est essentiel car nous sommes maintenant à un point clé dans la planification de la livraison de l'infrastructure numérique que les consommateurs et les entreprises auront besoin de au cours de la prochaine décennie. Cette étude fournit la preuve nécessaire pour prendre des décisions sur la mise en œuvre de la DSM pour la construire en réalité.
- De plus, la possibilité d'un accord sur ce sujet parmi les États membres, qui est essentielle à son succès, est à un moment positif, critique. Il pourrait être possible de parvenir à un accord avec les principaux intervenants et les administrations nationales de la réglementation (les ANR), essentiellement par l'intermédiaire de leurs organes consultatifs, tels que l'ORECE (BEREC), sur la qualité des mesures nécessaires, en termes d'indicateurs, les méthodes de mesure et les valeurs de référence.

La convergence fixe-mobile aura un impact sur les formes de densification du réseau

- La convergence des communications fixes et mobiles (FMC) est, et sera, une tendance importante dans le développement des communications de l'UE à long terme. La complémentarité des deux familles de technologies sera probablement essentielle pour encore progresser avec la technologie des réseaux 5G. L'infrastructure fixe existante pourrait fournir une partie de la connectivité ('backhaul') pour les infrastructures mobiles dans certains endroits afin de réaliser des économies d'investissement et d'accélérer le déploiement et la densification d'une infrastructure intégrée ou convergée. Mais il existe des limites géographiques, économiques, techniques et réglementaires sur la façon dont l'infrastructure fixe existante peut être réorientée.
- La convergence FMC doit être comprise comme affectant beaucoup plus que le niveau physique du réseau. Son impact s'étend sur toute la structure opérationnelle, celui du marché, des services, des stations de base et des points d'accès, jusqu'au niveau des terminaux. Que les technologies fixes et mobiles soient complémentaires, ou substituables, est déterminé par la combinaison des prix du marché, des offres groupées de services et des interfaces humaines. Les services over-the-top (OTT) ont récemment rejoint le processus de substitution fixe-mobile, en particulier avec la voix sur IP (VoIP), un substitut proche de la téléphonie traditionnelle (par exemple Skype pour un usage domestique) ou un service pour la commerce, géré, tel que Vonage.
- L'intégration d'une connexion Wi-Fi et mobiles est également essentiel, car une connexion Wi-Fi peut servir les utilisateurs nomades ou fixes à un coût bien moindre que la téléphonie mobile, en cas de mobilité reste nécessaire à la vitesse, pour une couverture étendue et de transferts (handover) au cours d'une session de communications mobiles. Mais l'intégration cellulaire / Wi-Fi ne doit pas nuire au droit et à la capacité de l'utilisateur final de choisir les réseaux locaux à utiliser pour les décharges de données et quand allouer le trafic de données au réseau cellulaire et quand l'allouer aux réseaux locaux.
- Du côté de la fibre optique, certains operateurs des réseaux mobile (ORM) et fournisseurs d'accès Internet (FAI) – en particulier ceux qui ne sont pas des filiales d'opérateurs de réseaux convergents – souhaitent que les opérateurs historiques et dominants soient plus ouverts et flexibles sur le prix et la disponibilité de la «fibre noire» ('dark fibre') pour la téléphonie mobile et le haut débit FTTH. Ils ont demandé aux régulateurs d'enquêter si les propriétaires / exploitants de fibre noire aura un pouvoir de marché significatif (SMP) sur cette offre qu'il exploite abusivement.

S'assurer un marché concurrentiel ouvert en gros pour l'accès à l'infrastructure fixe et mobile - en particulier pour les liaisons - encouragera la prolifération des cellules. Il pourrait impliquer la séparation et le partage de tous les éléments de réseaux mobiles, ainsi que des réseaux fixes pour l'utilisation par les nouveaux entrants. Il s'appliquerait à l'infrastructure existante, ou à de nouvelles petites cellules denses 5G soutien de l'infrastructure, qui pourraient être partagées avec d'autres nouveaux venus et ainsi de réduire les obstacles à l'entrée sur le marché. Comme l'indique la note explicative à la 2014 Recommandation de la Commission sur les marchés pertinents, les ANR peuvent tenir compte des problèmes de concurrence au sein du marché de l'acheminement de la fibre dans le contexte de l'analyse du marché de l'accès à la haute qualité. En général, ce marché est réglementé. Cependant, cela n'exclut pas la possibilité pour les ANR d'identifier les problèmes de concurrence sur la base de leurs conditions nationales. Ainsi, ils peuvent définir un marché séparé pour l'accès à l'infrastructure passive de retour (‘backhaul’), à condition qu'il respecte les trois critères requis ; aucun test ANR a fait jusqu'à présent.

Obligations de couverture peut être efficace pour accroître la connectivité

- Obligations de couverture peut être un outil efficace pour augmenter la couverture. Mais leur conception nécessite une définition précise, avec une attention constante à travers l'application par des mesures fréquentes, suivi sur le terrain sous l'égide de l'ANR, avec la vérification active par l'ANR, même si des organismes externes, tiers partis, sont contractés pour cela.
- Vingt-six des 28 États membres de l'UE ont imposé des obligations de couverture mobile dans une ou plusieurs bandes de fréquences. Ces obligations sont plus communs dans les bandes bas UHF, en particulier 800 MHz et ci-dessous. Souvent, ils concernent à la fois les services voix et données. Les obligations de couverture de données seulement sont devenues plus courantes récemment, en particulier dans les bandes désignées pour LTE, c’est à dire 700, 800, 1800 et 2600 MHz. Souvent les obligations de couverture de la population minimum ou, moins souvent, la couverture d’une surface géographique minimum - ou une combinaison des deux. Les obligations sont souvent plus strictes dans les bandes inférieures à 1 GHz, moins sévères au 2.1 et 2.6 MHz, comme celui-ci peut viser à empêcher l’accumulation de fréquences (‘spectrum hoarding’) plutôt que de maximiser l'accès.
- Confirmation de couverture comporte généralement deux étapes: (1) une auto-déclaration de la part d'opérateurs dans lequel ils fournissent la preuve de la couverture, généralement les calculs de la puissance du signal à l'extérieur de l'utilisation du réseau de données de planification; (2) Les ANR ou les sous-traitants peuvent alors suivre avec contrôles sur place pour confirmer.
- La puissance du signal, habituellement cela reçu, est le plus commun utilisé pour définir des métriques de couverture de la voix, tandis que pour les données, c'est le minimum de taux de transfert de données de liaison descendante (‘downlink’). Pour LTE, le seuil de données élevées étend généralement de 1 à 30 Mbits/s. Aussi, si spécifié, l'obligation pourra concerne généralement une couverture à l’extérieure. Si la couverture est incluse à l'intérieur, elle implique souvent des hypothèses d'atténuation (par exemple pour un mur 10 à 12 dB d'atténuation pour estimer l'intensité du signal en intérieur).
- Bien qu'il existe de nombreuses similitudes entre les États membres, ils diffèrent aussi considérablement en termes de la façon dont ces obligations sont précisées, par exemple sur les limites de temps, si les blocs de fréquences sont différentes et/ou les titulaires traditionnels (‘incumbents’) et les nouveaux entrants ont des obligations différentes, si plusieurs bandes peuvent être utilisées, etc. Dans plusieurs États

membres, les organismes de réglementation définir une liste de domaines à couvrir, avec une certaine mesure, par une certaine date.

- Alors que la connectivité mobile et la couverture dépendent de nombreux facteurs, dont la plupart varient d'un État membre à l'autre et au fil du temps, l'évidence suggère que la couverture des obligations peut accroître l'accès du public aux services à large bande si les obligations sont bien conçus. Pour cela, les obligations devraient être précisées pour répondre aux besoins de la politique, être spécifique mais assez simple, au bon moment, et comportent des incitations (législatif et économique) à construire-dans des domaines ciblés. Afin d'améliorer la couverture, des obligations sans ces conditions doit être éviter.
- Néanmoins, à partir de nos entrevues et sondages avec les ANR, de nombreux États membres sont réticents à considérer l'harmonisation de leurs obligations de couverture mobile. La diversité et la spécificité des conditions locales (y compris les distributions différentes de la population et des accords avec les États voisins, avec certains d'entre eux en dehors de l'UE) produire différents objectifs et cibles, qui à leur tour nécessitent des interventions politiques, y compris les différentes façons de spécifier les obligations de couverture. Parmi les régulateurs, l'opinion est que ces sujets sont dans le domaine de décision de chaque État membre, surtout pour les mesures d'application.
- Cependant, l'importance du partage de connaissances et de bonnes pratiques entre les États membres est également reconnue, et est déjà en place dans une certaine mesure. Cela devrait être encouragé et soutenu par l'Union européenne, en particulier pour les questions relatives à l'assujettissement le long des principales voies de transport, à l'intérieur et à l'éloignement et à l'autrement les zones mal desservies.
- Nos recherches indiquent également que l'harmonisation européenne et la normalisation des définitions et mesure de la couverture et ses indicateurs connexes pourrait présenter d'importants avantages. Il s'agit notamment des économies d'échelle dans les activités d'application de l'ANR, avec une plus grande certitude quant à l'interprétation des objectifs de la politique et aussi l'amélioration de la comparabilité à travers l'Europe. Ces avantages sont généralement reconnus par les ARN, bien que certains soulignent aussi les difficultés et les coûts de la mise en œuvre des mesures harmonisées. Les Recommandations ci-dessous examinent ces points.

L'utilisation des indicateurs QoE/QoS par Les États membres est varié mais avec des tendances similaires

- Les États membres de l'UE se rendent compte que la performance de leurs réseaux de télécommunications et de services doit être contrôlé à l'aide d'indicateurs de qualité. Cependant, leurs indicateurs de qualité d'aujourd'hui ont accumulé peu à peu, en grande partie en réponse aux initiatives régionales, avec peu de planification et de prévoyance. QoE QoS/obligations de mesure, les niveaux minimaux d'efficacité et les exigences en matière de rapports sont dispersés dans de nombreux types d'instruments réglementaires, des directives et des lois nationales de licences de téléphonie mobile, le service universel et les accords d'interconnexion, lignes louées, contrats, etc.
- Le 28 États membres de l'UE exigent maintenant la mesure régulière de rapports et d'au moins 858 indicateurs QoE/QoS, une moyenne de plus de 30 par pays. Mais avec cette moyenne cache le fait que certains États membres reposent largement sur les mesures QoE QoS/tandis que d'autres ne les utilisent presque de tout. Seulement approximativement un quart des indicateurs ont des valeurs cible prédéfinie, et ce sont principalement destinés aux prestataires du service universel.
- Bien que l'objectif (et parfois les définitions des indicateurs) aient pu être établis par des directives européennes, les États membres déterminent comment les mesures

sont effectuées, par qui, à quelle fréquence et avec quelles valeurs cibles. Les normes ETSI sont souvent à la base de leurs décisions. Mais la mise en œuvre varie et cette diversité est devenue un obstacle à la formation du DSM. Les indicateurs basés sur les mesures actuels sont essentiels pour le DSM, pas seulement des estimations purement théorétiques.

- Fondamentalement, il existe aujourd'hui une grande disparité dans les normes d'assurance de qualité pour les réseaux de l'avenir, car elles sont une sélection assez aléatoire. En outre, le projet de code européen de communication électronique (EECC) note que l'extension de la disponibilité et de la vitesse du haut débit a été l'un des principaux objectifs politiques de l'Europe en matière de TIC. Mais à l'avenir, l'amélioration de la fiabilité, la sécurité et les mesures de performance (telles que la réduction de la latence) sera également importante.
- En conséquence, la modernisation de la sélection des indicateurs est nécessaire pour préparer les scenarios d'utilisation futurs, qui seraient plus difficiles, étant donné que les réseaux fixes et mobiles convergent vers la 5G, avec des exigences de performance plus strictes. Et de manière optimiste, le fait que les normes ETSI soient largement utilisées comme guides et que l'on considère les mesures de la vitesse des données fournies par les moyens comme 'cloudsourcing' suggère qu'une rapide évolution des méthodes et métriques est possible.

La flexibilité et la volonté de changement sont maintenant apparentes pour la mesure de QoS

- L'étude a commencé avec l'impression que les obligations de mesure de la qualité de service étaient plus ou moins statiques parmi les ANR et, par conséquent, elles pourraient être difficiles à modifier. Cependant, ce n'est pas le cas: il existe des preuves de flexibilité généralisée et une forte tendance à améliorer les normes de qualité dans tous les États membres.
- De plus, nous avons également constaté que ce domaine est plus dynamique que ce qui est généralement reconnu. Des nombreuses ANR procèdent à des examens approfondis périodiquement, après plusieurs années, modifiant leurs programmes de surveillance de la qualité de service. Certains repères sont mis à jour, tandis que d'autres sont à la retraite. Par conséquent, ce serait une erreur de supposer que la stratégie spécifique d'un pays est figée et ne peut jamais changer.
- Donc les résultats de l'étude suggèrent que les ANR peuvent ainsi être disposés à s'entendre sur un ensemble commun d'indicateurs de qualité de service, des définitions et méthodes de mesure et des fourchettes acceptables de valeurs de référence. Cet optimisme est fondé sur une analyse des règles de QoS dans les 28 états qui montre que les différences ont généralement des explications logiques. Des discussions et négociations peuvent réduire ces divergences. De nombreuses différences apparentes entre les implémentations nationales sont superficiels – résultant des traductions dans chaque langue, plutôt que toute autre chose - bien qu'il y a aussi des différences plus substantiels qui pourraient être difficiles à surmonter: spécifiquement, certains pays préfèrent une approche "marché" alors que d'autres préfèrent une approche "régulateur". Les premiers ont tendance à imposer peu des obligations sur la qualité de service, alors que les derniers ont tendance à imposer plus (jusqu'à dix fois plus nombreux).
- La plupart des États membres ont adopté et modifié leur réglementation QoS par vagues, en réponse aux initiatives de politique régionale (suivant Directive 98/10 / CE, téléphonie vocale et service universel dans un environnement concurrentiel, Directive sur le service universel 2002/22/CE; Directive 2009/136/CE, modifiant la Directive de 2002). Ils ont généralement accepté l'orientation régionale tant que l'harmonisation

des informations détaillées peut être considérée comme volontaire, par l'état. Le meilleur exemple est dans les mesures de la gestion des appels d'urgence "112" aux centres d'accueil. C'est le seul groupe de mesures des paramètres de QoS suivant la même réalisation dans tous les États membres ; et les principes sont volontaires. Cela pourrait être un modèle pour plus des approches en communes.

- Le projet de code EECC charge l'ORECE d'élaborer des lignes directrices pour harmoniser les indicateurs de qualité de service et les mesures, et nous soutenons cette solution.
- Une approche future pourrait être le suivant - bien que la Commission suggère des mesures et des méthodes en coopération avec l'ORECE, les ANR pourraient alors décider si elles sont appropriées. De cette façon, l'ANR serait dans la position de proposer des méthodes de mesure que la Commission pouvait évaluer conjointement avec l'ANR pour arriver à un accord. Par exemple, l'acceptation croissante de données crowdsourcing et les tests de qualité par l'utilisateur final est un domaine important de la convergence, même si les sites web utilisent des logiciels différents. Les adaptations de M-Lab, d'Ookla et de NetzTest en Autriche sont à la base de plusieurs sites sponsorisés par les ANR. Toujours dans ce contexte, les normes ETSI fournissent beaucoup de points communs, sur les méthodologies de mesure, les définitions, les descriptions, l'analyse statistique et les techniques d'échantillonnage.
- En résumé, tous les États membres se rendent compte qu'ils ont besoin de leurs réseaux de télécommunications et de services d'être surveillé régulièrement et les et les valeurs mesurés de ces indicateurs d'être toujours contrôlés. Ils semblent disposés à accepter des conseils régionaux par une régulation de l'UE sur la mise en œuvre technique nationale, pour les mesures de qualité en termes de métriques et la méthodologie en vigueur, aussi longtemps que les aspects de gouvernance (par exemple des amendes pour non-conformité) peuvent être considérés au niveau national. Donc, la plupart des différences entre les États membres dans le choix et l'utilisation des indicateurs QoS/QoE semblent surmontables.

Les recommandations ci-dessous indiquent les étapes nécessaires pour achever une cohérence des politiques régionales.

Recommandations

On examine d'abord les perspectives politiques, suivi par les mesures réglementaires nécessaires à la mise en œuvre de la DSM.

Recommandations de politique générale

- Un cadre institutionnel est nécessaire pour rassembler les ANR, ainsi que les organismes d'élaboration de normes, les opérateurs, les fournisseurs de matériel et de logiciels et les communautés des utilisateurs. Grâce à une telle initiative, l'UE avec l'ORECE peut organiser collectivement l'actuel mélange d'indicateurs pour la qualité de service (QoS) et de l'expérience (QoE) et les performances du réseau (NP). Cela demande la suppression de qui soit redondantes ou obsolètes – et puis d'assembler ceux qui sont laissés pour former des "principaux indicateurs de qualité" (KQIs) pour le DSM, de façon cohérente.
- Pour promouvoir cette approche commune sur la qualité des réseaux et de la couverture, la Commission européenne se trouve en meilleure position pour déclencher les actions nécessaires de coopération européenne. Ce processus doit être guidé par un forum des parties concernées, dirigée par les ANR et l'ORECE, dans le but de produire une nouvelle génération d'indicateurs. Ces indicateurs soutiendront des

applications à large bande, novatrices et ubiquistes, abordable et performantes - dont les futurs réseaux 5G.

- Le partage entre les Etats membres des expériences sur l'assurance de la qualité du réseau est important, soulignant les connaissances acquises et les meilleures pratiques. Il est déjà en place dans une certaine mesure, par exemple par l'ORECE et grâce au projet de la cartographie des services à large bande en Europe. Il devrait être soutenu par la Commission européenne.
- D'une manière générale, il n'y a pas d'exemple à l'échelle internationale à l'extérieur de l'UE qui offre un modèle à suivre en termes de QoS/indicateurs QoE, obligations de couverture, les méthodes de mesure ou de pratiques d'application de la loi pour l'UE. Le seul exemple utile, au-dehors de l'UE, est le Canada, qui a se concentré sur le détail de la fiabilité de la qualité de service et de l'expérience (QoS/QoE) pour le consommateur en termes de continuité de service. À partir de son histoire de maintenir des services de haute qualité dans des conditions climatiques et géographiques difficiles, son règlement met l'accent sur la qualité de service pour les opérateurs fixes et mobiles, qui doivent souvent partager une infrastructure héritée de la titulaire (incumbent) rival. Cet opérateur historique et les opérateurs concurrents doivent rendre compte publiquement de la qualité de leurs réalisations, et des échecs, y compris les pénalités payées pour les transgressions, sur les sites web des consommateurs.

Recommandations pour les mesures réglementaires et des réformes pour réaliser le DSM

Ces supports du politique en forme des recommandations sont importants pour le long terme. En conséquence on propose d'abord un cadre dans lequel ils pourraient être organisées et réaliser. Une convention collective est la base des accords à l'échelle de l'UE, décidé en collaboration avec toutes les parties intéressées.

1. Un groupe d'experts européens sur les indicateurs de qualité est nécessaire – avec le but de produire des décisions collectives sur lesquelles les indicateurs de qualité seraient adopter, avec le choix de leurs paramètres de base. Cela nécessiterait également un plan de mise en œuvre. L'évolution vers de nouveaux niveaux de qualité ne pourrait pas se produire dans une seule étape et dans une courte intervalle. Une introduction progressive, avec trois phases est probablement nécessaire. La sélection des principaux indicateurs de qualité (KQIs) serait fondée sur les paramètres de qualité de l'expérience et de service (QoE/QoS). Une telle initiative à l'échelle de l'Europe pourrait être basée sur les groupes de travail de l'ORECE, et donc dirigé par les ANR (comme proposé dans les articles 5 et 22 de la code EECC). Le succès de la COCOM (avec ces groupes d'experts, tels que le numéro d'urgence 112 et le nouveau groupe COCOM 5G group) montrent la pertinence d'une telle structuration. Ce groupe de travail peut se réunira fréquemment (une fois par mois, plus si nécessaire) et prendre responsabilité pour trois activités: la sélection des indicateurs ; la planification de la tâche de mise en œuvre ; et la supervision de l'adoption des indicateurs dans l'UE à un déploiement progressif, en trois phases.

Il est recommandé que, si l'ORECE (BEREC) avec les ANR diriger ce processus, d'autres intervenants clés sont inclus- les organisations de normalisation européen (ETSI/ 3GPP, CEPT, etc), les opérateurs de réseau, les fournisseurs, les groupes d'utilisateurs pour les citoyens et les secteurs de l'industrie. La tâche principale serait d'examiner les principaux indicateurs de qualité et puis de former la sélection KQI, avec choix des méthodes de mesure, que tous les États membres sont encouragés à mettre en œuvre. Un ensemble de KQI composites de niveau supérieur, intégrant des paramètres QoS et NP, doit être conçu pour simplifier la compréhension des performances des réseaux hétérogènes convergents complexes pour les utilisateurs finaux et les ANR. Cela créerait une série d'indicateurs composites pour les KQI qui évolueraient vers la QoE pour l'utilisateur final.

Egalement, il serait nécessaire de disposer de formats standardisés pour les valeurs captés et les résultats de l'indicateur (identifiés par des clauses numérotées pour les définitions des organisations de normalisation, comme ETSI ou UIT afin d'éviter les divergences de traduction dans les différentes langues des Etats membres). La liste finale des principaux indicateurs de qualité (KQIs), et leurs détails de mesure, pourrait faire l'objet d'une Régulation de l'UE, pour des raisons d'assurer l'uniformité de la mise en œuvre, suivant les lignes directrice de l'ORECE, pour une mise en œuvre cohérente. Nos recherches ont montrés les disparités actuelles dans les méthodes et paramètres de mesure suivant les plusieurs Directives, ce qui indique la nécessité de cette approche plus sure, par une Régulation. Avec le but de construire un cadre européen qui assura la qualité des réseaux, le groupe d'experts serait également responsable pour les décisions sur les aspects de base suivants:

2. Une plateforme commune pour la mesure – un système de surveillance de la qualité pour les réseaux est nécessaire via une plateforme commune pour les ANR pour observer les principaux indicateurs de qualité. Des équipements pour l'instrumentation, intégrée dans les réseaux, peuvent être configurés individuellement pour chaque ANR. Cependant, plus avantageux et utile serait une plateforme partagée, au niveau de l'Union européenne, et utilisée par tous les ANR. Cela apportera la cohérence et l'harmonisation des paramètres, les méthodes de mesure avec les formats de données et stockage. Elle serait favorable à l'interconnexion des réseaux transnationaux avec les aspects de contrôle de la qualité, bout à bout, exploitant l'harmonisation des méthodes de mesure et paramètres a travers ces réseaux différentes. Cela a été proposé déjà par l'ORECE.

3. Financement de la plate-forme commune de mesure – afin de surveiller la qualité et la performance des opérateurs de réseau, les ANR peuvent avoir besoin de leurs propres installations à l'avenir, pour mesurer la qualité. Cela nécessiterait des ajouts aux budgets de l'ANR. Par conséquent, le coût du processus de mesure pour les ANR peut devenir un facteur décisif dans le choix des paramètres et des méthodes. Alternativement, une plateforme partagée éventuellement financée au niveau européen, peut donc être nécessaire pour lancer ces initiatives qui garantiront l'adoption cohérente de supérieurs niveaux de qualité des réseaux dans tous les États membres, afin de protéger le DSM. Dans le domaine de la cartographie large bande, pour vérifier la mise en œuvre de la QoS dans l'UE, un financement au niveau européen pourrait être aussi nécessaire pour une plateforme commune qui soutiendrait l'harmonisation des méthodes et des métriques, tout en reconnaissant le rôle des ANR et de l'ORECE. Cela peut également servir de base à la normalisation internationale des indicateurs de cartographie.

4. Une base de données européenne des mesures KQI de qualité pour les consommateurs – pour fournir des informations constamment actualisées sur la qualité des différents opérateurs, une base de données européenne pourrait être attachée à la plateforme de mesure des KQI (elle pourrait également tirer des sélections des grands bases de données des mesures QoE/QoS, s'il y a des types d'information compatibles et en formats standards). Ceci devrait afficher les résultats dans une forme facile à comprendre pour les consommateurs. Il pourrait également mettre en évidence deux principaux indicateurs comparatifs:

- Les opérateurs et les réseaux qui sont les plus fiables et performant (et où).
- Publication du dossier des transgressions par les opérateurs, contre les engagements et obligations de leurs autorisations d'opération des services.

5. Élargir les paramètres pour répondre aux besoins de l'économie DSM - L'inventaire actuel de l'Europe est chargé des indicateurs de qualité de service, qui a besoin de modernisation. Il est toujours orienté vers la téléphonie vocale et comprend des normes dont la pertinence est discutable. Plus important, il ne reconnaît pas certains thèmes en qualité de réseau, qui seraient indispensable dans les années à venir pour le DSM. Des actions sont nécessaires pour:

- Moderniser la sélection d'indicateurs et se préparer pour les cas d'utilisation plus difficiles et complexes, comme la convergence des réseaux fixes et mobiles, et des exigences plus sévères en précision et rigueur pour l'ensemble des applications de grande valeur envisagée pour les réseaux 5G.
- Travailler à un niveau plus élevé, avec des indicateurs composites, pour les utilisateurs finaux et les ANR afin de simplifier la compréhension de la qualité et de la performance. Cela doit être accompli dans une situation de complexité élevée, avec des réseaux convergeant d'haut débits.

Un plus large ensemble de paramètres de qualité complète pour le DSM devrait introduire:

- **Paramètres de référence (benchmarks) pour la fiabilité et résilience** - la Bulgarie, la Finlande et la Suède ont des points de référence pour la résilience du réseau visant à réduire la possibilité de rupture physique pendant des intempéries ou la coupure de courant, qui entraînent une perte de service. Bien que la fiabilité apparaisse sur notre liste complète des indicateurs de qualité de service, il n'apparaît pas sur le plupart des listes d'indicateurs des pays européens, qui manquent d'exigences de fiabilité minimale pour les réseaux publics. Des normes internationales, par exemple de l'UIT et de l'ENISA, existent sur ce sujet. Avec la croissance en dépendance de notre société sur les services des réseaux, des normes minimales uniformes pour la continuité du service seront de plus en plus important pour la vie quotidienne et la prospérité de l'Europe.
- **L'efficacité énergétique et la réduction de la pollution** - des télécommunications peuvent réduire les émissions de gaz à l'effet de serre pour les transports et l'industrie, mais l'empreinte carbone de l'industrie de télécommunications lui-même est en progression constante. Plus denses avec les réseaux 5G, la densité d'énergie pourrait augmenter en proportion. Des normes pour la consommation d'énergie devront être adoptées, ainsi que pour le recyclage de l'équipement, par exemple, avec les normes IEC/UIT, dans lesquelles l'UE a participé déjà.
- **Sécurité du réseau** - un examen des normes de sécurité réseau approprié pour l'adoption au niveau de l'UE devrait être poursuivi, potentiellement dans un cadre fonctionnel comme l'ISO.27001, coordonnée avec les organismes européens et nationaux de la cybersécurité ; ETSI est actif ici.
- **Protection de la vie privée avec protection d'identité** - la vie privée et la protection d'identité devraient être reconnus comme des éléments essentiels de la qualité de réseau dans une société basée sur le web.
- **Règles de santé et de sécurité du personnel-** les effets biologiques de l'énergie des fréquences radios sont encore mal compris, même après un siècle d'exposition de la population européen. Alors que nous passons à des bandes de fréquences plus élevées dans les gammes millimétrique et centimétrique, où la teneur en énergie des signaux est plus grande et les effets de résonance moléculaire

deviennent significatifs, de nouvelles normes de sécurité sera nécessaire. Ces devrait être formé dans une politique cohérent de normes, avec des limites maximales d'exposition clairement définis.

Plusieurs de ces paramètres sont mentionnées dans le projet pour le code EECC.

6. Un modèle régional pour les obligations de couverture mobile – Avec le but d'atteindre un niveau optimal d'accès à large bande ubiquitaire, une variété de formes d'aide publique peut être avec un support financière sont nécessaire. L'intervention de l'ANR de diverses manières seront également nécessaires. Les outils pertinents peuvent inclure la couverture d'obligations, des règles de partage en réseau pour protéger la concurrence, etc. Certaines de ces derniers sont fait au projet du code EECC (par exemple les articles 30 avec 18 et 19, 45 qui fixe les objectifs généraux et les obligations de couverture et de l'art.47 (3) destiné à promouvoir la convergence dans les critères utilisés- les méthodes de conception des obligations de couverture, comment les encadrer, etc., mais pas d'harmoniser les conditions de couverture). De telles interventions ne seront efficaces que si lis ne sont pas judicieusement conçus (par exemple, répondre aux besoins de la politique, avec un niveau de détail spécifié, et un délai approprié, etc.). On recommande donc un modèle régional pour les obligations de couverture mobile soit produit – comme guide pour l'UE, y compris les principes d'application. Ses lignes directrices de conception devraient être basées sur les meilleures pratiques pour les indicateurs de qualité, offrant une définition des mesures et des niveaux de paramètres acceptables avec des méthodes de mesure, ainsi que ce qu'il faut considérer dans la conception des obligations de couverture. Toutefois, les obligations et les procédures d'application des obligations de couverture du haut débit resteraient des prérogatives nationales pour les ANR, orchestrées par l'ORECE.

Abbreviations

2G	Second generation mobile communications (GSM)
3G	Third generation (mobile communications)
3GIS	3G Infrastructure Services
4G	Fourth generation (mobile communications)
5G	Fifth generation (mobile communications)
AGCOM	Autorità per le Garanzie nelle Comunicazioni (Authority for Communications Guarantees, NRA, Italy)
AKOS (formerly APEK)	Agencija za komunikacijska omrežja in storitve Republike Slovenije (Agency for Communications Networks and Services of the Republic of Slovenia)
ARCEP	Autorité de régulation des communications électroniques et des postes (French Regulatory agency for electronic communications and posts)
AWS	Advanced Wireless Services
BER	Bit Error Rate
BEREC	Body of European Regulators for Electronic Communications
BEUC	European Consumer Organization
BIAC	(European Commission's) Broadband Internet Access Cost study
C-ITS	Co-operative and Intelligent Transport System
CAPEX	Capital expenditure
CCCE	Commission consultative des communications électroniques
CEPT	Conférence Européenne des administrations des Postes et des Télécommunications (European Conference of Postal and Telecommunications Administrations)
CMA	Cellular Market Area
COCOM	Communications Committee (DG CONNECT)
ComReg	Commission for Communications Regulation (Ireland)
CQI	Channel Quality Indicator
CPE	Customer Premises Equipment
CRC	Communications Regulation Commission (Bulgarian NRA)
D2D	Device-to-Device
DAE	Digital Agenda for Europe
dBμV/m	Decibel above 1 microvolt per meter
dBm	Decibel referenced to milliwatts
DOCSIS	Data Over Cable Service Interface Specification
DMM	Distributed Massive MU-MIMO
DSL	Digital Subscriber Line
DSM	Digital Single Market
EA	Economic area
EC	European Commission
ECC	Electronic Communications Committee
EECC	European Electronic Communications Code
eMBB	Enhanced Mobile Broadband
EMF	Electromagnetic field
ERC	European Radiocommunications Committee
EUTC	European Utilities Technology Council
FCC	US Federal Communications Commission
FDD	Frequency division duplex
FICORA	Finnish Communications Regulatory Authority
FMC	Fixed-mobile convergence
FMS	Fixed-mobile substitution
FTTC/H/B	Fibre To The Cabinet; Fibre To The Home; Fibre To The Basement
FWA	Fixed Wireless Access

G.mgfast	Multi-Gigabit Fast Access to Subscriber Terminals
GDP	Gross Domestic Product
GIS	Geographic Information System
GPON	Gigabit Passive Optical Network (based on ITU-T G.984)
GPS	Global Positioning System
GPRS	General Packet Radio Service (narrowband data for GSM)
GSM	Global System for Mobile Communications, 2G (orig. Groupe Spécial Mobile)
HD	High definition (audio or video)
HDTV	High definition Television
Hetnet	Heterogeneous Network (also HetNet)
IAS	Internet Access Service
IEEE	Institute for Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
INTUG	International Telecommunications Users Group
IP	Internet Packet (protocol)
IPDF	IP Packet Variations
IPER	IP Packet Error Ratio
IPLR	IP Packet Loss Ratio
IPTV	Internet Packet Television
IEEE	Institute for Electrical and Electronics Engineers
IT	Information technology
ITU	International Telecommunication Union
KPI	Key performance indicator
KPO	Key performance objective
KQI	Key quality indicator
KTH	Kungliga tekniska högskolan (Royal Institute of Technology)
LAA	Licensed Assisted Access (introduced in 3GPP release 13)
LoS	Line of sight
LTE	Long-Term Evolution
LTE-U	LTE-Unlicensed (a variant of LTE for license exempt spectrum)
M2M	Machine-to-machine
MFCN	Mobile/fixed communications networks
MIC	Ministry of Internal Affairs and Communications (Japan)
MU-MIMO	Multi-User Multiple-Input/Multiple-Output
MIMO	Multiple Input–Multiple Output
MNO	Mobile network operator
MS	Member State (in the EU context)
MSE	Mean squared error
MSB	Myndigheten för samhällsskydd och beredskap (Swedish Civil Contingencies Agency)
MTBF	Mean Time Before Failure
MTTR	Mean Time To Repair
N4M	Net 4 Mobility
NBP	National broadband plans
NFV	Network Function Virtualization
NFV MANO	Network Function Virtualization Management and Orchestration
NP	Network performance
NRA	National regulatory authority
NGA	Next generation access
NGO	Non-governmental organization
NSA	(US) National Security Agency
Ofcom	Office of Communications (UK or Switzerland)
OPEX	Operating expense
P2P/CWDM	Point-to-Point/Coarse Wavelength Division Multiplexing
PBX	Private Branch eXchange

PoP	Point of Presence
PTS	Post och TeleStyrelsen (Swedish Post and Telecom Authority)
QoE	Quality of experience
QoS	Quality of service
PBX	Private branch exchange
RAN	Radio Access Network
REAG	Regional Economic Area Grouping
RSCP	Received Signal Code Power (a parameter for measuring UMTS coverage)
RSPG	Radio Spectrum Policy Group
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
RSSI	Received Signal Strength Indicator
RSU	Road-Side Unit
RTT	Round Trip Time (for ping test for latency)
RxLEV	Received signal LEVel
RxQUAL	Received signal QUALity
PTS	Post och TeleStyrelsen (Swedish Post and Telecom Authority)
SDN	Software Defined Network
SDO	Standards development organization
SG-12	Study Group 12 (quality, ITU)
SFR	Société Française du Radiotéléphone
SINR	Signal-to-Interference-plus-Noise Ratio
SMP	Significant Market Power
SP	Service Provider
SSNIP	Small but Significant and Non-transitory Increase in Price
ST	Sub task
TCP/IP	Transmission Control Protocol/ Internet Protocol
TDD	Time Division Duplex
UE	User equipment
UHD	Ultra-High Definition (video)
URLLC	Ultra-Reliable Low-Latency Communications (5G use case)
UMTS	Universal Mobile Telecommunications System
USD	Universal Service Directive (2002 and later amendments)
UX	User experience
V2I	Vehicle-to-(roadway)-infrastructure
V2P	Vehicle-to-person/pedestrian
V2V	Vehicle-to-vehicle
V2X	Vehicle-to-anything
VHC	Very High Capacity
VHS	Very High Speed
VM	Virtual Machine
VNF	Virtualized Network Function
VoLTE	Voice over LTE
WAN	Wide Area Network
WAP	Wireless Access Protocol
WDM	Wave Division Multiplexing
WLAN	Wireless Local Area Network
WPT	Wireless Power Transfer
WRC-19	2019 ITU World Radio Conference
WWRF	Wireless World Research Forum

1 Introduction

1.1 Convergence and Next Generation Networks Form the Context for this Study

The advent of the Digital Single Market (DSM) implies massive efforts to both reinforce current networking for broadband services (fixed and mobile), as well as their reuse for the next generation of denser small cell networks. This will demand both significant technical advances and financial investment. That implies that the integration of mobile and fixed networks into a single seamless offering, termed fixed-mobile convergence (FMC), is of immense interest in terms of the logistics of rollout and also of overall cost savings from reuse of existing fixed and mobile infrastructure, which includes Wi-Fi.

Discussions around the next promised generation of 5G networks so far have focused on the technical solutions needed for major leaps in network performance and spectrum efficiency, as well as use of millimetric and centimetric bands. There has been less practical discussion about the costs of deploying and operating the networks and the optimal quality metrics, based on user experience, that will make the services useful and attractive. That requires careful preparations for the market reality of a competitive environment. Consequently, this is now recognized as a significant area for study.

1.2 Objectives

A reality check is called for as we inch closer to commercial 5G deployment. While the business case for 5G is still uncertain, existing operational models remain even more unfinished. There has been little work on the technical difficulties of ubiquitous coverage and quality of service (QoS), which will have to cope with services over heterogeneous networks, end-to-end. The companion to our study, on an integrated platform for broadband coverage (the Mapping Study on Broadband Coverage in Europe, Smart 2014/0016) has clearly shown the diversity of definitions for coverage, measurement methodologies, and metrics across the EU Member States (MS) with diversity of opinions on these topics among the national regulatory authorities (NRAs).

It is in this context that the European Commission called for a study to examine FMC, the obligations for mobile coverage and, most importantly, the quality measures for networking now in place and the key indicators that will be necessary for the next generation of Europe's networks to support the DSM's commerce and society in everyday operation. Hence, this study replies to six key questions outlined in the call for tender, carried out in six main tasks:

1. What is the history and potential impact of fixed-mobile convergence (FMC) in terms of connectivity? What is FMC's current state of play? And when and how does mobile substitute for fixed line services – or vice versa – and what triggers substitution? How does this FMC phenomenon operate at market, infrastructure and service level?
2. How can FMC aid connectivity in the future, in view of the cost breakdown of high density future networks, for broadband take-up and the reuse of fixed-line infrastructure services, especially Wi-Fi for the nomadic user?
3. What are the differences in mobile coverage obligations among the MS? What are the effects of coverage obligations on connectivity and what insights can be gained for their further use? And what are the technical, political and economic obstacles that prevent the definition of common coverage metrics in the EU?

4. Where are we today with quality of service and performance metrics and methods used in various networks across the EU? This is a complex subject defined in various directives, statutes and regulations that differ in nature and interpretation across the MS. But what are the barriers to a common approach to network quality?
5. What are the optimal measurement approaches, especially in the context of radio-based connectivity, with 5G, for the future? What indicators should be included, in view of the social and economic measures of quality such as reliability of service, cybersecurity, privacy, etc?
6. How should a coherent framework for an EU network quality initiative be shaped, and how should rollout be engineered across the MS in a multi-year timeframe?

1.3 Methodology and Description of Work Carried Out

The study took place over 12 months in 2017 and used various data gathering processes to prepare the analysis presented:

- A literature search especially on the technical and regulatory aspects. This included gathering statistics on coverage obligations in the EU-28.
- Collection and analysis of standards from the main standards development organizations (SDOs). Over 100 quality standards were examined, from ETSI, the ITU, IETF, ECC/CEPT, IEEE, as well as recommendations from BEREC, the European Commission, OECD and certain NRAs.
- Research into the laws, statutes and network regulations of the EU-28 MS, in their own languages. This step required translation from the original languages to produce key insights on network quality indicators and regulations with the differences across the EU-28.
- A survey of NRAs, with two structured questionnaires. We also interviewed certain NRA teams via teleconference. Some NRAS who supported us wished to keep their responses confidential and we have respected this. In conducting this survey, we were aided by BEREC, who most kindly distributed our questionnaires to their members. We also contacted leading SDOs on relevant standards as well as telecommunications operators and equipment vendors to canvas their views.

1.4 Structure of the Report

The report is structured as follows:

First, an Executive Summary presents key findings and recommendations. This is followed by a Main Findings section, which gives a brief synopsis of the whole study. The approach, methodology, sources and key findings for the study form the Methodological Section, with detailed description of the analysis of the six tasks assigned by the terms of reference for the study. Bibliographic references for each task are presented at the end of each subsection. A brief final Conclusion closes the report. The whole study has been supported by extensive research among the many stakeholders.

2 Main Findings

Guide to this Chapter

This Main Findings chapter gives a summary overview of the study, which addresses six key issues: fixed-mobile convergence versus fixed-mobile substitution; the possible role of fixed networks in the densification of 4G and 5G mobile networks; the impact of coverage obligations in cellular licences; EU Member States' use of quality of service (QoS) indicators; and the possibility of moving toward a common set of QoS indicators; and how that might be accomplished. It covers these same topics but in less detail than the full accounts in the Methodological study report following.

The chapter begins by looking at fixed-mobile convergence as an aid to the development of Europe's Digital Single Market. This is explored then further as a factor in mobile network densification, after briefly examining why densification is necessary and why it is so costly. The next sections examine the current situation in the EU in terms of:

- Effectiveness of coverage obligations in mobile license conditions on mobile coverage; and
- How and why the Member States measure the technical performance, Quality of Service (QoS) and quality of experience (QoE) of electronic communications networks and their services.

The chapter then explores ways to improve the use of quality indicators, making them more relevant to the user experience and more appropriate to new wireless technologies like 5G. The final section offers a comprehensive plan for modernising these indicators in 12 steps, to meet the Digital Single Market's needs for better network quality, with a phased roadmap for introduction of new quality indicators.

We were also asked to consider the proposed European Electronic Communications Code measures and its relevance to the implementation of the study recommendations related to Quality of service and coverage obligations. Thus, this Main Findings report also explores the various regulatory changes proposed in the EECC draft (of September 2016) in its role in the implementation of the proposed study recommendations for the next generation of networks

2.1 Do Mobile Networks Complement or Substitute for Fixed Networks?

Since the early 1990s, Europe has grown used to having two types of public electronic communication networks – fixed line and mobile cellular. As future networks will progressively use both, especially in dense small cell configurations, it is necessary to reassess the relationship between fixed and mobile – and between broadband and narrowband networks as well. The reason for this is to understand the capabilities for integration to produce new heterogeneous networks, which requires identifying where each type complements the other, or may substitute for it. This must be examined from different standpoints, taking regulation, technology, infrastructures, services and markets into account.

In understanding the relationship between fixed and mobile networks and the issues that arise, this report:

- Defines convergence and substitution between fixed and mobile;
- Reviews the history of their convergence and the extent to which they are substitutes;
- Examines the impact of convergence on the telecommunications industry and its regulation; and
- Explores operator strategies in response to fixed-mobile convergence (FMC) and fixed-mobile substitution (FMS), specifically, the bundling of fixed and mobile services and infrastructures.

First, it is necessary to understand the terminology commonly used:

- ***Convergence*** is the progressive integration of two sectors or sub-segments of those sectors. This integration can be at the market, service or infrastructure level or it may combine all three levels.
- ***Substitution*** refers to mobile networks substituting for fixed networks.
- ***Complementarity*** implies that two infrastructures and their services can interwork without competing, as each network type has its own role. They may even enhance each other, as when the use of one type of network increases the use of the other type of network.
- ***Compatibility*** implies that various network types can interwork technically.

The convergence of fixed and mobile communications is, and will be, an important trend in the development of EU communications over the long term. The complementarity of the two technologies is likely to be essential to progress further with 5G. The existing fixed infrastructure could supply backhaul for mobile infrastructures in certain circumstances, to save investment and speed up deployment of an integrated or converged infrastructure, and the mobile Core and RAN networks could be similarly integrated, in suitable conditions.

FMC should be understood as impacting much more than the physical network level. It can be considered as a layered architecture of market, services, base stations and access points, down to the level of terminal devices. Whether fixed and mobile technologies are complementary, or substitutes, is determined by the combination of market pricing and services offered, and by the ease of use of the human interface.

"Over-the-top" (OTT) services recently joined the fixed-mobile substitution process, particularly with Voice over IP (VoIP), a close substitute for traditional telephony (e.g. Skype for home use) or a managed business service such as Vonage.

2.1.1 A Brief History of FMC and FMS

The first wave of FMS was probably at the market level, as mobile voice services began to take market share away from fixed-line voice communications in the EU in the late 1990s. This trend gained traction as cellular handsets became progressively more convenient to carry in one's pocket. This enabled mobile take-up and rapid substitution of fixed calls, driving the growth of mobile operators towards market dominance for narrowband voice in many EU Member States. This was particularly the case in those MS that lacked a dense fixed-line infrastructure, such as Portugal and Poland. Eurobarometer (2016) notes that some 33% of EU households had only mobile access in October 2015, with no fixed line connectivity. This was especially the case in the southern and eastern parts of Europe.

Broadband services were launched more than a decade ago but FMC in broadband is a more recent phenomenon. Mobile networks in the late 1990s were at best carriers of narrowband data, circuit switched over the voice channel at perhaps 9.6 kbps. Data packet services over GSM (GPRS) were then added.

The history of FMC follows the three major dimensions of convergence: infrastructure, services and markets. Elements of mobility for previously fixed handsets (or at least restricted portability within the customer premises) were added to the fixed network with the sale of cordless telephones. These were introduced in the USA in the 1970s but did not become a mass market product in Europe until the early 1990s. Five main stages of the market development in FMC can be identified:

- **Voice convergence at the device level**: The first major market for FMC was the office market in the late 1990s and after: It was centred on the private branch exchange (PBX), for voice and voicemail.
- **The PBX as a mobile hub hosted on a PC**: for the "bring your own device" (BYOD) market: The conventional PBX air interface technologies have been augmented by all the mobile standards, as PBX manufacturers tried to accommodate any mobile handset and any MNO as call carrier.
- **Unified communications (UC):** a complex, sometimes ambiguous FMC concept that incorporates various forms of FMC at the device, service and network levels. It is usually based on integrating communication services on a server.
- **A trend to convergence between public services and markets took off with mobile subscriptions:** In 2001, mobile subscriptions overtook fixed line subscriptions globally[1] to the surprise of many in an industry still oriented towards fixed line network infrastructure and its services. FMS grew from this.
- **Cordless nomadic users become dominant for in-building connection:** At a terminal device level, the convergence of many different RLANs in one portable or handheld smart phone type of device has evolved with the pace of radio technologies, integrating all the generations of mobile cellular with non-cellular: Wi-Fi, Bluetooth, NFC; RFID, UWB, etc.

Our survey of national regulatory authorities (NRAs) across the EU showed that, as convergence became a goal of telecommunications operators, ISPs and content providers, regulators in Europe have taken more notice of the trend in their public policy statements, giving more attention to network rollout and its impact on competition.[2] Converged telecoms/media companies are gaining market share in many EU MS with converged services and markets (e.g. Virgin Media, Liberty Media, Altice, Vivendi, etc.). Also, the satellite and cable TV industry, such as Sky, originally focused on pay-TV, have become players in retailing broadband Internet access and the telecommunications services derived from IP access over the Internet – voice and video chat, etc. Although NRAs observe this changing market and the bundling of telecommunications, pay-TV and Internet access, they still consider these elements to be separate and not, as yet, forming a single market.

2.1.2 Impact of Convergence on the Telecom Industry and Regulation

The impact of FMC and FMS can be clearly seen in markets and on competition, leading to regulatory consequences. The traditional separation of markets is challenged by convergence, both the broadband and narrowband segments, fixed and mobile. While fixed and mobile markets are both subject to telecommunications regulation, there have been major differences in the level of regulatory supervision. These differences originally

[1] ITU, World Telecommunications Indicators Database (WTID), https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx.

[2] Responses were received from 19 MS NRAs on their views on the changing market's competitive challenges, away from narrowband voice to one of converged telecommunications, pay-TV and Internet access.

arose from the presumption that the mobile market was separate from the fixed market, being much younger and without an incumbent former monopoly. As mobile was "born competitive", it was assumed that a lighter touch was needed to encourage this nascent sector.

However, this may be changing. Regulators see protecting and expanding consumer choice as a key objective, and FMS must be seen in this context, if mobile and fixed offerings are from different operators. Effectively this would take the form of infrastructure competition, of mobile broadband versus xDSL, for example. Of course, same-market (mobile) competition would still be present from MNOs and those operators using the unbundled mobile infrastructure to carry their services, the MVNOs.

Our survey of NRAs found that the majority have considered whether fixed and mobile services belong to the same or different markets. However, so far, only one (RTR of Austria) has decided that fixed and mobile services serve the same market. In general, NRAs vary in their thinking about whether mobile is a competitor to fixed line services. For instance, Ofcom in the UK took the opposite view to Austria's RTR on broadband mobile substitution:

- "…mobile broadband packages (offered via a USB modem or "dongles") tend to have a fraction of the download limits compared to fixed broadband access…"
- "…Current maximum speeds for mobile broadband access … generally are achieving …a fraction of the speeds achieved through fixed broadband
- "neither mobile broadband (i.e. dongles) nor internet access via smartphones will be strong substitutes for fixed broadband access over the review period ending in 2021 (Ofcom, 2012).

Our findings echo Ofcom's sentiments. Dissimilar usage patterns characterize different markets. File downloads and streaming video are faster on fixed line networks than on mobile, more reliable, often of higher quality and much cheaper for high data volumes. This explains why most NRAs still do not currently consider fixed and mobile services to be part of the same retail market.

2.1.3 Does Convergence of Fixed and Mobile Markets Require Regulatory Change?

Decisions on possible deregulation of fixed line are currently based on the degree of effective competition by substitution, for fixed-line, by other telephone services. But mobile substitution for fixed broadband is limited and fixed narrowband voice substitution by mobile voice has slowed. The EC Recommendation on relevant product and service markets in the electronic communications sector (2007) considered that ex ante access obligations could be removed for access and call origination on the public telephone network provided at a fixed location. The EC notes that although both mobile voice and VoIP can provide pricing competition to the fixed line incumbents, only managed VoIP is comparable, and thus a substitute, for fixed-line voice, because it has similar attributes (European Commission, 2014).

However, there is less clarity about VoIP and its relationship to the narrowband services for which it may substitute, especially for managed VoIP, although Lange and Saric (2016) suggest a stronger degree of substitution between fixed and mobile than between fixed line telephony and VoIP. The next stage in fixed network technology is the rollout of Next Generation all-IP networks in all the MS. So, in the future, VoIP substitution for fixed line voice may spread.

At the EU level, the regulatory impact may be to favour joint market definition for managed VoIP and public operator services, i.e. increased competition, perhaps resulting in the termination of some regulatory activities. But that will require a broader comparison with VoIP and bundling effects to be carried out. Since market conditions, competition and regulation differ so much across the EU, such changes might be better considered at the national level first by each NRA. Thus, the answer to the question of whether the threat of abuse of Significant Market Power (SMP) by fixed wireline incumbents still exists is moot. More analysis is called for. MNOs, once the challengers to fixed-line incumbents, are the new incumbents today. Furthermore, the fixed line incumbent may also be the dominant mobile player in many MS.

2.1.4 Complementarity and Regulatory Impacts

The market strategy of many incumbent operators now is to leverage their position in the fixed-line market to help them expand into the mobile market (Grzybowskiy and Verboven, 2013). Broadband technologies such as xDSL and cable can generate strong complementarities between fixed and mobile access, while mobile broadband (MBB), within its limits, strengthens mobile substitution, e.g. for content sampling. The emergence of fixed broadband has thus been an important additional source of complementarity with mobile in the broadband market. Policies aimed at regulating the broadband market have an impact on the structure of the market for voice services through complementarities. Two common regulatory responses to this phenomenon are:

- Promotion of local loop unbundling through regulation for service-based competition, and
- Promotion of infrastructure competition by encouraging multiple broadband technology platforms.

In the past, some EU MS have chosen service-based competition on shared infrastructure. The UK is one example where BT's Openreach offers unbundled access for fibre optic and copper networks at wholesale prices of "cost plus". This may still not ensure a competitive market. Other MS have pursued infrastructure-based competition with a high market share for multiple broadband technologies. Infrastructure competition from mobile broadband might be the only alternative when the fixed line infrastructure is still poor. In such cases, the two technology platforms might possibly be considered as parts of the same market. Moreover, dark fibre has still to be opened up for general sharing in the EU. The draft EECC is silent on this point, although it retains the SMP regime and with it the possibility to intervene in backhaul markets if competition problems are identified, as well as endorsing sharing of infrastructure in other areas (Article 45-46). Also, as stated in the explanatory note to the 2014 Commission Recommendation on relevant markets, NRAs may consider competitive problems within the fibre backhaul market in the context of the analysis of the high-quality access market, which is typically regulated.

2.1.5 Bundling Services Strategies for Fixed and Mobile

Since the 1990s and until fairly recently, the MNOs had been highly successful in luring voice traffic away from fixed-line operators (usually the national incumbents in each MS). However, these incumbents are now likely to have mobile subsidiaries, as well as dominance in fixed-line services. Thus, FMS effects are being mitigated by new market tactics. In response to incursions by "pure" MNOs into the voice market, the fixed-line incumbent operators have successfully responded to mobile narrowband voice by bundling, using broadband offers. The service level business model is to bundle mobile service with fixed-line calls, pay-TV and Internet access for "quad play" with discount pricing. Our survey of NRAs found that this has been highly successful in Spain, France and the Nordic countries. While an increase in substitution effects could indicate that ex ante access obligations imposed on fixed incumbents might be superfluous, the bundling strategies of EU incumbents have produced a new source of market power. Thus, any reform of the existing regulatory framework requires a more complete analysis of the possibility of cannibalization between fixed and mobile voice against managed OTT VoIP and unmanaged VoIP telephony when bundled and unbundled.

Our findings, therefore, confirm the limits of FMS, with the growth of fixed-line broadband preferred for high-volume streamed entertainment while also offering OTT voice. It is also evident from our NRA survey that the majority of users in the EU now appreciate that mobile broadband is not equivalent to fixed broadband, especially not equivalent to FTTH. Fixed-line communication has so many practical advantages because its quality of service (QoS) tends to be more stable and its greater bandwidth offers more data at lower cost. To sum up, mobile and fixed-line *broadband* are not seen as substitutes in the EU, but possibly as complements.

2.2 Fixed-Mobile Convergence and Network Densification

Fixed-mobile convergence has important implications for future connectivity in the EU, especially if fixed networks can be exploited to provide backhaul links for mobile networks. To the extent that *existing* fixed networks are usable, the cost of densifying mobile networks might be reduced while at the same time increasing rollout speed.

The integration of Wi-Fi and cellular is also important, as Wi-Fi can serve unmoving or nomadic users at much lower cost than cellular, while cellular remains necessary for those moving fast enough to need hand-offs during a communication session and those outside the coverage of an accessible Wi-Fi access node. Cellular/Wi-Fi co-existence is in fact essential for the success of fixed-mobile convergence, offering a cost-optimized meld of broadband infrastructures. Cooperation between the standards organizations responsible for developing these two technologies – IEEE and 3GPP/ETSI – is thus also necessary.

2.2.1 The Need for Densification

The next generation of high-speed wireless networks must densify for four main reasons. First, data transfer rates decrease rapidly and non-linearly as the distance between user and base station increases. For example, LTE-Advanced (with 8x8 MIMO in 3GPP Release 10) offers peak throughput of 440.3 Mbps at the base station. That becomes 9.6 Mbps at the cell edge. Data throughput is less than a quarter of the peak speed in 86% of the cell's coverage area, and less than half the peak value in 94% of the cell area. With 5G cellular, the speed decrease from centre to edge will be even steeper, as shown by the wide gap between "peak data rate" and "user experienced data rate" in the ITU's 5G performance targets. (ITU-R, 2017).

A second reason is the reduction in throughput when a base station is shared by multiple users. If there are five concurrent sessions, the data speed attained by each will be about one-fifth of the base station's total capacity. So, another reason for reducing 5G cell size is to reduce the number of users communicating concurrently within each cell.

Third, 5G networks will need small cells because the only blocks of available spectrum large enough to accommodate the high data traffic expected are in the centimetric and millimetric (microwave) ranges. But at these frequencies, signal range and building penetration will be far less than today's cellular allocations. So, cell size must shrink in response to diminished propagation.

A fourth reason is to strive for the data speed targets proposed for the European Gigabit Society initiative. An access speed of one Gigabit (1 Gbps) is specified for schools, transport hubs, public services, etc., with blanket coverage of urban areas and main ground transport routes, and for all European households, rural and urban, at 100 Mbps, upgradable to one Gigabit. These targets stretch wireless capabilities beyond what is practical now, given the physical constraints just cited, so they are only attainable near the base stations.

2.2.2 Existing Fixed Networks Could Provide Backhaul for Cellular in Some Locations

Backhaul media capable of supporting the throughputs implied by Gigabit Society targets would seem to be limited to optical fibre or microwave. However, in a few years, new and more affordable alternatives may be available: G.FAST, XG.FAST and DOCSIS 3.1 Full duplex running over coaxial cable and twisted-pair copper wires.

The data throughput of DOCSIS 3.1 already rivals optical fibre: 10 Gbps downstream, 2 Gbps upstream, under ideal conditions. As SamKnows found in a 2014 study for the European Commission, the average copper cable broadband connection in Europe is faster than fibre optics (66.57 Mbps for DOCSIS versus 53.09 Mbps for fibre). Unfortunately, cable networks are not available everywhere but, where they are, they have greatly accelerated the deployment of next generation networks because upgrading them is much cheaper than deploying new fibre.

Developed by the ITU, G.FAST is the latest variant of xDSL. Equipment based on that standard entered the market in 2016. G.FAST can deliver gigabit speeds when the street cabinet is less than 70 - 100m from the subscriber's terminal, 100s of Mbps when the cabinet is 300m from the terminal. More recently, XG.FAST, still in development and not yet standardized, has been shown capable of delivering up to 11 Gbps over twisted pairs of copper wire – the kind of infrastructure originally deployed for telephony – but only over short distances (30-50m). Commercial offerings based on XG.FAST are expected in about three years. Recently, the "father of DSL," John Ciofi, claimed that a hundred-fold increase in DSL's range and speed is technically possible (Ciofi *et al.,* 2017).

Both XG.FAST and G.FAST have problems typical of xDSL: the distances over which their throughput can be sustained are short and poor quality wiring impairs service. Yet the cost advantages of these solutions are so great that they cannot be ignored, particularly for serving small cells mounted in or on buildings already connected to fixed telephone networks. The total cost of ownership for small cells using G.FAST for backhaul is 24-46% lower over five years than microwave or fibre (Jaber et al, 2016. Deploying high speed broadband throughout Amsterdam using G.FAST in a copper/fibre hybrid network would cost 70% less than a fibre-only network (van den Brink, 2014).

But fibre has two advantages over any alternative: first, the inherent data speed limit of a single-fibre link is about 1.2 petabits per second (1.2 million Gbps). Although the speed actually delivered to end-users today is much lower, that is because of the speed of the equipment connected to the fibre and network management policies that may limit throughput. New fibre installation may be expensive, but repurposing already installed fibre can be as easy as plugging a new appliance into a wall socket. Second, the amount of energy needed to push light through the fibre is negligible. The cost of electricity for coaxial cable, microwave and copper networks increases linearly with time, eventually becoming a significant burden. That does not happen with fibre. These two traits – easy repurposing and nearly-zero running costs – make fibre "future proof" and thus attractive even with the high cost of installation.

So far, wire, cable and fibre have been discussed as if they are separate – perhaps even rival – media. This is an oversimplification that hides an important fact: fibre has been the high capacity "backbone" medium for cable TV, cellular mobile and wired telephone networks for more than a decade. When we refer to a network as "cable" or "wire," we are using the connection medium seen by end-users to describe the whole network. But actually, all broadband delivery networks today make extensive use of fibre. Thus, they have more in common technically than policy debates generally acknowledge.

2.2.3 Densification Makes the Cost of Backhaul a Crucial Issue

Repurposing existing infrastructures for backhaul could make 5G roll-out faster and the small cell business case more viable. What are the choices?

According to the FTTH Council's European forecast, nearly 62.8 million fibre "lines" will have been deployed by 2018 (Finnie, 2017). This may be an underestimate as there is also an unknown amount of unused and unreported "dark fibre". Dark fibre in Europe is mainly owned by telephone incumbents who lease out access. City governments and utilities compete with them to some extent, but in many places network coverage does not overlap so price competition is limited. It is not unknown for telcos with dark fibre to give their own mobile subsidiaries discounts or preferential treatment while overcharging or denying service to others.

Copper leased lines can also be used for backhaul, though they might not be an MNO's first (or second or third) preference. Leased lines are subject to ex ante regulation in some Member States but offers are generally not closely scrutinized so prices vary greatly, often for no apparent reason.

Cable TV networks are not a universal solution for broadband as their penetration varies enormously from country to country. They certainly will not help in rural areas, but where they are available, they might offer significant economic advantages.

BEREC's recent survey and report on these issues (2017c) are so relevant that they deserve to be quoted at length:

> Some MNOs are calling for regulated wholesale products to cater for their needs to connect mobile base stations, including options such as active leased lines access, dark fibre and duct access… A majority of MNOs indicated that the existence of regulated offers is important; allowing them also to negotiate better commercial terms when they bought unregulated products…
>
> Some operators also expressed concerns on the sustainability of current pricing practices of backhaul services, given the expected growth in mobile data per mast site, the growth in the number of mast sites required and the declining revenue environment for mobile services… A number of respondents lament a general lack of regulated services specifically defined for mobile backhaul, asking for dark fibre access products instead… In this context, some NRAs plan to impose on the incumbent the obligation to give access to dark fibre…
>
> [But ten] NRAs do not think that regulation on mobile backhaul needs to evolve in the medium term… some respondents, especially incumbents, consider that regulatory interventions are not necessary since the market is already competitive… Therefore, the need for the creation of a separate regulated mobile backhaul market has not been clearly identified yet. Nevertheless, given the advent of 5G networks and increasing demand for capacity by mobile operators, it is important for NRAs to continue monitoring the needs of mobile backhaul transmission and fine-tune their regulatory toolbox accordingly.

Microwave is another option. Despite all the interest in fibre for mobile backhaul, it is still a secondary option in practice, held back by high costs and long waits for connection to the backbone. Nearly two-thirds of all mobile backhaul is implemented now with point-to-point (P2P) or point-to-multipoint (PMP) microwave, and Ericsson (2017) believes that will not change anytime soon.

However, the growth of cellular over the past two decades increased demand for in-city backhaul to the point where channels wide enough for LTE backhaul are no longer available between 6 and 42 GHz in most of Europe's large cities. So CEPT recently increased the maximum permitted channel sizes in the Fixed Service allocations at 40-57 GHz.

The 60 GHz band has high signal absorption which reduces range, but noise and interference are also reduced making very dense deployments practical. The Wireless Gigabit Alliance promotes 60 GHz use with WiGig, a high capacity version of Wi-Fi, with throughput up to 7 Gbps.

The microwave bands at 71-76 GHz and 81-86 GHz are not absorbed by oxygen so their signals reach farther. And because signals in these bands can be focused into pencil-thin beams, interference can be avoided by precisely aiming at the target antenna. CEPT introduced new rules for these bands when their value for cellular backhaul was recognized. The so-called "E bands" provide 40 channels 250 MHz wide, each capable of delivering up to 10 Gbps at distances of several kilometres along line-of-sight paths. Market predictions for small cell backhaul anticipate that, between 2016 and 2020, 60-80% of equipment sales will be for microwave links, led by 60 GHz and E-band products.

But most urban installations of 5G will probably be below the roof line, to reduce inter-cell interference and to increase signal strength within the coverage area. That could make it impossible to use existing line-of-sight microwave technology, although summed beam reflections might be used. On the positive side, many European cities already have extensive fibre deployments in their commercial districts. Leasing existing fibre capacity is cheaper than new build, effectively replacing capex with opex, so the cost saving depends on the length of time considered: a 30-year lease might end up costing more than building and owning from the start.

5G deployment costs cannot be extrapolated from homogeneous 3G macrocell networks because "heterogeneity", which is needed to support 5G's diverse use cases, implies a much more complex infrastructure. Unfortunately, hetnet complexity leads to increased implementation costs and makes the details of specific locations decisive as to which medium is most cost effective for backhaul. Although microwave is usually the least expensive option for homogeneous macrocell networks, it is the most expensive option for large hetnets because of component costs and power consumption. For a high density of small cells, fibre backhaul will often be more cost efficient when considered over a 20-year timeframe (Mahloo et al., 2014).

This leads to a major conclusion for 5G cost analysis: the opportunities to save on small cell deployment costs by using existing fixed infrastructures are likely to be limited. Exceptions are where the cell sites are in buildings already connected to the fixed telephone network and served by fast DSL. This is good news, since in-building "hotspots" will probably constitute 80% of all the small cells needed for densification (according to the Small Cell Forum and Rethink, 2017, p. 5).[3] The EC's *Study on Broadband Coverage in Europe 2016* (2017) says 94% of all residences in the EU have DSL access and 44% have cable broadband. However, only about 16% of the DSL connections promise to deliver 100+ Mbps.

Another positive aspect of indoor deployment is that the cells can be built and installed more cheaply than outdoor cells – weatherproofing, site preparation and vandal resistance being less necessary. And since backhaul for Wi-Fi is normally paid by the end-user or facility-owner, "offloading" the cost of indoor cellular backhaul might find more public acceptance than has been the case so far with femtocells – if the small cell combines cellular with Wi-Fi.

For small cells deployed outdoors, the situation is not so good. As noted by Boch (2014), "In the outdoor environment, fiber 'close' to a micro-cell site doesn't generally mean that there is a point-of-presence which allows cost effective or timely deployment of a fibre spur-line to the micro-cell site (located on a store front, or lamp-pole for example)." Deployments of "fibre to the street lamp" or "fibre to the traffic light" are rare and even a gap of a few metres significantly increases costs and delays activation as the link must be trenched. BEREC's survey of MNOs (BEREC, 2017c) raises additional issues:

> The majority of these operators, forty-one, declared that they are able to satisfy most of their mobile backhaul service needs – more than 75% of the traffic – by means of self-supply on their own fixed and/or mobile infrastructures. In particular, seventeen operators declared to rely exclusively on their own infrastructures…
>
> A key factor obtained from the survey is the growing need of operators to have full control over technical conditions; this could explain why the operators rely mostly on self-provided mobile backhaul solutions. As a general rule, operators however at least partly rely on services provided by other companies when the deployment of a proprietary network results to be too expensive.

But when the "services provided by other companies" are also too expensive, that solution does not work. Yet there are mobile operators who depend on other companies for backhaul, particularly when they are not part of a converged fixed/mobile enterprise. The advantages of self-provision suggest that converged operators will find 5G networks easier to develop while mobile-only networks will be disadvantaged:

> If products suitable for mobile backhaul are not available, the likely consequence will in the near future be a reduction in the ability of non-integrated mobile operators to compete on a level playing field in relation to high speed LTE services, to the detriment of end-users (Allen, 2014).

2.2.4 Does Fixed Cellular Make Business Sense?

Connectivity via fixed cellular might be less costly for broadband than wired media in areas of low population density. It might also supplement an MNO's mobile revenues. It is already being used in remote parts of Sweden and has taken root in the USA where AT&T offers fixed LTE from 400,000 sites (Dano, 2017). But download speeds are apparently limited to 10 Mbps in AT&T's network and prices are higher than DSL or cable. Such a service is probably only viable in underserved rural areas (where in fact it is deployed).

Verizon, on the other hand, plans to introduce residential fixed broadband service in the second half of 2018 in up to five US cities using pre-standard 5G equipment (Verizon,

[3] The reasons for such a high percentage of indoor deployments are that the vast majority of mobile data traffic originates and is consumed indoors, especially at home, and the high frequencies likely to be used by small cells have very poor outer-wall penetration capability. See the discussion of Verizon's experience with broadband delivery at 28 GHz (below).

2017). Urban settings were chosen because foliage blocks the network's 28 GHz microwave beams: "The idea of this solving the rural problem is folly. There are too many trees", says Tod Sizer of Nokia, which developed the equipment for Verizon (Jones, 2017). 28 GHz also does not penetrate brick, concrete or low-emissivity glass, so receivers must be mounted outdoors with Wi-Fi used indoors to distribute content. No information has been released yet about cost or speed.

These projects suggest fixed LTE is workable under certain conditions but the jury is still out on fixed 5G.

However, cellular networks were developed to serve communicators travelling fast enough to pass out of the range of one base station and into the range of another within the duration of a single phone call. "Handoffs" from one cell to another are cellular's hallmark. When handoffs are not needed – in fixed services, for example – the complicated user tracking and continuity features of cellular are superfluous. Using this technology to serve "things" and people at fixed locations is rather like using a motorcycle as a chair.

Fixed cellular has also been touted as ideal for the Internet of Things. But even the usually optimistic GSM Association (2016) foresees the average ARPU for an "operatorless device" falling as low as €1 per month. France's SIGFox offers IoT service today at prices ranging "from 1 EUR per device per month to 1 EUR per device per year" via their [non-cellular] long range/low power radios (SIGFox, 2016). The 3GPP is a latecomer to the low-bandwidth IoT scene. This niche is already crowded with providers of much cheaper, unmetered services. Consequently, if LTE or 5G find ways into this market, it could be without the MNOs (Deutsche Press-Agentur, 2017).

2.2.5 Wi-Fi and Cellular Embody Fixed/Mobile Convergence

Not many realize it but LTE was conceived by the cellular industry as "the answer to the threat posed by Wi-Fi" (Chitrapu *et al.*, 2012). Until a few years ago, 3GPP and IEEE, the standards bodies responsible for cellular and Wi-Fi, worked independently. As a result, Wi-Fi and cellular are minimally compatible. Incompatibility was not a problem when they used different frequency bands, but now that LTE is moving into Wi-Fi spectrum and mobile network operators want to control their customers' use of Wi-Fi, cooperation has become imperative.

Formal cooperation between 3GPP and IEEE began in 2015 with Licensed-Assisted Access (LAA). Requirements for "fair" band sharing and "acceptable" levels of interference between LTE and Wi-Fi were explored, as well as bandwidth aggregation techniques combining Wi-Fi and LTE data streams. IEEE expressed interest in working with 3GPP in developing 5G. Liaison statements were exchanged as 3GPP responded positively (Dutta *et al.*, 2016). Then in July 2017, IEEE created a new workgroup (1932.1) to develop standards enabling 5G/Wi-Fi interoperability and joint use of spectrum.[4]

Will end-users suffer as a result of SDO pre-emption of WLAN choice?

Most cellular subscribers switch between Wi-Fi and cellular multiple times each day, generally choosing Wi-Fi when that option is available. The experience of 4G suggests this will not change with the introduction of 5G.

Wi-Fi is now seen as essential to 5G – to the extent that 5G networks are being designed to control handovers to and from Wi-Fi, and to balance and allocate data traffic between the two network types according to the 5G network operator's criteria. This is called "traffic

[4] http://sites.ieee.org/sagroups-1932-1/.

steering" and it is described in purely technical terms as "load optimization" which needs to be handled algorithmically. There is a real danger that in implementing 5G traffic steering, end users will be excluded from these decisions and denied the right and/or opportunity to choose which WLAN they want to use, or if and when to use Wi-Fi instead of cellular.[5] The IEEE, which one would think should understand the importance of protecting Wi-Fi users' right to choose, is inclined to give 3GPP complete authority in these matters. In their Roadmap for "5G and Beyond" the IEEE 5G WG state:

> **6.4 3GPP-as-a-Control-System** …Notably, one needs to research the architectural and protocol approach to have 3GPP act as a control channel/system for all wireless systems available globally. Going well beyond today's licensed assisted access (LAA), cellular would be responsible to coordinate various IEEE 802.11™ "Wi-Fi®" and other systems to ensure best possible link performance while offering mobility/roaming, as well as billing. (IEEE 5G Working Group, 2017)

Thus, it may fall to the European Commission and the Member States to articulate and protect (through regulation, legislation like the EECC or mandates to regional entities) the right to choose among available electronic communication networks including WLANs. This is an essential complement to EU citizens' "freedom to provide electronic communications networks and services, subject only to the conditions laid down" in the Authorisation Directive (2002/20/EC), and reiterated in Article 12 para. 1 of the draft European Electronic Communications Code.

Because 5G is still being defined, the "traffic steering" principles are incomplete and it is not too late to ensure that they reflect the basic values of European society.

2.2.6 The Way Forward

Wi-Fi's success, with hundreds of millions of users voluntarily investing in and managing their own access points ("bottom up broadband" as the Commission calls it) suggests the feasibility of combining Wi-Fi home-spots[6] with cellular networks to create a cost-optimized blanket of small cells interconnected for public and private use. This is in fact close to the cellular industry's current concept of 5G. But it is important that this arrangement does not result in cellular companies restricting users' access to their own networks or charging them for data sent and received through their private WLANs.

2.2.7 Applications Enabled by Converged High Performance Networks

Many new applications have been proposed to justify the giant leap in performance that 5G promises. So many applications, in fact, and of such diversity, that there is great confusion about what a 5G network could or could not do, the resources needed and the real-world benefits. But 5G is still being envisioned, so it is not possible yet to evaluate the costs and benefits rigorously.

Use Cases Point to Quality Requirements Beyond Download Speed

The most interesting common factor that emerged from the use cases explored in the Methodology Section (Section 3.2.6) is that *reliability and consistency* will often be more

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[5] See clause 22A ("LTE-WLAN Aggregation and RAN Controlled LTE-WLAN Interworking") in 3GPP TS 36.300 V14.4.0 (2017-09) for a high-level description of LTE-WLAN integration in 5G - http://www.3gpp.org/ftp/Specs/archive/36_series/36.300/36300-e40.zip.

[6] "Homespots" – where half the Wi-Fi bandwidth (partitioned by a firewall) is offered for use by outsiders while half is retained for private use – are predicted to increase six-fold from 2016 to 2021 (Cisco, 2017): "Homespots are proliferating fast and have the potential to radically alter Wi-Fi's social impact while shifting the boundaries between public and private."

important than throughput. The draft European Electronic Communications Code recognizes this: "While in the past the focus was mainly on growing bandwidth available overall and to each individual user, other parameters like latency, availability and reliability are becoming increasingly important" (Recital 13) (European Commission, 2016) Briefly summarising our findings by industry vertical, we found challenges in every one of them:

- **The Connected Car** – safety requirements show the extreme challenge of reliability in a complex FMC environment of changing combinations of heterogeneous networks that must act together as one system with very low latency. People will not trust a driverless car if causes accidents or fails to reach the destination. Reliance on external guidance means that network coverage must extend into underground parking lots, private garages, repair shops, probably even dirt roads.
- **eHealth Systems** – to support tele-medicine, remote care, early detection and prevention of illness; patient monitoring; ambient assisted living for the aged and frail; etc. Safety of life is critically dependent on reliability.
- **Media and entertainment** – has the challenge of throughput, as content distribution requires far more active dataflow management than just linking a consumer to a media server. Quality of experience (QoE) is of primary importance and that depends on the quality of service (QoS) across multiple networks.
- **Smart cities** – the challenge of heterogeneity. So many different systems are needed to manage the city. Some must be open to citizens, others need to be totally inaccessible, many others need to interact. Many will be narrowband while others require massive bandwidth. Security will be a major concern.

2.3 Mobile coverage obligations

2.3.1 Introduction

Most EU MS attach geographic or population coverage obligations and rollout deadlines as conditions in cellular mobile licences. Most countries' conditions are unique, so we analysed the differences to see which approaches achieve the best results, and to identify elements of a common approach to maximize end-user access to economically sustainable mobile networks at affordable prices throughout Europe.

Our work on this task began with a detailed review of current mobile coverage obligations in the EU-28. The effects of different coverage obligations were investigated in terms of market impact and improved or reduced connectivity. Six countries were studied in depth (France, Germany, Hungary, Slovenia, Sweden and the UK). We also drew on the experiences of non-EU countries and prior research. Finally, in order to attain future connectivity goals, elements to consider at the EU level for mobile coverage obligations were identified.

Our findings are based on an analysis of interviews and questionnaires completed with NRAs, MNOs and vendors, licence conditions, tender documents and other policy information published by the NRAs.

2.3.2 Coverage Obligations in the EU Member States

There is ample evidence that broadband connectivity for public access to the Internet provides significant socio-economic benefits. Recent research also suggests that higher quality connections (higher data rates and greater reliability) amplify these benefits. The need for better connectivity is also reflected in the policy objectives and targets set out at the MS and regional levels. But it is also clear that technical and economic factors limit the ability of fixed (wired) networks to deliver these benefits in full. For ubiquitous connectivity, fixed and mobile networks must provide coverage that is complementary and overlapping. But measuring the quality and extent of coverage can be a challenge. Most mobile use actually occurs indoors yet methods for calculating field strengths to determine the adequacy of coverage often assume an outdoor environment. Cost is a major barrier to investment in optical fibre or copper wire infrastructure in rural areas, but rural coverage can also be costly for cellular when there are few subscribers per cell. Outdoor rural wireless coverage is important for emergency services as well as for modernising agriculture and tourism. However, that market is unlikely to deliver a socially optimal level of connectivity without government intervention, perhaps in the form of coverage obligations. That is why such obligations are so prevalent.

Coverage obligations are typically attached to licences awarded through competitive tenders (often spectrum auctions). Twenty-six of the 28 EU Member States have imposed coverage obligations in one or more cellular bands. Obligations are currently in force for at least 111 of the 145 bands studied (see Table 2.1). Coverage obligations are more common in lower frequency ranges, especially 800 MHz and below. They often concern both voice and data services. Data-only coverage obligations have become more common in recent years, especially in bands designated for LTE (Long-term Evolution), i.e. 700, 800 and 2600 MHz. Obligations often specify a minimum population coverage or (less often) minimum area coverage, or some combination of the two, sometimes including coverage obligations for major transportation routes and/or specific locations. The latter may be defined by population size (e.g. "all settlements of more than 10,000 people"). Obligations are often stricter in the bands below 1 GHz, and less stringent in the 2.1 and 2.6 MHz bands, as the latter may aim at preventing spectrum hoarding rather than maximising access.

Table 2.1 Coverage obligations per frequency band in the EU Member States

Band (MHz)	Obligation					No obligation	Unclear	Total
	Voice only	Data only	Voice and data	Not specified or N/A	Total			
450	1	1		2	4		1	5
700		3			3			3
800		16	5	4	25	1		26
900	4	2	10	6	22	5	1	28
1500		1		1	2	1		3
1800	2	3	10	5	20	6	2	28
2100		6	6	9	21	5	2	28
2600		7	3	4	14	9	1	24
Total	**7**	**39**	**34**	**31**	**111**	**27**	**7**	**145**

Meeting coverage obligations is often linked to specific dates and becoming progressively stricter, in that a greater share of the population, a wider area or more locations must be covered by later dates (e.g. 70% of households by 2015, 90% by 2017). Minimum data speeds may also become higher (e.g. at least 2Mbps within seven years, 5 Mbps thereafter, as in the Czech Republic). Coverage obligations may also differ within the same frequency band. Often, new entrants are allowed more time than incumbents to fulfil conditions. Sometimes, only one block (and hence one licensee) is subject to the obligations. There may also be stricter obligations on a preferred block. In some cases, licence holders can use any of several frequency bands to fulfil their obligations, while in other cases a specific band must be used.

Some coverage obligations are quite specific and detailed, often in response to member states' policies to extend rural coverage. In these cases, the regulator may define a list of priority areas (France), communities (Germany), districts (Czech Republic), municipalities

(Italy), small communities (Spain) or specific addresses (Sweden) to be covered to a certain extent by a certain date.

Emitted signal strength and received field strength are the most common criteria used to define voice coverage, while for data it is minimum downlink data rate. For LTE, threshold data rates typically range from 1 to 30 Mbps, using various definitions. If specified, the obligation concerns outdoor coverage, with a few exceptions. If indoor coverage is included, it often involves some assumption about wall attenuation (e.g. 10-12 dB).

Confirmation of coverage usually involves two steps: (1) a self-declaration from operators in which they provide evidence of coverage, typically calculations of outdoor signal strength using network planning data; (2) regulators or subcontractors may then follow up with spot checks, either through field measurements (drive-tests are common) and/or their own theoretical simulations (less common). Either might be complemented with crowdsourced data, subscriber complaints about poor coverage in specific places or “third party” investigations (e.g. by news media). The methods, procedures and equipment used vary considerably across Europe.

If licence holders fail to achieve the coverage required of them, regulators have two types of sanctions available: fines or other forms of financial penalty and, second, revocation of licences. In practice, both types of sanctions are rarely applied.

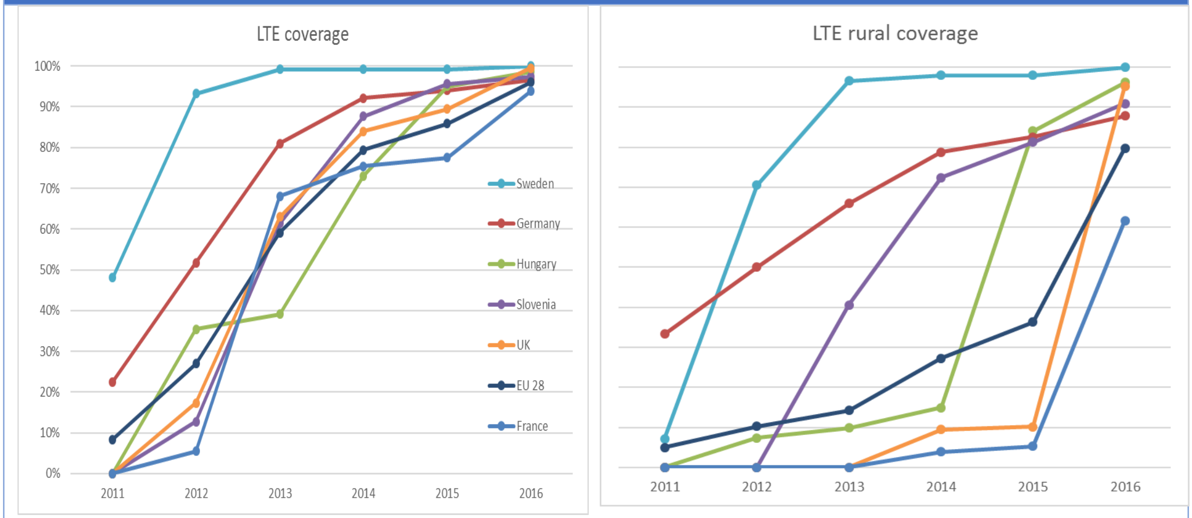
To conclude, we present some emergent patterns in the use of coverage obligations among EU MS. Obligations have typically been specified so that shares (%) of total national population or geographical area should covered at certain dates. Early obligations seem to have promoted basic mobile coverage in the MS. The release of additional frequencies (and new generations of mobile) improved network capacity, coverage and enabled the introduction of data services. Sometimes obligations then included coverage criteria related to data. Recent releases of the 700, 800 MHz and 2600 MHz bands (and the introduction of LTE/4G) have provided opportunities for MS to address additional policy objectives, e.g. to improve mobile (broadband) coverage in rural and other underserved areas, to improve coverage for transport paths and indoors. Accordingly, coverage obligations for those bands are sometimes specified reflecting these needs. In particular, several MS identified specific poorly covered areas (e.g. municipalities) and attached coverage obligations for those to new licences, often with a broadband QoS criterion (downlink data rates). Sometimes coverage indoor and along major transport path were also included in the obligations. In the future, we may expect additional MS to introduce obligations addressing those needs, possibly including additional criteria (e.g. low latency, reliability, mobility requirements) based on the needs of new applications and services (e.g. connected cars).

2.3.3 Impact of Coverage Obligations on Connectivity

The study team examined the effectiveness of coverage obligations more closely in 6 EU Member States (France, Germany, Hungary, Slovenia, Sweden and the UK). A wide variety of deadlines and other criteria were found, along with varied initial levels of connectivity and different goals for LTE deployment in rural areas. LTE spread rather rapidly in Sweden, Slovenia, Hungary and Germany, more slowly in France and the UK (until recently).

Figure 2.1 Impacts of LTE coverage obligations in six MS

The situation in six MS as LTE was introduced with coverage obligations. The timing and specification of obligations varies widely, as do the general levels of connectivity and the degree of focus on build-out in rural areas



Note: 2011-2014: end of years. 2015-2016: mid-year.

Source: 2012-2016: European Commission (2017b); 2011: European Commission (2014c).

While mobile connectivity and coverage depend on many factors, most of which vary from one MS to another (i.e. geography, population distribution, disposable income, network sharing arrangements, earlier deployments of complementary infrastructure, etc.), evidence suggests that coverage obligations can increase public access to broadband services if the obligations are suitably designed.

Lessons from the mini-cases, our survey and desk-research suggest the following factors to be important in coverage obligation conditions (see further Section 3.3.3). First, obligations should address policy needs, be they just to avoid spectrum hoarding or to ensure mobile broadband to rural or remote areas. The nature of these needs has implications for how to define the obligations. To exemplify, it makes little sense to specify them in terms of a percentage of the total national population if the intention is to provide coverage to specific areas. In that case, it is better to specify those areas (like in e.g. Portugal and Slovenia) or to include transport paths (like in France) in the obligation. Another case of best practice is to let coverage of one generation build on and complement coverage of earlier generations (cf. the case of Sweden).

Obligations and their timing should be strict enough to stimulate build-out beyond what market forces would have led to, but not too strict (or applied to too many operators). Incentives need to be significant enough for operators to fulfil the obligations at required dates (cf. the case the 800 MHz bands in Germany and Sweden). In addition, is also important to ensure that authorities have the necessary powers to verify and enforce the obligations (as proposed in EECC – European Commission, 2016d – Article 30). Finally, regulators need to strike a balance between keeping obligations simple enough for operators to interpret and for NRAs to enforce, while at the same time make them specific enough to avoid conflicting interpretations.

In other words, vague and complicated obligations that are not relating to policy objectives, having deadlines far in the future, no prospects of operator cost recovery and with insufficient incentives and limited possibilities for NRAs to enforce them, should be avoided if the objective is rapid improvement of coverage.

Coverage obligations are also used outside the EU (e.g. in the USA, Canada, Singapore, India, New Zealand, Switzerland and Norway). Yet it is difficult to identify best-practice. In several cases, notably Australia (which has vast, sparsely populated areas), public funding seems to have been the preferred policy tool to stimulate coverage. Network sharing has also been promoted in several cases.

These practices are in line with what has been shown by previous research. Although we found no research explicitly relating coverage to take-up, better coverage does enable take-up by end-users and socio-economic benefits follow from that. However, to reach socially optimal levels of coverage, government intervention is often necessary. Relevant tools include coverage obligations, promotion of network sharing (with protection of competition) and public support to expand coverage in unserved areas. In some cases (that is, in very remote areas) other technologies such as satellite may be needed and supported as well. In any case, mobile coverage obligations, in combination with network sharing as set out in EECC (European Commission 2016d) Articles 45 and 47(2) and possibly, other forms of public assistance (carefully designed to avoid distorting market competition) seem to be the way forward.

2.3.4 A Regional Future for Coverage Obligations?

One of our objectives was to identify the key elements of coverage obligations to consider at EU level. These might be critical in meeting EU connectivity goals and could potentially involve harmonising: (1) specifications of the terms of the obligations; (2) definition of coverage criteria; (3) measurement methods; and (4) enforcement mechanisms.

In brief, our research suggests that definition of coverage criteria and measurement methods should be considered for harmonization and inclusion in future (e.g. 5G) coverage obligations, while detailed specifications (e.g. which areas should be covered, specific percentages of population, timing etc.), and enforcement procedures (i.e. penalties in case of breaching obligations) should remain at MS level to allow them to respond to specific policy objectives and local circumstances. This also seems to be the prevalent opinion among the surveyed NRAs and seems to be roughly in line with the EECC proposal (European Commission 2016d), e.g. Articles 18,19, 30, 45 and 47, with 47(3) intended to promote convergence in the use of the parameters framing such coverage obligations and convergence in the methods and the parameters framing such coverage obligations (e.g. methods for determining coverage obligations) but not necessarily harmonising coverage conditions (see European Commission, 2016b).

To elaborate, as described in later sections of this Main Findings chapter, our research indicates that European harmonisation and standardisation of QoS indicators, their definition and measurement, could have important benefits. Common measurement standards would lead to economies of scale in the enforcement activities of NRAs, greater certainty in interpretation of policy objectives and improved comparability across Europe. In the case of coverage obligations, while the surveyed NRAs recognize that harmonization could yield benefits, but they also point to difficulties in implementation, such as the need for retraining to replace already developed expertise, and the need for new budget allocations to replace monitoring and measurement equipment.

Our research found that many MS are reluctant to consider harmonising cellular coverage obligations. The diversity and specificity of local conditions (including different population distributions and agreements with neighbouring states, some of them outside the EU) produce different policy objectives and targets, which in turn demand different policy interventions, including different ways to specify coverage obligations. The prevailing opinion among the NRAs we interviewed was that these matters should be left to individual MS. Enforcement procedures in cases of non-compliance (e.g. fines, revocation of licences, etc.) should remain national prerogatives. However, the value of sharing knowledge and best practice among the MS is also recognized, and is already taking place to some extent, e.g. via BEREC, RSPG and CEPT, for example regarding indoor coverage, coverage in poorly covered areas and for road and rail transport (see also BEREC, 2017b). This should be encouraged and supported by the EU.[7]

The Way Forward

Harmonising methods for measuring coverage would benefit everyone, without limiting any state's ability to set or enforce their own coverage obligations. Therefore, we see a way forward in voluntary agreements on methods for measuring LTE coverage – including the measurement of data download speeds, quality/intelligibility of speech for Voice over LTE (VoLTE) and criteria for measuring indoor coverage. That would build on previous work by European institutions. We note the scepticism expressed in ECC Report 256 (CEPT, 2016) about the possibility of reaching consensus on a regional approach to the measurement of LTE coverage by regulators. Such an effort could be productive nevertheless, even if it only results in agreement to rely on crowd sourcing.

A second possibility arises from the introduction of 5G, with its expanding set of network performance indicators. One or more of these could be considered for inclusion in spectrum licence obligations, based on a regionally harmonized approach to definitions and measurement.

Finally, as proposed by at least one NRA, adopting a standard format for the MS to announce or report their mobile coverage obligations, how they will be measured and enforced, could be a useful starting point towards standardization, without interfering with Member States' rights to set their own targets. The experience gained by the Mapping of Broadband Services in Europe project (SMART 2014/0016) could contribute to this, as could BEREC's current initiatives on network neutrality and measurement of quality of service.

2.4 Measuring Quality of Service and Experience

2.4.1 Our Approach

In this part of the study we examine the parameters, metrics and measurement methods used in Europe to assess electronic communication networks' performance (NP), quality of service (QoS) and quality of experience (QoE). Our approach was to:

1. Identify the QoS/QoE indicators that EU MS require to be measured and reported on a regular basis;
2. Identify significant differences and commonalities in these requirements, and the reasons for these differences and commonalities; and
3. Explore possibilities, potential barriers and catalysts for harmonising the definitions and measurement of the QoS/QoE indicators.

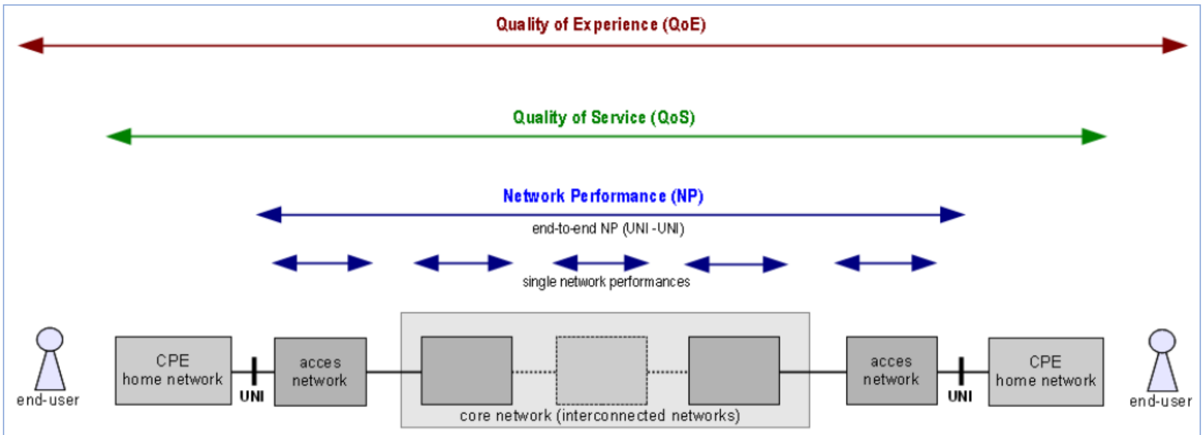
[7] Note also that some aspects of such exchange of knowledge and best practices are proposed in the EECC code (European Commission 2016d) Article 35, "Peer Review Process" and by BEREC (BEREC BoR (17) 129).

The findings of other studies were also reviewed, including those by the BEREC Working Group on Net Neutrality, the Broadband Mapping Project, and regulatory policies regarding QoS/QoE in other parts of the world. The findings of this part of the study provide the basis for our proposed common approach to QoS and QoE measurement.

2.4.2 Defining Network Performance, Quality of Service and Experience

Quality of service (QoS) refers to the effectiveness of performance of a system in support of end-user needs or that contributes positively to another system's performance. QoS is distinguished from quality of experience (QoE) by encompassing the system only up to the user interface. For QoS, performance *at* the user interface is key. Network performance (NP), on the other hand, is mainly of interest to network managers. It is more limited in scope than QoS because it excludes user interfaces. QoE, in contrast, goes beyond the interface to encompass personal impressions, expectations and judgments.

Figure 2.2 Relationship of NP, QoS and QoE

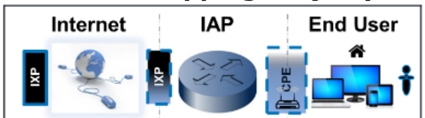


CPE: Customer Premise Equipment, UNI: User-to-Network Interface

Source: BEREC, 2011.

The TUV Broadband Mapping project uses a different 3-part descriptive framework; it distinguishes between theoretical calculated availability service which it calls QoS-1 and the actually measured provision of service (QoS-2). The difference between its QoS-1 and QoS-2 is due largely to the network performance. In addition, the project refers to Quality of Experience, QoE as QoS-3 (see Figure 2.3).

Figure 2.3 Relationship of QoS-1, QoS-2 and QoS-3 (EU Broadband Mapping Project)



QoS-1: Calculated availability of service	**What:** Theoretical network performance of existing infrastructure **How**: Assessment / calculation / marketed speeds by providers	Calculated availability of Service
QoS-2: Measured provision of service	**What:** Line qualification **How:** Measurement through panel probes or speed tests with filter to <u>exclude</u> end user's environment	Measured provision of Service
QoS-3: Measured experience of service	**What:** Actual user's experience when using Internet Access Service (IAS) **How:** Measurement via online speed tests <u>including</u> end user's environment	Measured experience of Service

Source: TUV Rhineland Consulting (2016)

Regardless of how they are categorized, QoS indicators all have the same essential features:

- A clear *definition;*
- At least one *measurable parameter;*
- An agreed *unit of measurement* (to reduce the risk of misinterpretation); and
- A reliable *measurement method* (standards address this need)

An important, though optional, additional element is a *performance target or acceptable limit* for the measured variable. Our survey of QoS indicators in Europe found most indicators that telecom regulators require to be measured and reported regularly do not have specified target values.

Indicators' Content and Purpose Depend on the Target Audience

Quantification and measurement are important for comparing service offerings objectively. But no single number represents the entirety of QoS or QoE. Rather, specific variables or attributes are measured as indicative of overall performance. For example, download speed is often used as an indicator of broadband link quality. Variables tend to be used as indicators either because of their relevance to user experience or because their measurement is relatively simple.

Quantification enables comparisons but that does not mean customers, regulators and network managers evaluate QoS similarly. There are often persistent gaps in perspective: customers' perceptions of the QoS offered by a network may differ from their needs (a "value gap") or diverge from what the network actually offers (a "perception gap"). An "execution gap" exists when a network's performance claims differ from the actual performance. NRAs may then intervene with independent assessments and remedial actions. Some of the diversity among QoS/QoE indicators comes from the range of purposes they serve:

- Showing regulators whether licence conditions are being met,
- Discouraging operators from misrepresenting their network's performance,
- Reducing the number of subscriber complaints,
- Helping officials assess progress toward Digital Agenda goals,
- Enabling the public to decide which service best meets their needs,
- Letting subscribers know if their network is delivering the performance promised in their service contract, and
- Increasing recognition of the best operators' achievements.

Reducing the burden of measuring and reporting so many indicators is an attractive idea, but it must be noted that their number reflects the many purposes served and so reducing them means that some purposes will no longer be served. However, some purposes are no longer required (e.g. for dial-up modems, such as connection speeds).

The Need for QoS Indicators Arose with Liberalization and Universal Service

In Europe the need for QoS indicators grew with the de-monopolization and privatization of fixed telephony in the 1990s. A key step in this process was Directive 95/62/EC, which asked ETSI to "draw up European standards for common definitions and measurement methods in QoS", and noted that, "the national regulatory authority of each Member State should play an important role in the implementation of this Directive, particularly in matters relating to the publication of targets and performance statistics [and] the supervision of conditions of use…". Appended to the Directive were specific indicators for the phone networks to report, including:

- Supply time for initial network connection
- Fault rate per connection
- Fault repair time
- Call failure rates
- Dial tone delay
- Call set up delay
- Transmission quality statistics
- Response times for operator services
- Proportion of coin and card-operated public pay-telephones in working order
- Billing accuracy.

Most of these are still tracked by the Member States' regulators today, although benchmarks apply mainly to the universal service provider.

The Universal Service Directive (USD) 2002/22/EC expanded the monitoring and reporting of QoS indicators to telecommunications services that were not universal. Then Directive 2009/136/EC, which amended the 2002 USD, added a process of interlayer consultation that carefully balanced subsidiarity rights and regional recommendations. It too achieved wide acceptance, but it also set the stage for departures from regional norms.

After 2009, the updating of QoS specifications was driven not so much by directives but by the NRAs' interest in expanding public access to accurate performance data for mobile broadband. As the popularity of smartphones with browsers grew, NRAs received many complaints about unkept promises of broadband access speeds. But measuring mobile broadband speeds objectively proved problematic. Regulator-operated probes can compare one network to another fairly and objectively, but do not accurately reflect the experience of individual subscribers: distance from the base station, the amount of data passing through the base station, the sensitivity of each handset's antenna, and even the way the device is held, all affect data throughput, and there is no way for a regulator's probe to replicate all of these variables. As a consequence, there has been a bifurcation in measurement strategies, between crowdsourcing and probes operated by regulators or operators as well as disagreements about how to measure mobile data transfer speeds. Today NRAs need measurements that are authoritative, that is to say, operator and user neutral – to determine if licence conditions and service contracts are being fulfilled. But they also need tests that are representative of an individual subscriber's experience. The bottom line is that they need technical advice and consensus on approaches, metrics, benchmark values and measurement methods.

2.4.3 Current approaches to QoS/QoE measurement in the EU

To gain an overview of current QoS indicators and how they are measured, we conducted an extensive search of national legislation, mobile licence conditions, interconnection agreements and regulatory rules, decisions and reports from all EU MS. In addition, we circulated three questionnaires among the NRAs and received written replies or arranged telephone interviews to explore their answers in greater depth. We also reviewed previous efforts by BEREC, ECC and COCOM, and visited all of the websites sponsored by EU regulators that advise the public about QoS or enable the testing of broadband link speeds.

From this exercise, we estimate that the 28 EU Member States currently require regular measurement and reporting of at least 858 QoS/QoE indicators – an average of 30.6 per country. Averaging, however, hides the fact that some countries (e.g. Germany, the Netherlands, Slovakia, Luxembourg, and Malta) hardly monitor QoS at all, while others (e.g. Italy, Bulgaria, Greece, Latvia and Lithuania) monitor it extensively (see Table 3.15 in the Methodology Section for a complete list by country).

Hard and Soft Indicators

Of the 858 QoS indicators identified in this inventory, 616 (71.8% of the total) are "soft", that is, they have no target value set by law or regulation. Only the value actually measured is reported. If we consider just "hard" indicators, over half of them apply only to universal service providers (129 out of 242).

Overall, the largest group of QoS measurement obligations (191 of them, of which 95.3% are "soft") concern call handling by "112" emergency phone-in centres. The indicators for emergency call handling are the only ones currently implemented across all of the MS with uniform definitions, measurement methods and reporting requirements.

Further Analysis

The main categories of QoS/QoE indicators currently used in the EU are for:

- Emergency call handling
- Universal service obligations
- Voice (mobile/fixed)
- Internet access (mobile/fixed)
- Customer service: billing, complaint handling and service restoration.

16.6% of all QoS indicators apply to mobile Internet while 9.7% apply to fixed Internet, so a total of 26% applies to Internet access. Despite all the attention given to minimum download speeds and latency, only 17.8% of the Internet access indicators are benchmarked, compared to 34.4% for voice networks. Currently, 82.2% of broadband indicators require only the reporting of measured performance, with no particular targets or minimum acceptable levels defined.

On the other hand, 13.6% of the indicators apply to mobile voice, 10.4% apply to fixed voice, 22.3% apply to "112" emergency calls and 18.2% are for universal services. In other words, *64.5% of all mandated QoS indicators apply to voice networks*. This suggests the indicators list could use some updating, as it still includes items like the percentage of working payphones and minimum connection speeds for dial-up modems.[8] Meanwhile, a growing number of MS are reviewing whether ex ante regulation of fixed telephony is needed at all anymore.

Europe's QoS/QoE indicators are based on 47 different standards, the vast majority of which come from ETSI. Indeed, the regulators have a clear preference for definitions and measurement methods approved by ETSI, which suggests that ETSI has an important role to play in any move toward greater regional harmonization.

Why is there currently so little harmonization? QoS indicators have many attributes: methods of measurement, benchmark values, update cycles, implementers, audiences, cited standards, etc. Most permutations of these options exist in most MS. In addition, opportunities for variation are created by reliance on single-parameter indicators, even though many network applications depend on combinations of parameters for good user experiences (e.g. video streaming, VoIP, gaming, etc.). Finally, the principle of subsidiarity gives MS the right to determine the form and method of implementation even when a regional directive sets common goals and obligations. On the other hand, some of the

[8] The proposed European Electronic Communications Code would eliminate from the scope of universal services mandates for providing "legacy services" like public payphones or published directories unless the need to ensure the availability or affordability of such services is duly demonstrated.

apparent diversity is superficial, based simply on language differences and styles of expression. However, some national differences are quite real, grounded in different preferences for regulator-led or market-led policies.

2.4.4 Comparing the Member States' Approaches

Since the 1990s, the MS have generally adopted QoS requirements in response to regional initiatives and directives, so it may seem surprising to find large differences in practice. A possible explanation can be found in attitudes toward markets and regulation, which vary significantly. Some countries, such as the Netherlands, Sweden and Estonia, are willing to let market forces work with minimal regulatory intervention. A slightly different attitude is found in Slovenia, which encourages industry self-regulation. Poland tried "co-regulation" but gave up when the mobile operators could not agree on a way to measure QoS. A typical "middle ground" arrangement is that the regulator determines the indicators but responsibility for measurements is split: either the regulator verifies the operators' measurements, or they work in parallel, measuring different parameters. In still other countries, outside auditors check the operators' measurements (e.g. Ireland and until recently, France). In a few countries, the regulator decides what to measure and makes the measurements (e.g. Latvia).

But it is a mistake to think that, just because a country implements a certain strategy now, it has always done so and always will. ARCEP of France, for example, made major changes in their QoS measurement programme in a short period of time before abruptly switching to crowdsourcing.

Perhaps the most conspicuous trait that MS have in common is the extent to which they rely on ETSI's guidance for measurement methodologies, definitions, descriptions, criteria for statistical analysis and sampling. The growing acceptance of crowdsourcing is another important area of convergence, even though the regulator sponsored link testing sites (there are currently 17 with two more starting soon) mostly use different software (see Table 3.16).

Looking at which QoS indicators are already the most widely implemented (apart from those related to emergency "112" call centres), the following would probably be the easiest to harmonize:

- The frequency of faults reported per subscriber line
- Average time to troubleshoot, repair and eliminate faults
- The proportion of mobile phone calls dropped or interrupted prior to normal completion
- Data transfer rate in the download direction
- Customer care metrics relating to help centre response times and billing-related complaints.

2.4.5 Potential Barriers and Catalysts for Harmonization

One area where there is a notable lack of commonality is in standards for network reliability. Bulgaria, Finland and Sweden have benchmarks intended to reduce the probability of interrupted service in networks with large numbers of subscribers, but most other MS do not, even though the Framework Directive (2009/140/EC) says, "Member States shall ensure that undertakings providing public communications networks take all appropriate steps to guarantee the integrity of their networks, and thus ensure the continuity of supply of services provided over those networks".

There are other areas where a current lack of consensus on a technical solution (e.g. mobile broadband speed measurement or LTE coverage) interferes with regional harmonization, although that does not lessen the value of a common regional approach. However, the main problems are political: namely, different preferences for regulator-led or market-led policies and the centrifugal force of subsidiarity. No list of QoS indicators is going to change national attitudes on whether policy should be market-led or regulator-led. However, there may be a practical path toward convergence in the Universal Service Directive's 2009 update.

The key point emerging from our survey of QoS regulations in Europe is that the MS adopted and modified their regulations in response to regional policy initiatives, ***generally accepting regional guidance*** so long as the harmonization could be considered voluntary. Applying the 2009 USD model means that when the Commission suggests standards and methods, NRAs can decide if they are appropriate; alternatively, if the regulators propose methods, the Commission can assess their impact on regional development and comment accordingly.

NRAs need performance testing capabilities that are authoritative – operator and user independent – as well as testing capabilities that are user-specific and consistent with experience. This could be achieved with common platforms for monitoring and reporting by NRAs with information about service quality published for consumers.

QoS Indicators Without Benchmark Values

Not setting benchmark values for QoS indicators or KPIs might make it easier to reach agreement on a regionally harmonized list covering a wider range of parameters. This is in fact the current situation in Europe: 72% of the QoS indicators mandated today do not have specified target values or minimum acceptable levels of performance. Whether that can be applied to all indicators is doubtful. There may be a lesson here: if a benchmark is essential, for instance, for reliability in networks for eHealth services or connected cars, then that must be followed throughout the EU. For less safety-critical services, allowing individual MS to decide on benchmarks ensures flexibility to accommodate local preferences and conditions.

Despite differences in the number and choice of QoS indicators, the MS are not so different in the ways indicators are measured and reported. Their reliance on a few dozen ETSI standards provides substantial commonality. This overlap suggests further convergence toward a common set of indicators, measurements and reporting requirements is feasible, with some leadership and effort, as proven by the unanimous acceptance of the emergency "112" indicators.

2.4.6 Other Approaches to Quality of Service

BEREC and QoS

BEREC has been working on QoS mainly in the context of net neutrality, because traffic shaping – which, generally speaking, is the opposite of net neutrality – can affect QoS. At the same time, measures designed to enhance QoS can trigger a "false positive" from measures designed to detect traffic shaping. Thus, the relationship between QoS and net neutrality is close and complex. BEREC will also be moving to QoE with its measurement tools in the 2018 programme (BEREC 2017d).

In October 2017, BEREC (2017a) published specifications for the development of a regional QoS monitoring system and the definition of a common measurement methodology for net neutrality. It is too early to understand if this will be adopted by all Member States but it provides a starting point for a converged set of indicators and measurements that reach beyond net neutrality.

This report could become the first volume of a set of measurement standards for the whole of the EU and in 2018 BEREC will be working on implementing the toolkit. It will supervise the development of three key components of its net neutrality measurement toolkit (its basic software which is open source, a reference system and its information portal). They will also consider ways to extend the system to monitoring mobile coverage, including indoor access, and the Internet of Things (BEREC 2017d). As these tools are deployed, BEREC's focus will progress from QoS to QoE.

Broadband Mapping Project

Launched two years ago, the Broadband Mapping Project is producing a website[9] that offers zoom-in maps of Europe and individual MS. These display EU broadband coverage in terms of speed, technology and availability of service at any location, using data from over 30 country-level mapping projects. Thus, it complements this study's analysis of broadband coverage obligations in mobile licences. The creation of this website has highlighted some critical problems for coverage mapping: first, that current practice is far from standard across the EU in what is measured, in metadata, or in detailed formats. Second, that maximising the resolution and reliability of the maps' geographic data is essential, although this magnifies the problem of keeping data accurate and up-to-date, factors that are nevertheless essential for maintaining the site's value. Public awareness of the state of broadband access in Europe is enabled by this initiative. Furthermore, it should support new infrastructure plans, specifically for rollout of 5G.

Looking Beyond the EU

The role of QoS monitoring and enforcement were explored in jurisdictions outside the EU – the USA, Canada, Japan and South Korea. While some differences among the EU Member States in the choice and use of telecom QoS indicators are substantial, when compared to other parts of the world, the differences seem smaller. Recently the USA has suspended most QoS reporting obligations, while Canada maintains its effective user protection. Eliminating harmful Internet content and promoting local broadcasts are South Korea's QoS priorities, along with promoting technologies developed by their major exporting firms. Meanwhile, Japan relies on the operators to maintain quality, with a light touch, yet would like their networks to be resilient enough to survive disasters. If anything can be learned from these comparisons it is that Europe's choices across the Member States may be compared to different items on a menu; but beyond Europe there are different menus driven by quite different motivations.

Possibly the most useful example outside the EU is Canada's meticulous attention to detail in enforcing QoS obligations. With a long history of maintaining service despite challenging geographic and climate conditions, its regulation focus on equal access to the incumbent's infrastructure now competing with newer and smaller networks. Decision CRTC 2005-20 finalized a plan for rebates if the local operators fail to achieve minimum acceptable levels for any of 14 QoS indicators. The size of the rebate depends on the number of indicators missed. This decision also established terms and conditions for the reporting and auditing of QoS measurements. A public consultation was launched earlier this year on whether this framework needs reform as CRTC recently gained new powers to regulate the wholesale market for telephony, which may enable it to improve measures based on QoS (CRTC, 2017). The results of this important consultation have not yet been published.

[9] https://www.broadbandmapping.eu/.

2.4.7 Flexibility and Willingness to Change is Evident in the EU

This research showed that minimum performance levels and targets, service benchmarks, and state-imposed obligations to measure and report QoS/QoE indicators are scattered across many types of regulatory instruments, from regional directives and national laws to cellular licences to universal service and leased line contracts. We also found this field to be more dynamic than is generally recognized, with many regulators making in-depth reviews every few years and modifying their QoS agendas. Some benchmarks are updated; others that yield the same results year after year are quietly retired.

We started this study with the impression that QoS measurement obligations were more or less static and thus might be difficult to change, but that is not so. There is evidence of widespread flexibility. This flexibility could be embraced by the MS to arrive at similar ways to measure quality. Thus, with sensitive leadership and frequent consultation, we believe it would be possible to move toward greater commonality in the choice of QoS indicators and how they are measured, even though complete convergence seems unlikely and unnecessary.

2.5 Common Standards for Network Quality and Performance Measurements

2.5.1 The Future Requires New Thinking on Quality Indicators

Using the previous section's findings on the current array of QoS indicators in the EU, we turn our attention to the possibilities for common standards. Our key findings are:

- Even though regional initiatives prompted the MS to adopt QoS indicators to influence the development of public electronic networks, the diversity of interpretations and benchmarks have become impediments to common quality measures for future networking in the EU and thus for the DSM.
- Modernising the selection of indicators is necessary to prepare for more challenging use cases as fixed and mobile networks converge, especially the stricter performance requirements of high value applications envisioned for 5G networks.
- New indicators for attributes like resilience, security, and energy-efficiency will be required, as well as greater use of composite indicators and more emphasis on quality of experience. QoE must be the focus when end-users are not sure if they are using Wi-Fi and fixed line, or cellular, or both simultaneously, or shifting from one to the other seamlessly. They will just use "services".

Experience shows that different kinds of networks must be measured with different tools in different ways. Future networks will tend to be more diverse (ad hoc converged and so heterogeneous with virtualized elements). Therefore, any common approach should be *open-ended,* permitting the addition of new criteria and standards. But can a "common approach" be applied to all the network types – fixed, mobile, voice, broadband, IoT, etc. – in better ways than today's forest of indicators?

- End-users need different QoS information than regulators and network managers. Network managers are most interested in network performance (NP), NRAs are generally most interested in QoS and end users care about QoE. Indicators today are a mix that serves all three groups, so each gets unneeded information which goes unheeded.
- Fewer indicators will reduce overlap which is an obvious source of uncertainty and extra work for those who compile the data. As technology becomes more complex, NP/QoS/QoE must remain understandable, which requires more carefully focused

- choices and positioning of indicators. Virtualization is a key challenge, as is network slicing in 5G (each slice may require different QoS benchmarks).
- Network managers build NP monitoring capability into their networks. NRAs might need to do the same when public safety is involved, as 5G's stringent reliability and latency requirements demand rapid alerting, response and repair.

In summary, QoS/QoE indicators must be made more fit for purpose, and need to be organized more efficiently and structured more logically to enable appropriate choices.

2.5.2 Indicators for the Digital Single Market

In order to identify the elements of a common standard for measuring network QoE/QoS, two key questions must be answered:

- How does Europe progress from the indicators now in place to those needed to regulate and support more advanced networks envisioned for the period after 2020?
- What actions need to be taken and barriers overcome to make progress in a manner acceptable to all stakeholders?

Distilling the Existing Indicators

As noted above, we found at least 858 QoS indicators that NRAs in the EU Member States want measured and reported regularly. When these are consolidated into a single list, grouped by parameter and theme, it is clear that many individual indicators can be reduced to a smaller set of shared topics (this set of topics appears in Figure 3.18 in the Methodology Section). That is our starting point for development of a common European approach based on current practices. But as that list would probably be too extensive for the "market-led" states, we approach the task from a different angle, by compiling a short list of the most widely mandated indicators, not including the emergency call handling parameters. If we expand that list to 26 indicators (the median number required by the Member States), the result is shown in Table 2.2.

Table 2.2 Most widely mandated existing QoS indicators across the MS

Category	Indicators
Internet	Data transfer speed (maximum, minimum, typical); Web page loading time; Latency; Jitter; Packet loss rate
Voice	Call set-up time; Unsuccessful call rate; Speech transmission quality; Response time for calls to the operator, customer service and directory assistance
Mobile	Network availability; Probability of successful connection in an area covered by the network; Dropped call ratio
Customer service	Time between request for service and start of service; Fault frequency; Time to troubleshoot & eliminate faults; Frequency of complaints about billing
Emergency calls	Total number of 112 calls per year; 112 calls as a percentage of total emergency calls; Percentage of false calls; Average time to answer; Percentage of calls answered within 10 seconds; Call abandon rate; Average time needed for operator to receive the caller's location

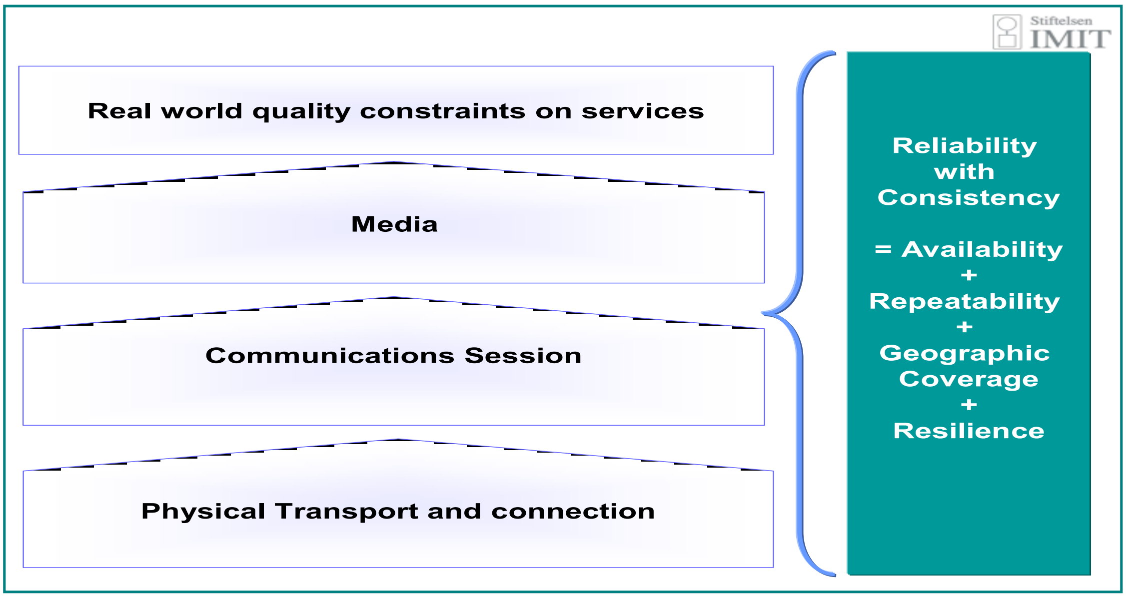
Source: Regulations published by NRAs.

The table above is a compromise between completeness and conciseness, so it could be a good starting point for the development of a common regional set of indicators of network quality. But again, it only reflects current practices. It is not sufficient to steer the development of future networks.

On the other hand, the set is too small to include all the indicators used in countries with a strong commitment to these tools, and too large for the countries without such commitment. The way to resolve these different approaches is through a regional process of discussion and consensus-building among regulators and other stakeholders.

Another way to organize indicators more efficiently is to categorize them according to the layers of network architecture, with physical transport, session and media layers supporting the higher-level application and QoE requirements and extending into the socioeconomic environment, with variables like geographic coverage, resilience and availability (see Figure 2.4).

Figure 2.4 Overview of future standards for networking quality for the DSM



New Indicator Themes for the Digital Single Market

Further development of standards in the following fields may be necessary before specific measurement protocols and reporting obligations are agreed:

Resilience/reliability – Minimum standards for continuity of service throughout Europe will be increasingly needed as society's dependence on network services grows with the DSM. As noted above, Bulgaria, Finland and Sweden have benchmarks for network resilience aimed at reducing the possibility of service disruption caused by bad weather or the loss of mains power. While reliability appears on our comprehensive list of QoS indicators, it does not appear on the lists of widely mandated indicators because most European countries do not have minimum reliability requirements for public networks. International standards exist on this topic (e.g. ITU-T Rec. Y.2614, IEC 60605-6:2007, ENISA's Technical Report on "Resilience Metrics and Measurements", etc.). Even though risk factors vary geographically (earthquakes may be the main problem in one place, dry season fires in another), relying entirely on national decisions in this field may no longer be sufficient. Uniform minimum standards for continuity of service throughout Europe will be needed as society's dependence on network services grows with the DSM.

Network security – Ubiquitous, effective cybersecurity will be a prime objective for the DSM's operation, particularly in Smart City, Connected Car and eHealth networks. Unauthorized access to medical implants and industrial control systems are recognized as dangers in the proliferation of IoT networks, demonstrating the risks of living in an always-connected world. Although there are some initial standards, they are not yet consistently implemented or complete – e.g. for certification of countermeasures. ETSI is active in this field. The EECC does mention effective network security (Articles 40 and 41) in an initial view.

Privacy/identity protection – It is time for personal data privacy (with identity protection) to be recognized as essential parts of network QoE. Even casual web browsing is being tracked to build profiles while rules for enforcing "the right to be forgotten" remain incomplete. The EU's General Data Protection Regulation, due to come into force in 2018, will be of major importance for protection of stored personal data. Additional relevant privacy standards are under development by ETSI.

Energy efficiency and pollution reduction – Telecommunications can reduce greenhouse gas emissions from travel and industry, but the telecom industry's own carbon footprint steadily grows in terms of electricity consumption and the footprint of its equipment. With the expansion in transceivers and denser connectivity backhaul it will grow far faster. In addition, discarded electronic devices and batteries are a growing source of pollution globally. Standards must be updated to take the complete equipment lifecycle into account.

Health and safety rules – The biological effects of radio frequency energy are still poorly understood even after a century of widespread human exposure. Standards on suitable limits are necessary for 5G networks, as they move into higher frequency bands where the energy content of signals is much greater and molecular resonance effects become significant. Existing standards governing human exposure to radio frequencies are inadequate because they do not provide clear design guidance. But guidelines are being developed by the ITU, IEEE, and the EC's safety and health committee, SCENIHR.

Assuring future networking quality may demand extra new indicators.

The set above is not fixed or closed. It will be the subject of intense debate so additional indicators can be envisaged. Some may well be only viable at the level of a smartphone app for crowdsourcing. For instance, future indicators might also include:

Analysing the degree of efficient sharing of spectrum - Intensification of spectrum use in the next few years will require more efficient and creative band sharing, with more intensive exploitation of bandwidth

Location accuracy indicators - All EU MS check the accuracy of emergency number 112 caller location data from mobile phones, and several of the future 5G use cases in Task 2 require very high location precision (cooperative ITS and medical tele-presence, for example). The EU's Broadband Mapping project also confirms the importance of common standards for geographic data with the resolution of location indicators with standards for their accuracy in general, not just for emergency services.

Additional technical gaps in the QoS indicators for future converged 5G networks - have been identified by the Korean Telecommunications Technology Association. They hope to begin filling these gaps by deploying the world's first commercial 5G network at the Winter Olympics in Pyeongchang in 2018. They expect this deployment to help them:

- Develop end-to-end measurement rules for bridging fixed and mobile networks
- Define QoS indicators for direct mode (terminal-to-terminal) links that bypass base stations
- Identify parameters relevant to the management of links between operatorless devices (for Internet of Things networking)
- Assess the impact of network slicing on QoE and QoS for multiple application environments and the virtualization of network elements
- Establish tolerable levels of jitter and packet loss for new use cases like virtual reality, remote control of driverless vehicles, etc.

2.6 Key Quality Indicators for Monitoring of Network Performance and Reliability

The way forward suggested in the pages below is a set of proposals to act as a focus for discussion. It will demand much effort to develop an improved integrated set of forward-looking indicators through EU-wide debate. The regional process of discussion and consensus-building will require inputs from those responsible for applying, measuring and using the indicators: i.e. all stakeholders – NRAs through BEREC, network operators, SDOs, vertical sector and consumer organizations and other relevant experts.

2.6.1 The Need for a Coherent Package of Quality Indicators

Our research found a clear need for NRAs to have indicators assuring constant network availability, everywhere, by monitoring the quality of performance perceived by end-users. End-users also need such indicators to identify the suppliers best able to meet their requirements. We propose a policy framework with 12 steps to achieve this:

1. Redefining the main indicators of network quality
2. Indicators should enable comparisons of services and equipment (and also where needed, replacement of best effort Internet service with guaranteed QoS)
3. A meticulous selection process is needed in developing quality measures
4. For future networks of converged fixed-mobile networks, compound sets of standards are needed – so KPIs become KQIs
5. An expert group should be tasked with identifying the critical parameters and measurement criteria to be incorporated into KQIs
6. NRAs should have their own facilities for monitoring quality
7. KQIs may need to be enforced in the future by a detailed approach (i.e. bottom-up)
8. A roadmap is needed for the phased introduction of more advanced indicators, (KQIs)
9. Measurement methods for quality parameters and benchmark values for parameters linked to KQIs should be specified
10. A public EU-wide database of KQI measurements by operator and location is needed, EU-wide
11. Extension of the NRA remit for the 5G world – i.e. include KQIs for vertical applications
12. Implementation at an administrative level - via EU Regulation

1. Redefining the main indicators of network quality

There is a need to identify the indicators needed for regulating networks like 5G, which differ substantially and conceptually from earlier networks such as fixed voice telephony and GSM. Most of the QoS metrics used today were determined by network type, and often by what was convenient for network managers to measure. But network have advanced and we need indicators for as well as voice telephony. Network quality indicators now should focus primarily on the current and emerging needs of regulators and end users. To assess user satisfaction, indicators based on technical performance should give way to experience metrics, QoE, even though they may still be summed from basic NP and QoS parameters.

2. *Indicators should enable comparisons of services and equipment and advance the boundaries of guaranteed service*

   Quality indicators must provide comprehensive metrics for comparisons of overall service quality end-to-end, as well as the underlying software and hardware, and yet be easy for non-specialists to understand. The current set of QoS indicators grew by accumulation, without any overall plan. A more coherent system of indicators is needed for the future and defining a coherent network quality framework is a major challenge. But fixed-mobile convergence, the spread of the Internet as a ubiquitous platform for all types of communication and the consolidation of diverse specialized radio networks into the 5G project makes it critical now.

   It is also necessary for network quality metrics to expand into Internet services. TCP/IP evolved as a "best effort" medium, without quality of service guarantees. But many proposed applications require more than a best effort, for example, telesurgery, remotely piloted vehicles, even video streaming as a paid service. EU research projects have been working toward this goal for more than a decade, e.g. Project NETQOS (Policy-based Management of Heterogeneous Networks for Guaranteed QoS), an FP6 funded project, 2006-2009. BEREC's work on the monitoring of QoS parameters to verify net neutrality is also relevant (see, for example, BEREC, 2014a; BEREC, 2017b; BEREC, 2017a).

3. *A meticulous selection process will be needed to assemble the new quality indicators from the various component QoS/QoE indicators*

   The concept of a composite, compound or "higher level" indicator might lead to a richer understanding of quality in a complex multi-network environment. Integrating multiple parameters is already practiced in the EU, in some MS. In Italy, for example, AGCOM introduced a "global quality index" for universal services in 2010. This is a weighted composite of seven single-variable indicators. Hungary uses the IETF's Media Delivery Index, which combines packet loss ratios and jitter measurements to assess the quality of IPTV. Several countries use combinations of "mean time between failures" (MTBF) and "mean time to repair" (MTTR) to calculate network availability, sometimes adding "coverage affected" to calculate "geographic availability".

   A further example of a composite measure of network quality is TALE (Throughput, Anomalies, Latency and Entropy) symptomatic of a more general move to more sophisticated measures (Ahmad, 2017). Composite indicators are being explored by standards development organizations (SDOs) like the ITU, e.g. ITU-T REC-Y.1545: "Roadmap for the Quality of Service of Interconnected Networks that use the Internet Protocol", and ITU-T REC-Y.1546: "Hand-over Performance among Multiple Access Networks". An EU-wide consensus building exercise is needed, led by a new Expert Group on Quality Indicators

4. *An EU-wide consensus building exercise is needed, led by a new Expert Group on Quality Indicators*

   As noted in Section 2.5.2, an EU-wide consensus-building effort toward the definition of a common set of quality indicators for public networks could produce beneficial results. This might be organized as an Expert Group on Quality Indicators, under the auspices of BEREC, to synthesize input from a wide range of sources and stakeholders, providing a forum for discussion and advising the Commission with opinions and reports on the basis of a specific mandate. It could operate according to the Commission Decision of 30.5.2016 establishing horizontal rules on the creation and operation of Commission expert groups, C(2016) 3301 final. The groups' participants may come from:

- BEREC for the NRAs, as the representative body in the region acting as the group leader and facilitator; NRA review bodies, such as RSPG, might also participate.
- Relevant SDOs, especially: ETSI with 3GPP, the ITU, IETF, CEPT/EEC, IEEE, etc. should also be closely involved as well as ENISA for networking security and privacy issues;
- EC DG CONNECT units for future networks and 5G as well as for standardisation, cybersecurity and spectrum policy
- Telecommunications equipment and software suppliers;
- Network operators, ISPs and communications service providers;
- Business user groups like INTUG and European consumer organizations like BEUC.
- Special interest groups (for accessibility, EMF health, sustainability, etc.) would participate, as well as NGOs and vertical industry groups (e.g. EUTC).

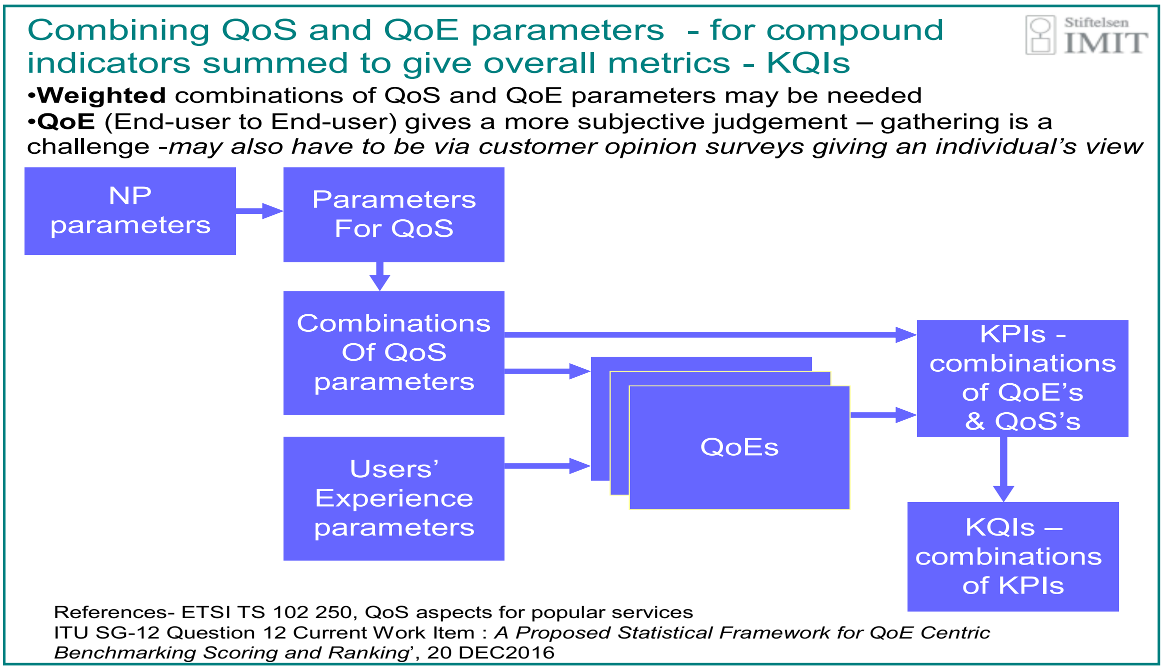
The expert group's agenda might include:

- Reviewing current needs for QoS/QoE and quality indicators looking forward;
- Defining a logical framework for partitioning the quality indicator space (as Figure 2.4 suggested), in order to avoid overlaps and gaps;
- Discussion of the role and value of benchmarks (and indicators without benchmarks);
- Agreement on a process for distilling the current indicators mandated nationally into a smaller common set of indicators for Europe as a whole;
- Analysing the different measurement procedures used for the same indicators in different EU Member States, to see if unnecessary differences can be eliminated and transnational comparability improved;
- Compiling a list of new candidate indicators from the themes (as suggested in Section 2.5.2) plus other quality criteria deemed useful and relevant;
- Selecting methods and criteria for creating or choosing composite indicators;
- Selecting which QoE indicators would be most useful for Europe-wide adoption;
- Deciding on the functions of key quality indicators and determine which composite form would be most useful (see step 5).

5. *Developing key quality indicators*

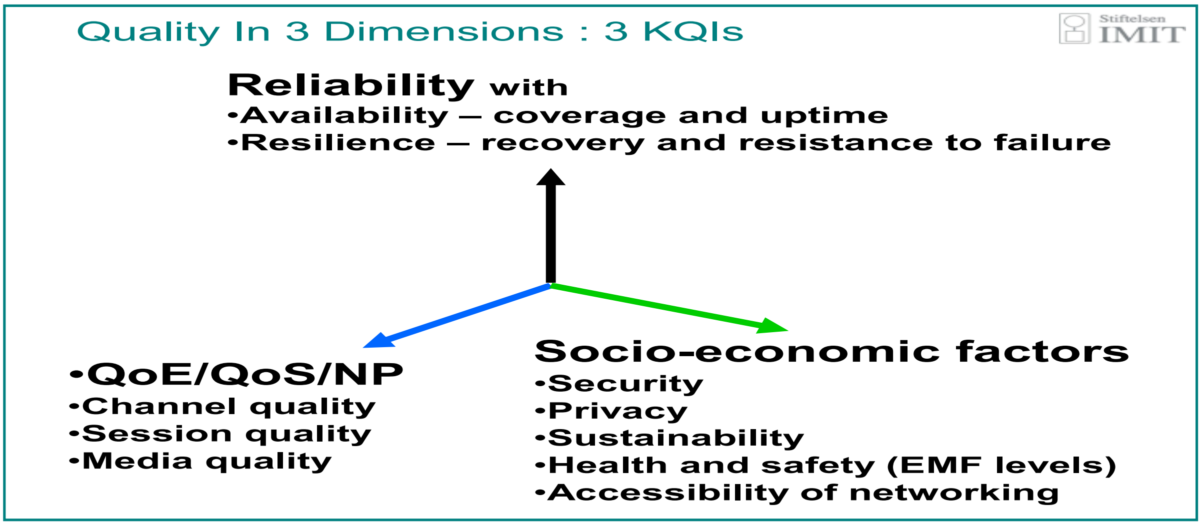
Key Quality Indicators (KQIs) are defined as a multiple or compound set of QoS and QoE standards and parameters with their associated measurement methods and benchmark values, possibly using weighting. This is also supported by the RSPG in its Second Opinion (RSPG, 2018) on the service performance indicators. They anticipate the needs of future converged networks, particularly 5G, where complex heterogeneous networks may be interconnected sequentially in a dynamic manner. The intended jurisdiction for KQIs would be the whole EU rather than just national and thus would be aimed more towards regional indicators. This approach draws on the experience of COCOM which has monitored the progress of emergency call number 112. Management of quality, using KQIs could be based on a group led by NRAs, perhaps with BEREC coordination, using the model of COCOM's Expert Group on Emergency Access, which compiled a list of Key Performance Indicators (KPIs) as the basis of an annual regional survey. As noted in Section 4.3.1, these KPIs are the only indicators implemented uniformly in all 28 EU Member States. The success of this strategy inspired our proposal for an Expert Group on Quality Indicators, led by NRAs as a group, described in the previous section. The process of creating KQIs might follow the steps outlined in Figure 2.5.

Figure 2.5 A procedure for creating KQI's



The domain of KQIs in the context of the Digital Single Market can be represented by three dimensions, shown in Figure 2.6.

Figure 2.6 KQIs should cover all dimensions of future network infrastructures



6. *KQIs should include critical parameters chosen by an expert group*

Tentative suggestions for the key quality indicators and their parameters are given in Table 2.3, as examples of the form and level that KQIs could take.

Table 2.3 Suggested parameters for prospective KQIs (an initial proposal)

KQI	Metrics Parameters	Measurement Method
Reliability	• Availability – temporal and geographic coverage for a given signal level; • Effective coverage i.e. signal strength at local loop extremity; • Resilience	• Compound measurements of service interruptions/availability, MTBF, MTTR, time/location variations of signal level, signal quality, media and session quality. • Monitor signal level over time for MTBF, MTTR by NRA and /or end-users (App) • Indoor monitoring for effects of attenuation by rain/foliage/ ferro-concrete/wall insulation; • Examine resilience measures in place - (power backup, diverse routing etc.)
Channel quality and signal quality	• Signal Strength (indoors/ outdoors) and variations; • Packet loss rate, jitter, latency and latency variance, acceptance rate of false packets • Data transport: Bit rate (D/L- U/L speed) i.e. effective bandwidth; Volume/capacity, number of parallel user sessions.	• Indoor and outdoor monitoring as for reliability of availability • Minimum received signal strength relative to that level the regulator determines is needed for service availability. For LTE, measure RSRP. For latency and jitter, measure RTT
Session quality	• Internet Access success rate; WWW access and performance • Set–up delay; blocking probability • Call success rate for voice calls • Access retention rate for IAS and voice calls.	• Test for access with all metrics parameters: 1) NRA testing on remote indoor sites 2) App for crowdsourced measures
Media quality	• Voice quality perceived (ETSI/ITU, etc. definitions) • Video quality perceived (ETSI/ITU, etc. definitions)	• Measure quality using ETSI and ITU methods: ETSI TR 101 578 V1.1.1 (2013-12): QoS Aspects of TCP-Based Video; ETSI ES 202 765-4 V1.2.1 (2014-05): QoS and network performance metrics and measurement methods; Part 4: Indicators for supervision of Multiplay
Privacy	• Digital privacy definitions (e.g. the "right to be forgotten" - GDPR) and for ownership of personal data • Privacy by default and design • Data control - by citizen of data collection and use • Active countermeasures: device protection; appropriate encryption; access control (e.g. passwords)	• Examine privacy measures implemented by service providers • Examine compliance to GDPR • Test for privacy by default • Test for data control by citizens and consent mechanisms • ISO/IEC 27552: Personal information/Privacy Management System Requirements (under development). Regulation proposal on ENISA for certification • KPI from METIS (2015), p. 17, Identity/location of communicator is not discoverable
Security	• Public, open EU-level standards in NIS are generally lacking today. A range of EU and international standards apply but there are gaps, especially for IoT security. Compliance to security standards is fragmented across the EU; • Certification of NIS services & products to provide EU level approval is lacking but national schemes exist. For future, use EU-wide certification metrics when available - as proposed in ENISA Regulation, 17 Sep 2017, and certification under the 'Cybersecurity Act' (2017) as part of the EU Cybersecurity Certification Framework (2017)	• Assure certified countermeasures • Apply "security by design" (as required under GPDR) • Assure a security framework under ISO 27001 is in place • Test for known vulnerabilities and add countermeasures, especially for SDN/ NFV hypervisor for small cell networks and its slicing as single point of failure • Examine cloud SLAs & ensure compliance • Also ENISA (2009), Cloud Computing: Benefits, Risks and Recommendations for information security - http://www.enisa.europa.eu/act/rm/files/deliverables/cloud-computing-risk-assessment.
Inclusion and accessibility	• EU standards are lacking apart from Standardisation Mandate 376 but	• Measurement methods should be set by stakeholder groups for each disability

	some MS have initiatives, perhaps under Universal Service Obligations with specific metrics; • Coverage obligations become critical for such groups; • Metrics are set by specific needs of each group; • Digital literacy campaigns form part of the needs and have their own metrics	• A key EU reference is the EDF (European Disability Forum)
Health and Safety – EMF, Millimetric RF	• General limits for manufacturers (IEC and EU) • Specific safety limits from medical authorities (e.g. SCENIHR, 2015): • Specific Absorption Rate (SAR) – defined as the RF power absorbed per unit of mass of an object, measured in watts per kilogram (W/kg) per gm of body mass.	• Defined procedures from EU medical safety authorities e.g. Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) Opinion on Potential health effects of exposure to electromagnetic fields (EMF), 2015 01 20; also IEEE Standard C95.1-2005 for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz
Energy efficiency and sustainability	• Power Consumption and pollution effects • Emission levels for GHG (ETSI, ITU, IEC, GSMA) • 3) Broadband network energy efficiency • Recycling and pollution assessment parameters	• Defined procedures from SDOs and EU ICT sustainability centres of expertise for power consumption & recycling, e.g.: 1) Clauses 6 and 7 ("Measurement of energy efficiency" and "Extrapolation for overall networks") in ETSI ES 203 228. See also Boldi, 2017, Chapter 8 ("Proposed metrics for 5G energy efficiency"); 2) ETSI TR 103 476 (Circular Economy in ICT). Directive 2012/19/EU gives rules and principles for the treatment of waste electronic equipment, as well as minimum targets for recycling and recovery by 2018. For mobile phones, see UL 110 (Standard for Sustainability for Mobile Phones, 2nd ed., 2017); IEEE 1680.1 "Standard for Environmental and Social Responsibility Assessment; ITU-T Recommendation L-1410 (2014), "Methodology for environmental life cycle assessments of ICT goods, networks and services; 3) See Clause 7.19 of 3GPP TR 38.913 V14.3.0 (2017-06) - http://www.3gpp.org/ftp/Specs/archive/38_series/38.913/38913-e30.zip - last 2 scenarios (urban and rural) to be simulated for evaluation for range of traffic load levels. Also see ETSI Green Abstraction Layer, GAL : ES 2003- 237, (2014)

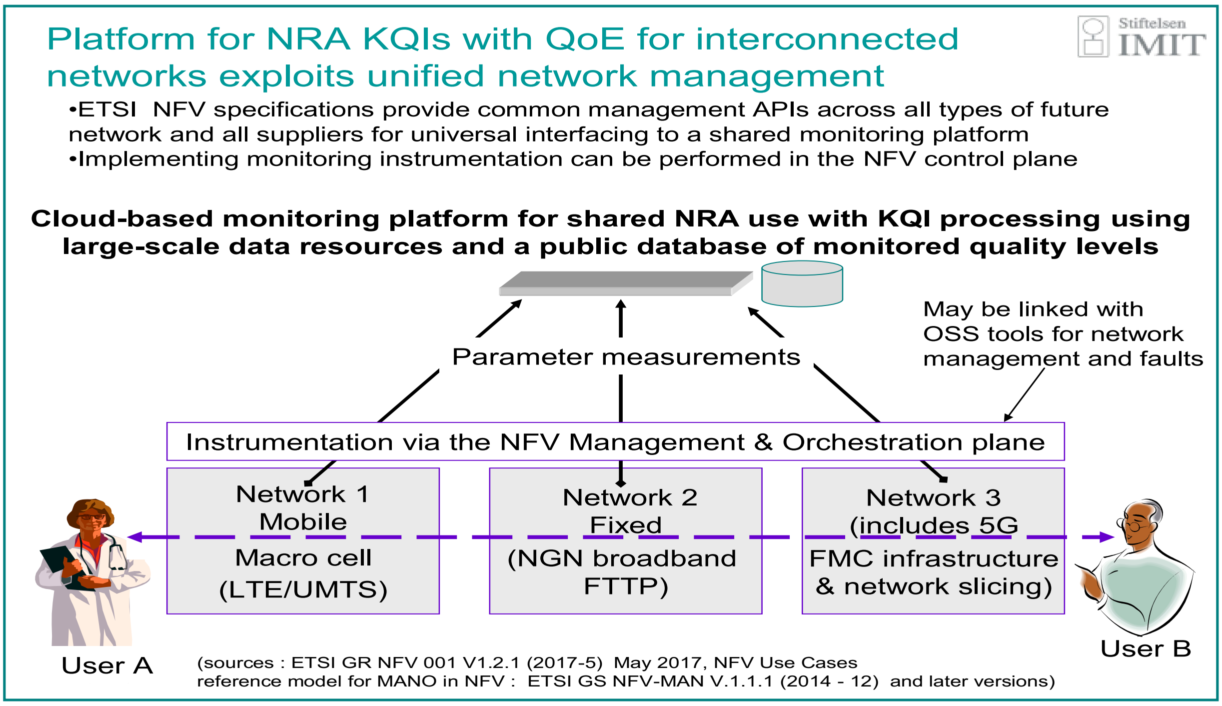
While this study can suggest systems of indicators, the final selection must be based on a more detailed analysis with input from industry and something like consensus support. The European Expert Group on Quality Indicators, described above, would be responsible for the details including the final selection of indicators, their definitions, parameters, standards and operating ranges.

7. *NRAs should have their own facilities for monitoring quality*

Facilities with embedded instrumentation of networks might be set up for each NRA. Alternatively, there might be consideration of an EU level measurement platform, shared among all NRAs (which may expand on BEREC's planned European net neutrality measurement system). It would bring coherence and harmonization to parameters, measurement methods and data formats. Either approach would require additions to NRA budgets. Consequently, the cost to NRAs of the measurement process would become a deciding factor in choices of parameters and methods. Here, European funding may be necessary to seed the initiatives, and to ensure consistent implementation and quality levels across all Member States.

Monitoring approaches could be of several types but two principal forms stand out: first, embedded monitoring via network agents and, second end-user measurements and reporting. To guarantee an accurate real time status of the network infrastructure, there should be multiple sources of measurement, which are independent of the service provider, network operator and also the equipment vendors. One approach is shown in Figure 2.7.

Figure 2.7 A common platform for quality measurement

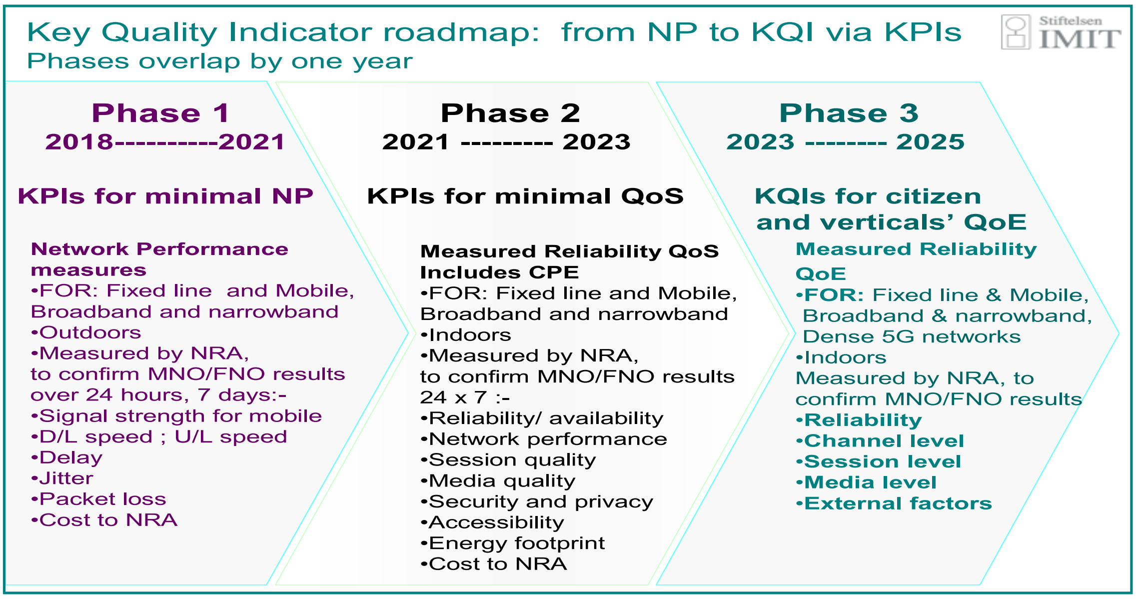


8. *A roadmap for phased introduction of more advanced KQIs is necessary*

A roadmap for more advanced KQIs with their accompanying standardization processes could describe a phased introduction. 5G support for such life-critical applications as connected cars and eHealth implies high levels of reliability and new levels of network quality. That will take some time to be agreed, accepted and implemented across Europe. The path to standardization must have a synchronized timetable.

A first phase of common network performance parameters and standards could end around 2021. With an overlap of the next phase by one year, the three-year second phase would finish in 2023, in which the extremities of network measurements are pushed to the user equipment interface. Finally, the user is included for QoE measurements, reached in 3 years (in 2026), again using an overlap. The phases in Figure 2.8 may each need a basic network reference model for the parameters and their levels of aggregation – a model that may have to evolve with each phase. That reference model would be agreed for all EU Member States. It would require a common understanding of measurement definitions (NP, QoS, QoE, KQI) across the different network types.

Figure 2.8 Future quality measures for the DSM could follow a three-phase rollout



To clarify responsibilities, obligations and targets, the reference model might even need service level agreements (SLAs) for the operators, especially where safety of life depends on network quality. Such SLAs might be attached to spectrum or to operating licences.

For the roadmap above, a simplified definition of a KQI with the indicators decomposed in more detail for each phase is useful. Extra KQIs and additional metrics may be progressively added for each phase. The KQIs and their breakdown are outlined Figure 2.9, e.g. Phase 1, NP, uses basic transport and communications session.

Figure 2.9. Breakdown of KQIs and their component elements by Phase

Breakdown of detailed quality metrics into a set of simpler KQIs

Stiftelsen IMIT

KQI	Metrics Parameters
Reliability	**MTBF, MTTR**, Physical Coverage, Availability/repeatability/ resilience/consistency, **Time variation in basic QoS metrics** (communications, session, media) during session, day, Week, year
Basic transport	**Signal strength**-Indoors & Outdoors at local loop extremity, rain/ foliage, via ferro concrete & insulation; network interconnection **Channel Capability –** Bandwidth, Bit rate (D/L-U/L), Volume capacity in parallel sessions, Latency
Communications Session	**Packet rate**, Packet loss rate, Delay, Jitter, False packets acceptance **Internet Access** and Web Performance **Voice & video Calls -** Success rate of set up, Drop rate/retention rate, Set–up Delay, Blocking rate
Media quality	**Audio quality for speech** - sound bandwidth, voice quality, noise level, distortion level, consistency **Full motion video quality** - channel bandwidth, picture and colour quality, resolution, luminescence, image distortion, pixellation /aliasing level
Accessibility with Health & Safety	**Accessibility** measures, as recommended by specialist organisations RF radiated signal limits (Centi / Millimetric)
Security & Privacy	Risk level ID Protection level
Energy Footprint	Energy Consumption, GHG level, recycling and pollution levels

Phase 1 KQIs

Phase 2

Phase 3

9. *A public EU-wide database of KQI measurements by operator and location will be needed*

   Following a phase of consultation with all stakeholders, results of the various measurement tests could become open data, placed in the public domain. The datasets could inform the public, relevant authorities and stakeholders (e.g. emergency services, energy companies) of the status of the various networks, in real time. BEREC is also preparing measurement tools that could be used for a common platform under its 2018 work programme (BEREC 2017d). Private organizations with supplementary data sources such as SamKnows could also be included. The public database would enable citizens to better understand the quality being offered currently and for studies on quality trends and gaps to be carried out. The latter may be critical for 5G operations. Possibly, creation of such a public, shared platform across Europe could need seed funding at EU level.

10. *KQIs may need to be enforced by a bottom-up approach*

    Enforcement of KQIs, across all of the EU, promises to be a major challenge. To be effective, it may need to be at the level of analysis of the component parameters, i.e. bottom-up. Effective enforcement will rely on reports at regular intervals (monthly, quarterly or semi-annually) – at a later stage becoming real time, perhaps, and publicly displayed. Enforcement may need the NRAs to give more guidance on testing methods for the industry players, perhaps with more support and guidance than today and to indicate and enforce the range acceptable for the parameters.

11. *Extension of NRAs' responsibilities and jurisdiction for the 5G world - KQIs for vertical applications*

    Increasingly, QOS/QoE metrics will provide the necessary support for smooth functioning of the 5G world – not just the networks but the applications they deliver and their end-users. The vertical sectors with a public offering, such as eHealth, ITS, smart city, smart energy, etc., could need specific KQIs for each industry. These would be less generic and more complex than those that apply to the networks themselves. NRAs could have a role in measurement and enforcement, possibly in conjunction with vertical industry bodies that provide inputs on critical performance factors, benchmarked values and range limits. Industry stakeholders would also provide feedback from the field on the actual observed functioning for critical parameters.

    This is a substantial undertaking for a single national NRA. Moreover, the equipment suppliers are likely to be international or Europe-wide, while user industries would possibly be organized at an EU level. It would thus be more effective if an initiative for each vertical sector could be implemented at a European level, with a period of consultation for each sector to understand the issues and context. Such an effort would need to be performed under an appropriate European framework as the consultation phase would then be followed by standards setting for the vertical industry, with the appropriate SDOs and a Reference Model to combine the standards and benchmarks into KQIs for the sector, with the monitoring scheme. Funding would possibly need to be at EU level, or in concert with the user industries. KQIs would be introduced as the 5G infrastructures are installed for each vertical application. This initiative implies that NRAs would participate in the setting of KQIs for the vertical sectors, in concert with appropriate industry bodies and SDOs. Entry of NRAs to vertical industry network regulation for 5G applications would probably need to be a phased process, based on expansion of the legal powers of NRAs into these domains.

12. *Implementation at an administrative level – via EU Regulation for introduction and for compliance enforcement*

The measures explored above require a framework for the different actions, if they are to be implemented within the timeframe suggested in the roadmap (see step 8). Consequently, implementation of the quality measures is likely to require some form of legal support at the EU level.

Movement through the phases of introducing new quality measures could be based on an EU Regulation. The aim would be to obtain common standards for quality indicators within the timeframe of each phase in the roadmap.

An EU Regulation is preferable to a Directive in order to assure consistent compliance. Without it, varied national interpretations and implementations would lead us back to the kind of fragmented market we have today. It is for this reason that technical standards are agreed at the highest level possible – if not globally then regionally – and quality of service and experience are largely governed by technical criteria. The Regulation would cover two main areas: first, the introduction of common quality indicators, and second, their monitoring systems in hardware and software with standard operating procedures to enable enforcement for the long term. This might be a logical extension of the BEREC system for net neutrality, as noted earlier, and use its Internet QoS measurement system.

The choice of EU Regulation is justified by the need for synchronized take-up that ensures ubiquitous and uniform levels of quality across the Union.

The Commission proposal for a European Electronic Communications Code (EECC) of September 2016 has already introduced some changes that, if approved by the co-legislators, would affect the implementation of the measures recommended by this study in terms of Common Standards for Network Quality and Performance Measurements and Key Quality Indicators for Monitoring of Network Performance and Reliability.

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3 Methodological Section

This chapter describes in greater detail the work performed on the six tasks assigned for this study:

- **Task 1**: Do Mobile Networks Complement or Substitute for Fixed Networks?
- **Task 2**: FMC as a Key Enabler of future connectivity in the EU
- **Task 3**: Impacts of Differences in Regulatory Coverage Obligations among Member States
- **Task 4**: QoS and QoE measurement in the EU Member States
- **Task 5**: Common standards for network performance measurement
- **Task 6**: Key Quality Indicators for regulatory monitoring of network performance and reliability

3.1 Task 1: Do Mobile Networks Complement or Substitute for Fixed Networks?

The key objective of this task is to assess the relationship between fixed and mobile services, narrowband and broadband, to understand the extent to which fixed and mobile networks are converging and whether they are complementary or whether they are substitutes. This is examined from different standpoints, by considering regulation, technologies, infrastructures, services and markets. Analysis focuses on how fixed and mobile services interact, from both the demand and supply side, in the context of evolving technologies (e.g. terminal equipment, such as smartphones) and consequent adoption of new patterns of use across the EU. Four sub-sections examine the issues arising between the various forms of network access:

- Defining convergence between fixed and mobile networks
- A brief background history of fixed-mobile convergence (FMC) and fixed-mobile substitution (FMS)
- The impact of convergence on the telecommunications industry and its regulation
- Operator strategies: bundling fixed and mobile infrastructures and services.

3.1.1 Defining Convergence Between Fixed and Mobile Networks

Assessing the relationship between fixed and mobile environments

At the outset, it is necessary to provide some clarity regarding the terms that are commonly used in connection with fixed-mobile convergence:

Convergence implies the progressive integration of two sectors or sub-segments of those sectors – which can be at market, service or infrastructure level; convergence may imply combining all three. FMC for telecommunications.

Substitution, as in FMS, implies that one infrastructure (generally) and its services replaces another. For FMS, for example, it most often applies to mobile voice services from the MNOs replacing narrowband fixed line voice. Substitution of over the top (OTT) Internet services implies service substitution, for fixed, or mobile, operators' services via IP voice (Skype, Vonage, etc.).

Complementarity implies that two infrastructures and their services can interwork in unison to support a specific service without competing, as each network type has its own role. An important example is offloading of mobile data to Wi-Fi via fixed line broadband.

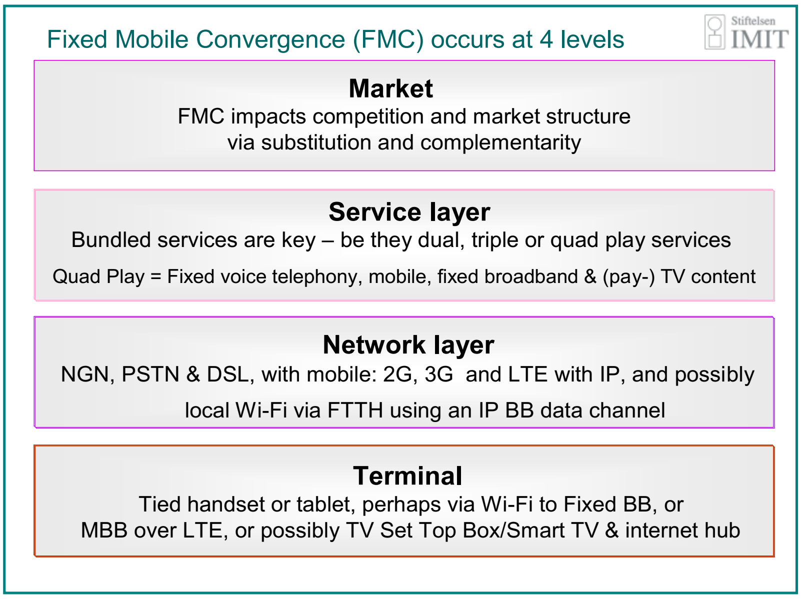
Evidence of complementarity may be provided by the increased use of one service producing increased use of another service.

Compatibility implies that various network types (mobile 2G, 3G, LTE and PSTN, NGN) can interwork, i.e. that interfaces exist and a service can be supported across both. That may occur at the terminal level as for Wi-Fi and mobile.

The convergence of fixed and mobile communications into a single channel is, and will be, an important trend in the development of EU communications over the long term. The complementarity of the two technology families is likely to be essential to progress further with 5G as the existing fixed infrastructure could form part of its backhaul, integrated into the 5G infrastructure. Also at a technology level, the future evolution of macro-cell mobile IP is for LTE (the ETSI-3GPP world) to become fully compatible via IP with the Internet world (as defined by the IETF) through higher bandwidths with lower latencies. This will enable operators to offer users guaranteed access and bit rate, for supporting delay and timing sensitive IP services such as voice in the form of VoLTE and video over LTE (ViLTE), rather than one based on "best effort", i.e. the current Internet.

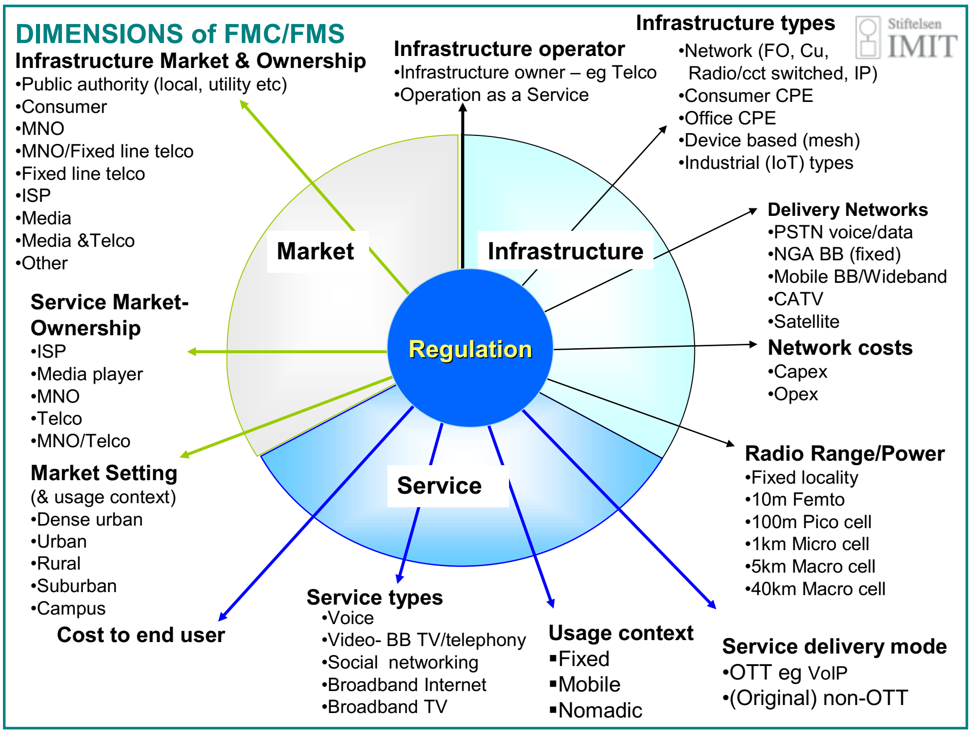
But FMC should be understood as impacting much more than the physical network layer. Whether fixed and mobile technologies are complementary, or substitutes, is determined by the combination of market pricing, services offered as well as the quality in terms of ease of use of the human interface through the terminal device. The various layers of compatibility are shown in Figure 3.1.

Figure 3.1 Convergence of fixed and mobile from terminal up to market



FMC has three dimensions: service, market and infrastructure, the main features of which are illustrated in Figure 3.2. All dimensions have specific regulatory foundations, defined by the features specific to fixed and mobile technology and their capabilities. Each dimension's regulation reflects the relative market positions and will evolve with FMC and FMS. Note that, more recently, substitution includes over-the-top (OTT) services, especially VoIP (e.g. Skype for home use, or Facebook Messenger, an unmanaged service and Skype for Business and Vonage, managed business services) which substitute for both fixed line voice (PSTN and NGN) and the MNO's cellular voice services.

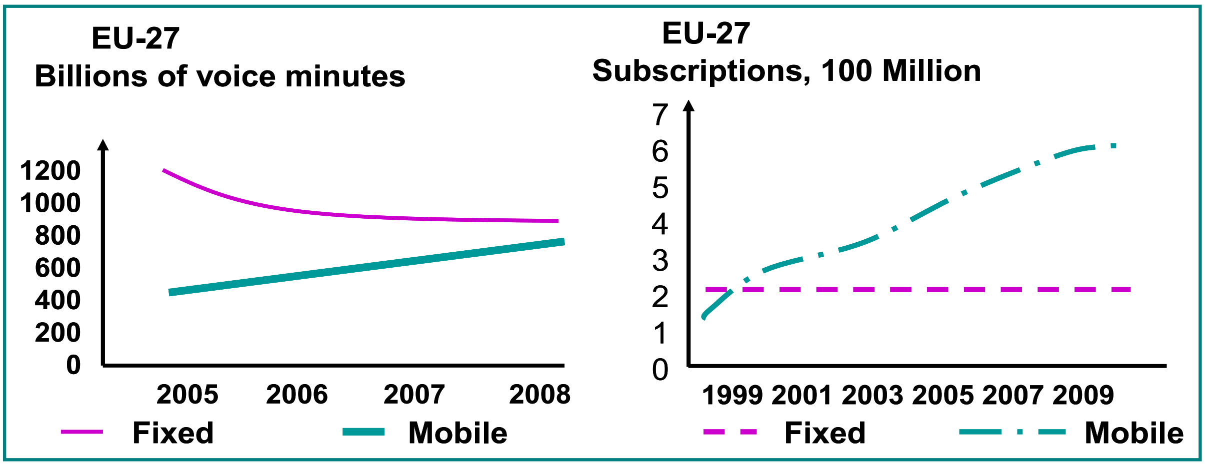
Figure 3.2 Three components to the FMC environment



Substitution has Multiple Business Implications

Perhaps the first fixed-to-mobile cellular interaction has been at a market level, by substitution (FMS), i.e. the replacement of fixed line voice communications by mobile service, beginning from the late 1990s onwards. Figure 3.3 shows the impact in the EU of mobile voice on fixed line use and subscriptions. Outgoing voice traffic in the EU in the growth period up to 2009 expanded as the number of mobile subscribers exceeded fixed-line subscriptions since around 2000. Thus, while fixed-line subscriptions were static (at some 200 million) the mobile subscription contracts (not necessarily users) grew from 100 to over 600 million adopters in 2009, reaching over 700 million today.

Figure 3.3 Mobile substitution in the EU



Sources: European Commission, 2010a; The World Telecommunication/ICT Indicators database, 2010; also cited in Barth and Heimeshoff, 2014a.

Thus, mobile take-up and fixed line substitution rapidly expanded, driving growth of mobile operators towards market dominance for narrowband voice over the past decade in many Member States, especially in those EU economies that lacked a dense fixed-line infrastructure, such as Portugal and Poland. Note that those MS with dense fixed line infrastructures already maintained higher fixed line minutes, e.g. in the UK and Germany (Barth and Heimeshoff, 2014b). The degree of FMS measured in minutes of mobile use against fixed line voice generally increased, essentially by progressively replacing PSTN voice services but also by enabling latent demand where fixed line infrastructures were poor, as in large rural spaces and mountainous geographies such as Finland and Austria, although other factors, especially pricing, also play a part in setting relative demand (Barth and Heimeshoff, 2014b). Eurobarometer notes that some 33% of EU households had only mobile access in October 2015 (Eurobarometer, 2016), with no fixed line connectivity (especially in the southern and eastern parts of the EU).

In many EU MS, especially those with poorer fixed line infrastructure, mobile rapidly substituted for fixed narrowband voice, first by GSM and then by UMTS (Barth and Heimeshoff, 2014b). That has driven the growth to market dominance of the MNOs in some MS, in terms of call volume in the narrowband voice market (BEREC, 2012a). Since 2000, fixed line voice telephony in the EU has followed the OECD community generally, declining both in terms of revenues and volumes, as traditional fixed voice telephony service providers have been increasingly replaced by mobile voice carriers as shown in the graphs above.

FMC May Lead to More Dependency on Local Radio Networks

What is forecast to be 5G is the likely next step in FMC, but not necessarily just in a mobile mode, as fixed wireless access (FWA) is also possible and could employ a denser cell configuration. But today without a working 5G network or something that has much higher bandwidth, major expansion of FWA is less likely. It might eventually lead to a final converged state with a fibre optic core network and radio tails for both fixed use with nomadic users, as for mobile, an architecture that has been anticipated for some time. For example, a common virtual private network (VPN) integrating 5G-type technology in the radio tails might appear as a future evolution of FMC (OECD, 2006).

Thus, in future, infrastructure convergence with fixed wireless access (FWA) could be much more common, being the basis for small cell implementations. It has already been taken as the first step in 5G services convergence by two major carriers offering entertainment TV and IP based telecommunications service in the USA – ATT and Verizon. First trials in 2017 claimed up to 1 Gbps and latency of under 10 ms, with trials being expanded in 2018 (Alleven, 2017). These pilots are testing millimetric and centimetric bands in 28, 37 and 39 GHz and also trialling NFV implementations of router software.

In Australia, the National Broadband Network (NBN) has already deployed LTE-based directional beams for the last kilometres of its broadband local loop to a transponder antenna on the outside of dwellings.[10] Similarly, EU MNOs such as Telia-Sonera have installed LTE links for remote residences in Sweden. Thus, future expansion of FWA might employ increasing re-use of existing fixed lines with sharing for multiple service providers through unbundling of both the local loop and longer distance lines. The same unbundling process may be necessary for the newly built small cell backhaul for denser 5G networks to enable entry of competing SPs. A similar unbundling of existing *mobile* backhaul with the base stations' elements could be beneficial to raise the level of competition by enhancing ease of entry for new 5G service providers. Note that in practice this would require NRAs to have suitable powers to intervene to open up infrastructure access for

[10] NGN website accessed 23Dec 2017, https://www.nbnco.com.au/learn-about-the-nbn/network-technology.html.

both the mobile and fixed line infrastructures. Moreover, it implies the capability to combat abuse of SMP conditions in both the retail and wholesale FWA access markets, setting wholesale rates where needed.

5G through FMC has Implications for Operator Business Models

FMC enables market integration in the current vertically separate telecoms industry structure, divided largely between fixed line players who also have mobile networks and MNOs who increasingly have acquired fixed line services offerings, some infrastructure, and are now moving into pay-TV operations. New broadband technology (e.g. 5G) may ease that FMC market entry with architectures that are not monolithic, but heterogeneous. That brings the possibility of more diverse forms of network ownership, of services offered and of separated operation. Depending on the regulatory regime, a variety of business models more varied than today could appear, particularly if new types of player enter the market, for example:

- ISPs: bundled services that are far more than Internet access
- Content providers: streamed entertainment extending into network ownership/operations
- Local authorities: low-cost hotspots and support for sheltered and social housing
- End users: own and operate indoor/local residential consumer and business networks – using low cost network technology (as now proposed by Facebook and others)
- New 5G operators: partnering with MNOs/MVNOs, using macro cell/micro cell mix by locality (e.g. rural).

3.1.2 A Brief History of FMC and FMS

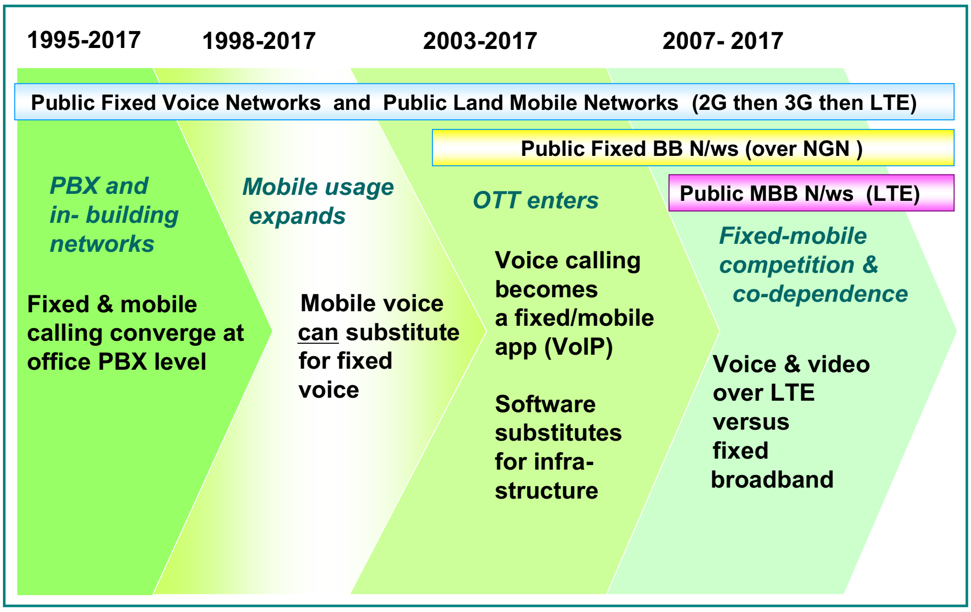
FMC is Not New

Broadband services were launched more than a decade ago but have been a more recent addition to convergence trends. Mobile networks in the later 1990s were at best carriers of narrowband data, circuit switched over the voice channel at perhaps 9.6 kbps. Data packet services over GSM (with GPRS) were added in 1997 while mobile Internet access protocol such as wireless access protocol (WAP) provided early handset browsers for Web access in 1999. However, the development of FMC in general goes much further back, before broadband, as early converged services were largely voice.

The history of FMC follows the three major dimensions of convergence shown in Figure 3.2 (infrastructures, services and markets) with progressive phases of integration. Network convergence drives device convergence with the aim of a seamless switchover between services. Inevitably the fixed and mobile markets tend to collide, with revisions of offerings that modify the business models of the players. Figure 3.4 summarizes the major technology trends over the past two decades in FMC and FMS.

Elements of mobility for handsets that were previously fixed (or at least restricted to portability within the customer premises) were added to the fixed network with the sale of cordless telephones in the early 1990s. Still with us today, they use cordless telephony standards such as CT-2 as well as proprietary and public European standards such as DECT. Thus, four main stages of the market development in FMC can be identified (see Figure 3.4).

Figure 3.4 A brief history of FMC trends in infrastructure and technology terms



- **Voice convergence at device level**: the office market of the late 1990s and since: The first major market for FMC was the office market. It was centred on the PBX, the office switch, for live voice and voicemail, because business had the funds and interest in integrating mobile and fixed line services, before consumer technology such as smartphones appeared. Unsurprisingly, each vendor at that time enjoyed its own definition of 'enterprise level FMC', but products tended to exploit different features and standards, both proprietary and public standards for air interfaces, such as DECT.
- **The PBX as a mobile hub hosted on a PC for the BYOD market**: The conventional PBX air interface technologies have been augmented by all the mobile standards, as PBX manufacturers have tried to accommodate any mobile handset and any MNO as call carrier. Moreover, with some PBX suppliers, a mobile phone can call the PBX when the user is within the building, as a fixed line extension would, if the device has a dual mode of operation with an air interface to the PBX's own transceiver. Treating the mobile phone as an extension to the PBX (via a software app on the smartphone) offers the PBX's features on the mobile handset, creating a virtual desk extension for the authorized mobile phones. Some vendors have their own software app while others license it from a third party (e.g. OptiCaller, CounterPath OnRelay, ShorTel, Tango Networks, etc.). The smartphone and software suppliers also have apps (e.g. Apple and Microsoft).
- **Unified communications (UC) a complex, sometimes ambiguous FMC concept**: UC or unified communications is another industry marketing term that has a variable definition by vendor of the equipment or service. The term UC typically incorporates various forms of FMC at levels of device, service and networking. It often is based on integrating a range of communications services on a dedicated server (that may be cloud-based – termed UCaaS or via a module attached to a PBX) merging different media into a single user environment. The media may include at least: a conventional PSTN fixed voice landline with cellular mobile telephony of any generation including IP voice, data (emails) and voice messaging (over IP or possibly an older in-house PBX-based voicemail), SMS texting (reception and transmission), voice and video conferencing and IPTV plus access to, physical presence, local RLANs such as Wi-Fi. More sophisticated services include speech recognition, desktop sharing and electronic whiteboards, with interactive voice response (IVR) for user access. It may have text to voice, for spoken emails, and voice to text messaging. Hence, over the last decade,

UC has come to imply many forms of convergence, at infrastructure, device, media and service levels.

- **The continuing trend to convergence within services and markets**: In early 2001, mobile subscriptions globally overtook fixed line subscriptions (ITU, 2002) - much to the surprise of many in an industry still strongly oriented towards the fixed line network infrastructure and its services. FMS grew out of this as mobile could offer a competing infrastructure at lower cost and faster rollout. With a greater number of mobile calling minutes than fixed, FMC became an attractive repositioning target for the fixed line operators. But today, considerable market focus is going further in market sector convergence to combine telecommunications and pay-TV over the same network for media convergence with streaming.
- **Cordless nomadic users become dominant for in-building connection**: At a terminal device level, the convergence of many different RANs in one portable or handheld smart phone type of device has evolved with the pace of radio technologies. Increasingly, DECT and other standards for indoor connection, such as CT-2, have been displaced in home and offices by multipurpose Wi-Fi networks running over RLANs, or often by indoor use of mobile, narrowband and broadband:
    - Hot spot/RLAN interfaces – Wi-Fi (2.4 and 5GHz); DECT; WiMAX; LTE-U OFDM.
    - Mobile cellular generations: GSM and CDMA; UMTS; LTE, all used in-building.
    - Non-cellular radio – Bluetooth; NFC; RFID; UWB.
    - Broadcasting: Digital Multimedia Broadcasting (DMB); Digital Video Broadcasting – Handheld (DVB-H); DAB (Digital Audio Broadcasting).

Our interviews with 19 NRAs across the EU show that, as the convergence goals of telecommunications operators and the non-telco ISPs in Europe (Yahoo, Google etc.) and content providers advance, regulators are taking notice in their public policy stances, with more analysis of infrastructure rollout and its impact on competition.[11] It should also be noted that the satellite and cable TV industry, originally focussed on pay-TV, are increasingly players in broadband internet access and the telecommunications services derived from IP access over the Internet – voice and video chat etc., in many MS across the EU with converged services and markets (e.g. Virgin Media, Liberty Media, Altice, Vivendi, etc.).

3.1.3 The Impact of Convergence on the Industry and its Regulation

FMC and FMS can clearly be seen in the impacts on markets and competition, leading to regulatory consequences. The traditional separation of markets is challenged by convergence, for broadband and narrowband segments, fixed and mobile.

Regulation of Fixed-line Offerings Compared to Mobile Services

Fixed and mobile telecommunications markets are both subject to regulation by laws and institutions, but with considerable differences in the level of supervision and actual exercise of that regulatory management. These differences originally arose from the presumption that the mobile market was separate from the fixed market, being much younger and so growing in competitiveness. That implied that new entrants should be nurtured to develop competition with the fixed line operators through a lighter touch regulatory regime, with less price regulation, little supervision of ancillary charges such as international roaming and no USO, apart from emergency calls in some MS. The result

[11] Interviews with 19 MS NRAs on their views on the changing market's competitive challenges to one of converged telecommunications, pay-TV and Internet access and away from narrowband voice.

was the successful growth in both mobile subscriptions and voice minutes detailed above, especially as in many EU MS subscribers may have multiple mobile subscriptions (e.g. company and personal). In contrast, fixed line markets were already mature, requiring regulated access surveillance as fixed line was the dominant communications technology. But in many EU MS that market was often operating under near monopoly conditions – with a national incumbent, protected by its bottleneck control of the fixed-line physical infrastructure – and so demanded heavier regulatory supervision.

Implications for Regulatory Policy – Market Definition Issues

Regulators see extending consumer choice as a key objective, and FMS can be seen in this context, if mobile and fixed offerings are from different operators. Effectively this would take the form of infrastructure competition, for instance, of mobile narrowband and broadband against xDSL, possibly even FTTH as well as against CATV (DOCSIS 3.1) from cable network operators. Of course, same-market (mobile) competition would still be present from MNOs and those operators using the unbundled mobile infrastructure to carry their services, the MVNOs.

However, to verify this, there is first a question of market definition for NRAs when considering competition, pricing and access conditions of mobile versus fixed as a single market. Is it a common, comparable type of offering or are they separate markets? Note that this is a moving target as it is technology dependent and technology continually advances, especially for mobile data carriage. The question for regulators, therefore, is where and how can mobile substitute for fixed so that it competes? Typically, that is dependent on three factors – functionality, usage patterns and price.

In the EU, from our survey, the majority of NRAs have considered whether fixed and mobile services belong to the same market. Only one NRA (RTR of Austria) has included fixed and mobile services in the same market. However, NRAs vary enormously in their consideration of whether mobile is a competitor to fixed line services. For instance, Ofcom in the UK took the opposite view to Austria's RTR on broadband mobile substitution classing mobile broadband as a different, limited and non-competing service, as noted in its analysis (Ofcom, 2012):

- "…mobile broadband packages (offered via a USB modem or "dongles") tend to have a fraction of the download limits compared to fixed broadband access…"
- "…Current maximum speeds for mobile broadband access … generally are achieving …a fraction of the speeds achieved through fixed broadband access…. it is unlikely that a mobile broadband service can offer a comparable service quality. In addition, given that a 30-minute TV programme streamed online would use around 175MB, a 1GB download (cap) could only provide less than 3-hours worth of video streaming…".
- This was repeated in our survey: "neither mobile broadband (i.e. dongles) nor internet access via smartphones will be strong substitutes for fixed broadband access over the review period ending in 2021 ... some 91% of 4G users and 88% of other smartphone users use Wi-Fi to connect their smartphone to the internet when at home … this suggests there is limited substitutability between mobile and fixed broadband where fixed broadband is available".

Considerations of usage patterns (i.e. particular ways of using each service, specifically mobile only when outside and on the move, but fixed at home/office) are important in assessing the degree of market substitution. From our NRA interviews, and other sources (BEREC, 2012a) NRAs have cited different factors and reached varied conclusions, for example:

- PTS (Sweden's NRA) noted that for wholesale markets, mobile radio alternatives do not meet the functionality demands of wholesale customers; they could not be considered a substitute according to the hypothetical monopolist test, within the wholesale market.
- ANCOM (Romania) found mobile is not a substitute for fixed access at a retail level, as a fixed line supplies an entire household, while mobile is personal, usually for one person.

The general NRA conclusion was that the dissimilar usage patterns define differing markets. Fixed broadband consumers tend to have more intensive use, demanding higher bandwidth than mobile broadband offerings, so that fixed line streaming and downloads are faster than mobile, more reliable, often of higher quality and far cheaper for high data volumes. This was the reason why the majority of NRAs do not include fixed and mobile services in the same retail market, as also confirmed by BEREC (BEREC, 2012a). Overall, the deciding factors for market segment separation are price differences, bandwidth limits, reliability, mobility and usage limits on data allowances. In the future, one factor that may limit the growth of fixed/mobile (LTE) substitution is mobile's speed. Although LTE headline speeds can be 30 Mbps or higher, they are well below current superfast fixed broadband speeds and tend to reduce with the number of users within a cell using a service simultaneously (for instance, Ofcom measured average speed in five UK cities at 21 Mbps in its Smartphone Cities report of 2016 (Ofcom, 2016)).

These were our findings from interviews with NRAs in Spain, Sweden, France, the Netherlands, Finland and also from Portugal (ANACOM, 2015). To test for potential monopoly presence and abuse of the position, the small but significant and non-transitory increase in the price test (or SSNIP, or hypothetical monopolist test) is useful.[12] Moreover, there is no real wholesale market in FMS voice or data services at the moment although the retail pricing of mobile, through FMS, may have an effect on the wholesale fixed line voice and broadband markets, as well as the retail fixed line market. That provides wholesale and retail price constraints, even when the MNO is vertically integrated, such that the wholesale offer is never obtainable in the wholesale market, as shown in Figure 3.5.

Does Merging of Fixed and Mobile Markets Imply Regulatory Forbearance?

Does the merging of mobile with fixed indicate a new approach, a more relaxed deregulated framework for fixed and mobile? The decision to deregulate currently is based on the degree of substitution between fixed-lines and other telephone services (European Commission, 2014a; FICORA, 2013). The EC Recommendation on relevant product and service markets within the electronic communications sector (2007), considered that ex ante obligations for the markets for access and call origination on the public telephone network provided at a fixed location could be removed (Laric and Sange, 2016). The Three Criteria Test[13] would be used by NRAs to prove that a market has failed, in order to retain

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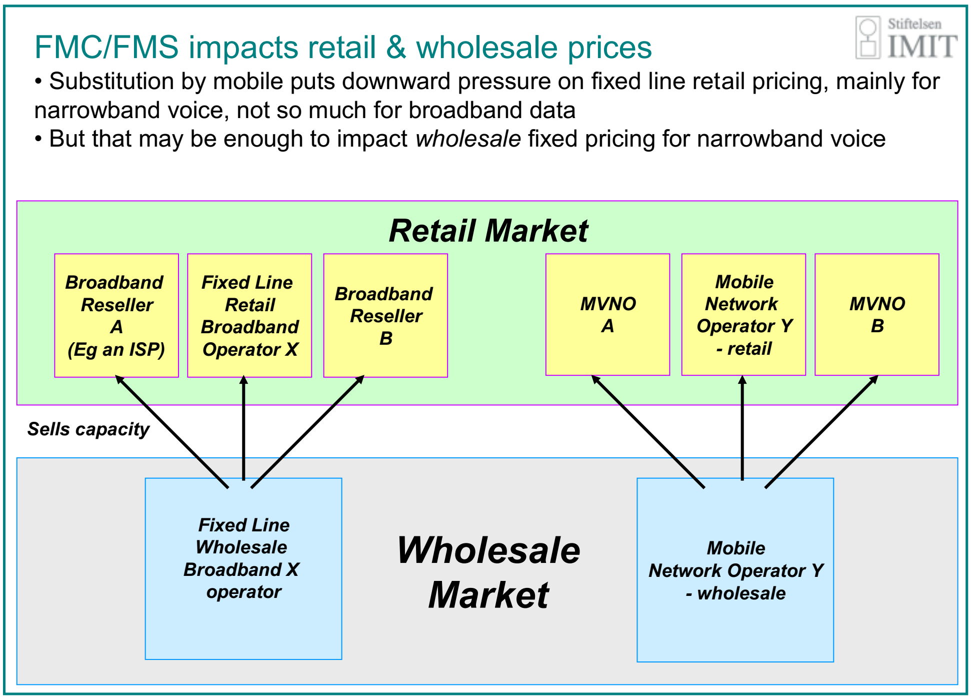
[12] The SSNIP test attempts to describe customers' reaction to a hypothetical small (e.g. 5-10 %) but non-transitory relative price increase on the services. The test is whether end-users leave the market altogether for a substitute, or suffer the price increase – because there is no substitute. There may also be an asymmetric substitution effect whereby the users of narrowband services may switch to broadband services in response to an increase in the price of narrowband services. But the opposite may not apply so asymmetry is present (e.g. because today's applications require more bandwidth for faster data speeds for larger data volumes).

[13] In 2003 the Commission recommended the so-called "three-criteria test" to define the requirements for regulatory intervention as follows: the first criterion is the presence of high and

the regulation. Based on the differences in features, contracts, and usage patterns between mobile and fixed-line telephony, the EC notes that although both mobile voice and VoIP can provide pricing competition to the fixed line incumbent operators, only managed VoIP is a comparable substitute for fixed-line voice, as it offers similar attributes (European Commission, 2014b).

Figure 3.5 Market impacts of fixed mobile substitution and complementarity



Source: Authors' elaboration based on BEREC, 2012a.

Impacts of VoIP: OTT Services as a Substitute for Mobile or Fixed Voice

However, there is less literature on VoIP telephony and its relationship to the comparable narrowband services for which it may substitute, especially for managed VoIP (Lange and Saric, 2016). Thus, while the literature finds an overall trend to increasing use of mobile voice compared to fixed telephony voice, overall VoIP impacts are yet to be analysed. Lange and Saric suggest stronger capability for substitution between fixed lines and mobile than between fixed lines and VoIP telephony but conclusive evidence is not yet available. Also, there are many areas in the EU that lack full fixed broadband coverage, having only limited fast broadband with slower take-up rate and rollout. But countering this, the next stage in fixed network technology is the rollout of NGN all-IP networks in all MS, so in the future, VoIP substitution of fixed line voice may spread. Substitution analysis should also include managed and unmanaged VoIP over mobile IP connections via mobile broadband and over Wi-Fi with smartphones for mobile offloading, as now offered by many MNOs. That comparison is not yet available (Lange and Saric, 2016). Such an analysis may favour retention of ex ante access obligations. At the EU level, the outcome might favour joint market definition and so, perhaps, discontinuing parts of the current regulation. But that

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non-transitory entry barriers whether of structural, legal or regulatory nature; the second criterion admits only those markets, the structure of which does not tend towards effective competition within the relevant time horizon; the third criterion is that application of competition law alone would not adequately address the market failure(s) concerned" (see Recommendation of 11 February 2003 on relevant product and service markets within the electronic communications sector susceptible to ex ante regulation).

requires a wider comparison with VoIP and bundling affects to be carried out. As market, competitive and regulatory environments differ so much across the EU, such changes might be better considered at national level first by each NRA.

Thus, the question of whether the threat of abuse of Significant Market Power (SMP) by the fixed wireline incumbents still exists is unclear today - more analysis is called for. The MNOs, once the challengers to fixed-line incumbents, are the new incumbents in the EU today. Furthermore, the fixed line incumbent may also be the dominant mobile player and thus control both national fixed and mobile markets. Increasingly, they also achieve a pan-European dimension in assets and traffic volumes. Such is the case for Orange, Telefonica, Deutsche Telekom, Telecom Italia, Telia-Sonera, KPN, and BT. Hence in the major EU economies that comprise some 70% of Europe's GDP and population, fixed and mobile services are sold by the same dominant operator.

A further consideration is that FMS can affect retail pricing incentives by incumbents when those operators can differentiate between customers with different substitution possibilities (Hoernig, et al, 2015). One suggestion is to use targeted access obligations which might offer a solution to protect a captive group of consumers (Lange and Saric, 2016). Alternatively, tariff controls might apply, as in the UK, where Ofcom in February 2017 proposed 25% reductions of fixed landline-only retail tariffs for two million of the BT's customers, as they are considered a captive group. Such measures should ensure a level playing field for all operators active in the market.

Complementarity – Not Substitution – and the Regulatory Impacts

Two studies highlight the main trends by using fairly large European datasets. Grzybowski and Verboven's (2013) study paper on substitution give estimates based on a discrete choice model where households may choose between having mobile or fixed-line voice access only, or using both technologies at the same time. Using a survey of 133,825 households from 27 EU countries between 2005 and 2011 confirmed strong complementarity between fixed-line and mobile connections when both were from the same fixed-line incumbent operator. Effectively the market strategy of incumbent operators is to leverage their position in the fixed-line market to attempt to expand into the mobile market. Broadband technologies such as xDSL and cable can generate strong complementarities between fixed and mobile access, while mobile broadband (MBB) within its limits strengthens mobile substitution, e.g. in use for content sampling. The emergence of fixed broadband has thus been an important additional source of complementarity with mobile in the broadband market. The study was repeated in late 2014 (Grzybowski and Verboven, 2016), using survey data on 160,363 households from 27 EU MS between 2005 and 2011, examining substitution from fixed-line to mobile voice access, and the role of various complementarities that could slow this process. Its findings confirmed the earlier investigation with conclusions suggesting that policies aimed at regulation of the broadband market have an impact on the market structure of voice services through complementarities. Two of the more evident regulatory approaches to respond to this phenomenon are outlined below, each of which would result in different market structures for the broadband services market:

- Promotion of local loop unbundling through regulation for service-based competition within the incumbent's copper network. New market entrants would gain access to the incumbent's infrastructure. That is equally applicable to new NGN optical fibre networks (although incumbents may protest about slower RoI on their capital investments, being forced to enter a wholesale market, rather than harvesting the retail market's higher margins).

- Alternatively, promotion of infrastructure competition by encouraging multiple broadband technology platforms - e.g. fibre optic NGN, xDSL, CATV cable modem model, Wi-Fi and within its limits, mobile broadband and in the future, 5G dense small cell networks in cities.

In the past in the EU, some MS have chosen service-based competition on shared infrastructure. The UK is one example where BT's Openreach offers unbundled access for fibre optic and copper networks at wholesale prices of cost plus. Note that this may still not ensure a competitive market if there is market abuse by collusion between operators, a situation that required Ofcom's intervention in 2017 (Kollewe, 2017).

Other MS have pursued infrastructure-based competition with a high market share for multiple broadband technologies (EC Communications Committee, 2016a). Due to complementarities with voice services, these Internet access policies have led to a different level of penetration of fixed-line and mobile connections. Note that infrastructure competition from mobile broadband might be the only alternative when the fixed line infrastructure is still poor, as in some Central and Eastern EU Member States (Grzybowski et al, 2014). Thus, in such MS, the two technology platforms might possibly be considered as parts of the same market.

3.1.4 Bundling of Services Strategies for Fixed and Mobile Infrastructures and Services

Since the 1990s and until fairly recently, the MNOs had been highly successful in attracting voice traffic away from fixed-line operators, usually the national incumbents in each MS. However, the incumbents often have mobile operations, as well as a legacy in fixed-line dominance. Thus, FMS effects are being mitigated by new market tactics. In response to incursions by 'pure' MNOs into the voice market, the fixed line incumbent operators have successfully responded to mobile narrowband voice by bundling, using broadband offers. Typically, at infrastructure level, fixed-line narrowband service for PSTN voice is complemented by broadband fixed-line services (increasingly via FTTH) and discount mobile. The service level business model is to bundle mobile service with fixed line calls, television and Internet access for "quad play" with discount pricing. Such operators offer quad play bundles with varying degrees of success – it has been highly successful in Spain, France and in the Nordic countries, from our NRA interviews, but less successful in the UK when mobile is added to triple play offerings. Thus, complementarity of fixed and mobile (not necessarily convergence) returns those incumbents with fixed line broadband offerings as well to a leading market position.

While an increase in substitution effects could indicate that ex ante access obligations imposed on fixed incumbents might be superfluous, the bundling strategies of EU incumbents have produced their new source of market power. Bundling services, especially with pay-TV, resets the market balance in their favour again, according to our NRA survey. Thus, any reform of the existing regulatory framework requires a more complete analysis of the cannibalization capacity between fixed voice and mobile voice against managed OTT VoIP and unmanaged VoIP telephony (typically based on Internet access over fixed broadband) when bundled and unbundled.

In this model of bundling of market offerings, market complementarity of different services offering the complete range of communications categories (pay-TV, fixed voice telephony, broadband Internet access and mobile voice/data) is more important than technology convergence of fixed and mobile, as it can expand the market hold. According to our NRA survey, this form of service market convergence increasingly dominates the offerings available in many EU MS. Thus, the findings confirm the limits of FMS with the growth of fixed-line broadband which is preferred for the high-volume streaming of entertainment video in Europe, and may offer OTT voice, where allowed.

Mobile and Fixed-line Broadband are Not Seen as Substitutes in the EU

It is also evident from our NRA survey that the majority of users in the EU now appreciate that mobile broadband is not equivalent to fixed broadband, especially to FTTH. Fixed-line communication has so many practical advantages because its quality of service (QoS) tends to be more stable and its greater bandwidth offers more data at lower cost. It can also support more devices at once than the mobile equivalent over LTE (or UMTS). Moreover, local ambient conditions randomly impact the mobile data rate actually delivered if signal strength is attenuated. Such factors include the local setting (e.g. urban canyons or wet foliage), weather, use indoors as well as the smartphone's proximity to the base station. In contrast, cabling is largely untouched by the ambient conditions (although copper xDSL is dependent on distance to the DSLAM cabinet and vectoring for data speed, signal strength and latency). Moreover, mobile data plans have relatively low caps on data volume per month (e.g. 2 to 3 GB) compared to fixed broadband (20-100 GB or far more at much lower cost/ GB) and raising those caps may rapidly increase the tariff charges, as MNOs are sensitive to the network being swamped by data. In the USA, higher limits and 'all you can eat' mobile data plans are coming back, despite being withdrawn in 2010-2012 in some major urban markets where the LTE infrastructure has recently been expanded in capacity, which is not the case in the EU. The result is a converged market model, as shown in Figure 3.6, originally forecast a decade ago. But it has taken much longer than expected to appear. Indeed, its infrastructure goal of a common broadband VPN, as illustrated below, has yet to be realized because both fixed line broadband and mobile infrastructures are spread across several technologies (e.g. for fixed line: FTTP, DOCSIS3.1, xDSL) with each often being operated by a different type of player e.g. cable TV provider, telco or ISP with fibre infrastructure.

There are Spectrum Policy Implications if Mobile Broadband Markets Stall

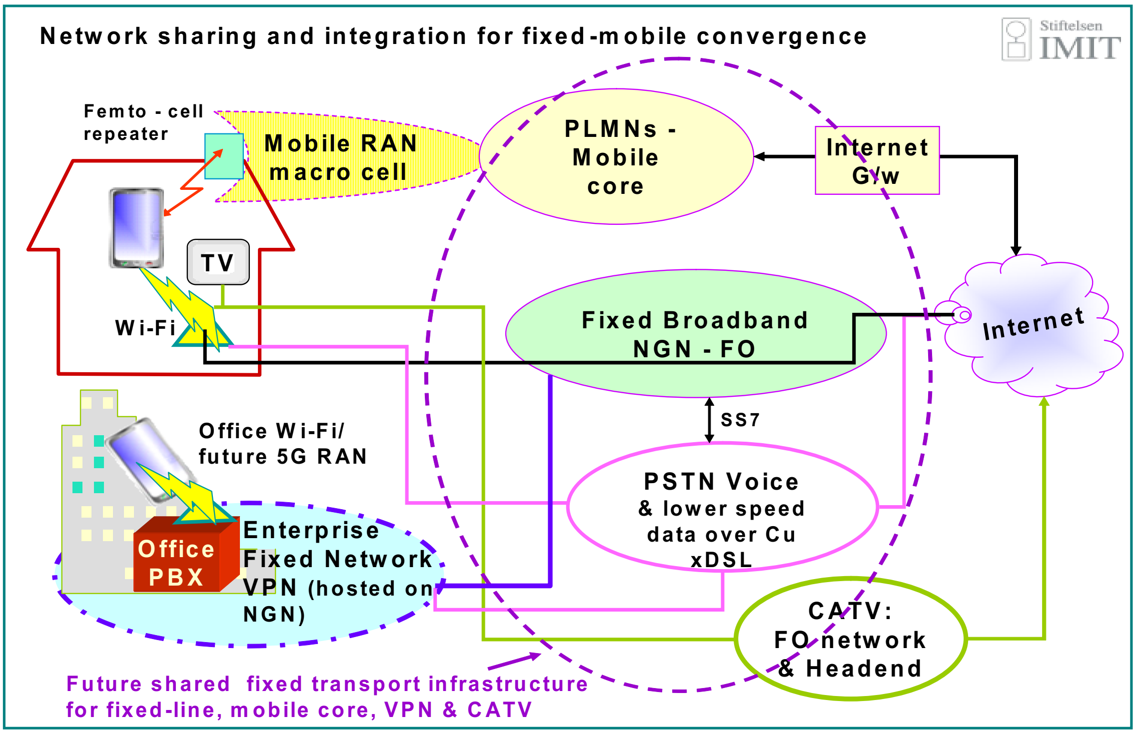
As a result, convergence spells longer term effects on future telecommunications use, specifically for Internet access, especially the extent of further effects of FMS on the market and thus on network infrastructures. From our survey of Member State NRAs, FMS seems to have stalled at the broadband level, being mainly used for sampling of content but not for long viewing sessions. Accordingly, limits to FMS have impacts on demand for more mobile spectrum, implying possible regulatory policy implications of FMS and FMC. In examining the trends in substitution and in complementarity of convergence, five main findings come from investigation of market research and academic studies, confirmed by our survey of NRAs:

- Mobile voice has substituted for fixed line (narrowband) voice in the past decades to a large degree but when consumers have both fixed and mobile narrowband voice today, they tend to use both at increasing rates and more recent indications are that mobile voice substitution is not going further. Services bundling led by the incumbent operators may also drive this trend. So mobile and fixed narrowband voice could be regarded as in the same market segment.
- FMC occurs inside the home and office, usually with Wi-Fi connections for smartphones
- Mobile broadband does not substitute for fixed in the EU – it is complementary, being used for sampling content but not for content streaming. The monthly caps in mobile broadband plans in the EU tend to counter this.
- VoIP, whether managed or unmanaged, increasingly substitutes for voice services over both fixed line (PSTN/NGN) and mobile (3G/LTE-VoLTE) due to the major tariff

differences. The rise of broadband access, both mobile and fixed, drives increased OTT use.

- 'Quad Play' bundling of services for fixed and mobile access with TV entertainment and broadband Internet (ISP) services is increasing across all the EU MS, and strongly influenced switching.

Figure 3.6 From narrowband fixed to broadband and on to converged with mobile



Source: Authors, with input on future market trends from the Broadband Forum, 2011.

Switching Motivations and Rates of Switching

Bundling success varies in the consumer loyalty it generates, apparently being linked to the number and nature of services taken by each consumer. One survey finding is shown in Figure 3.7. Bundling influences appear to be complex. The switching propensity appears to be accentuated with TV ("quad play") perhaps as the TV package is poorer, so a bundle with just broadband Internet, telephony and mobile would seem to satisfy the most.[14]

Propensity to Switch Services for Broadband and Narrowband, Fixed and Mobile

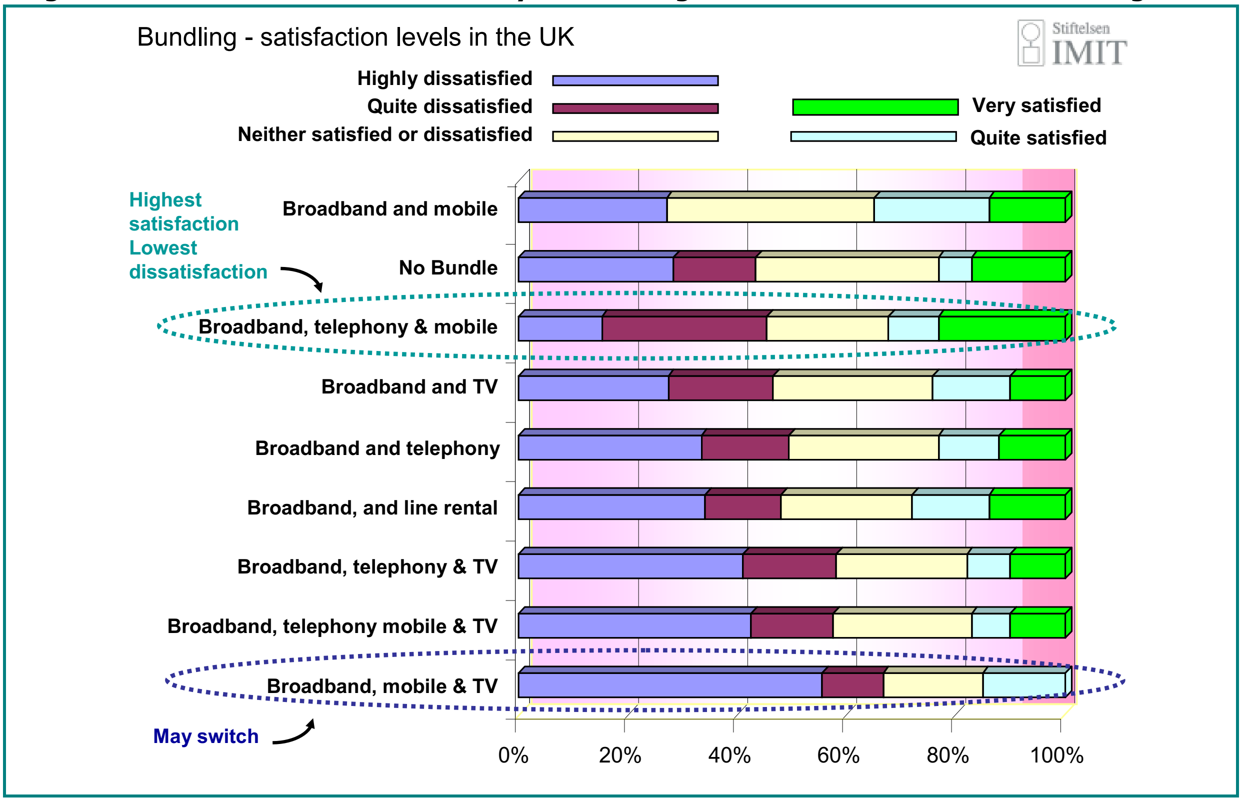
Various socio-economic motivations for switching include the service coverage available, with price and quality, but other factors of a more complex nature are now apparent across much of the EU. In particular, the incumbents with both fixed and mobile operations have used bundling strategies to protect their installed narrowband fixed voice base. Thus, when taking account of bundles in market definition, fixed-lines and mobiles tend to form part of the same market. A wide range of analyses and studies of the motivations for switching, following consumer perceptions of the technologies now exist. Many of these studies (such as that illustrated in the figure below) attempt to predict future switching propensity by differences in types of bundles and the number of components. Market analysis on

[14] The former CEO of Telefonica in UK until 2016 noted that bundling was used in Spain to increase pay-TV penetration by discounting mobile services, i.e. promoting one element of the bundle (Dano, 2017) against the others.

bundling and switching (for quadruple play with discount tariffs) has found that for such consumers, mobile data is complementary to fixed broadband access, which implies that these consumers use Internet access via mobile data to sample online content but complete their online activity using fixed Internet access on arriving home.

In contrast, mobile voice usage can act as an anywhere substitute to fixed broadband access for voice. But consumers may reduce their fixed line narrowband voice consumption further, once they have installed a fixed broadband connection that carries OTT voice via Internet access. So narrowband fixed voice may be retained as a secure backup or higher quality alternative for specific calls. Such research has also shown the existence of substantial switching costs between tariffs, which may significantly decrease the consumer surplus due to the bundling services' discounts. Propensity to switch also seems to differ by Member State as the markets differ in offerings, cultural preferences, etc. Hence, switching propensity between fixed and mobile is complex due to this multiplicity of options and preferences. Weighting all these factors with their positive or negative impacts is thus necessary to model switching decisions by strength of motivations.

Figure 3.7 How different bundles vary in affecting customer resistance to switching



Source: Authors, based on data from EY, 2013.

Future Directions in Fixed-mobile Convergence

In preparation for a new generation of FMC networking, as explored in the next section, the EU in the draft EECC (September 2016) considers taking infrastructure sharing further. To intensify infrastructure convergence for fixed and mobile as a single infrastructure, several basic developments are necessary. Some are noted by BEREC (2017) but most in the EECC for service competition with shared infrastructure (Article 44, also page 9 and page 56, referring to 2009/140/EC recital 43) with the statement:

> Improving facility sharing can significantly improve competition and lower the overall financial and environmental cost of deploying electronic communications infrastructure for undertakings, and to serve public health, public security and meet town and country planning objectives. The competent authorities should be empowered to require that the holders' undertakings which have benefitted from the rights to install facilities on, over or under public or private property share such facilities or property (including physical co-location)… … Competent authorities should in particular be able to impose the sharing of network elements and associated facilities, such as ducts, conduits, masts, manholes, cabinets, antennae, towers and other supporting constructions, buildings or entries into buildings, and a better coordination of civil works.

This could imply several regulatory developments to advance the FMC infrastructure:

- Both fixed and mobile infrastructures for long distance and local access networks would become unbundled for sharing so colocation of facilities could be widespread.
- Long distance dark fibre should be declared open to leasing by competing operators.
- Existing fixed and mobile infrastructure may be re-used for dense small cell backhaul.
- Mobile base station towers, support equipment and backhaul could all be unbundled and shared, to offer macro-cell facilities to small cell developers.
- New '5G' small cell infrastructure could also be shared with its elements unbundled.

Correctly structured, the measures above could prepare a new regulatory phase for FMC.

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3.2 Task 2: Fixed-mobile Convergence as Enabler of Future Connectivity in the EU

3.2.1 Overview

The primary aim of Task 2 is to evaluate the importance of fixed-mobile convergence – more specifically, mobile access to fixed networks – for densification through the deployment of small cells. The Commission's interest in this topic seems based on two insights: first, that offloading mobile devices' data traffic to WLAN networks (especially Wi-Fi) offers significant cost savings to both end-users and the operators of mobile networks; and second, exploiting existing high speed fixed networks for backhaul links can reduce the cost of mobile network densification while increasing rollout speed.

Another aim of Task 2 is to understand the requirements and socioeconomic impact of applications enabled by the next generation of high speed converged networks. To that end, we analyse several use cases that have been proposed by expert bodies.

Why Densify?

Network densification is necessary but it poses many challenges (Baracchi *et al.,* 2017). The next generation of high-speed converged networks must densify, firstly, to achieve the data throughput targets proposed for 5G and the European Gigabit Society initiative (European Commission, 2016a). The Gigabit Society targets for 2025 are:

- 1 Gbps connectivity for all main socio-economic drivers (schools, transportation hubs, hospitals, public services, etc.);
- All urban areas and major terrestrial transport paths to have blanket 5G coverage; and
- All European households, rural or urban, to have Internet access with a downlink of at least 100 Mbps, upgradable to Gigabit speed.

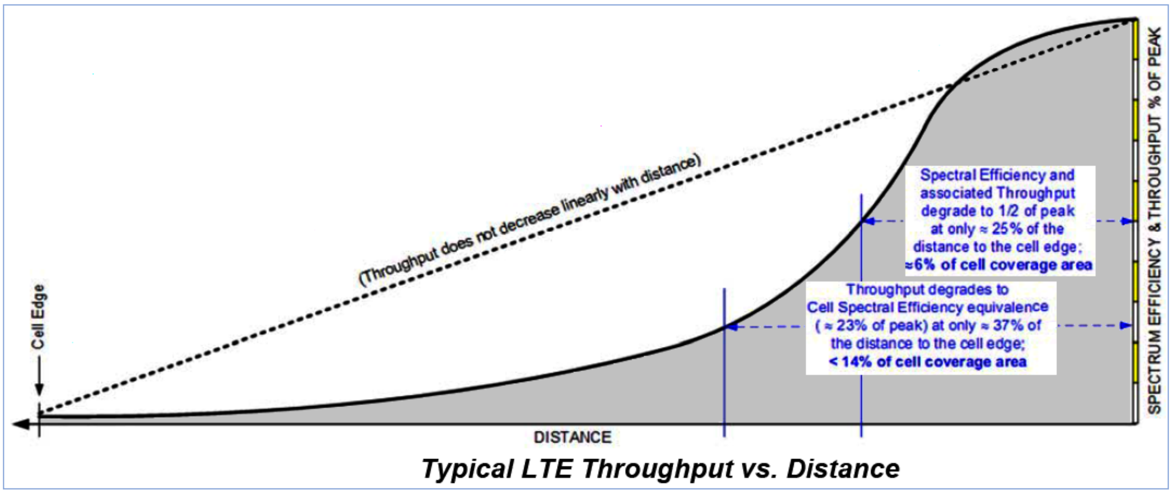
The ITU, meanwhile, has set minimum performance targets for 5G (ITU-R, 2017):

- Peak data rates = 20 Gbps downlink, 10 Gpbs uplink
- User experienced data rates = 100 Mbps downlink, 50 Mbps uplink
- Peak spectrum efficiency = 30 bits/s/Hz downlink, 15 bits/s/Hz uplink
- Area traffic capacity (total traffic throughput per area) = 10 Mbit/s/m^2 downlink
- User plane latency = 4 ms for eMBB, 1 ms for URLLC
- Connection interruption time during handovers = 0 ms
- Minimum connection density = 1 million devices per km^2
- Reliability = 1 minus 10^{-5} probability of success transmitting 32 bytes within 1 ms (defined for the URLLC use case)

These targets stretch wireless capabilities beyond what is practical now, requiring much higher reliability, wider channels and denser deployments than today's networks.

One characteristic of all high-order radio modulations, regardless of standard, is crucial to this discussion: data transfer rates decrease rapidly as the distance between user and base station increases. Figure 3.8 shows LTE's throughput decreasing with distance under ideal conditions (only one user and no environmental obstacles blocking the signals).

Figure 3.8 LTE throughput decreases rapidly with distance from base station



Source: Vantage Point Solutions, 2017.

As this diagram shows, throughput is less than a quarter of the peak speed in 86% of the cell's coverage area and only about 5% of the peak value at the cell edge. The throughput of LTE Advanced (true 4G) decreases faster with distance than LTE, and 5G's drop off from the cell centre will be even be steeper. (The ITU's performance target, quoted above, is for the "user experienced data rate" to be 5% of the "peak data rate" and not just at the cell edge.) This is the second reason why cell sizes must shrink: to reduce the area in which users find their data transfers occurring at a disappointing fraction of the "headline" speed. Additional numerical examples are shown in

Table 3.1.

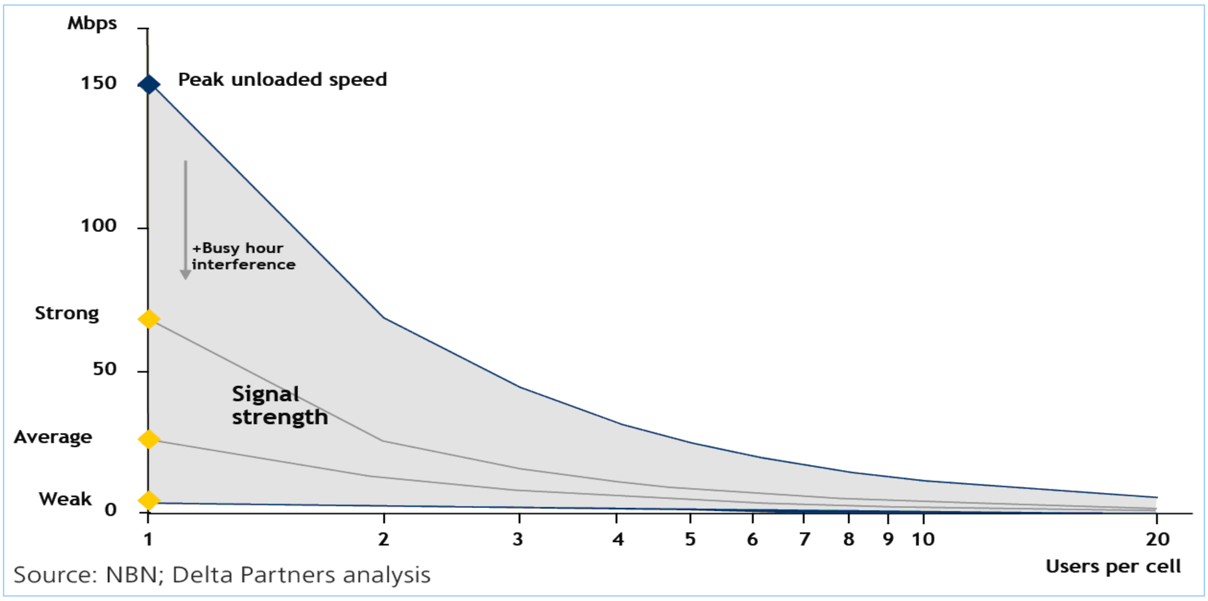
Table 3.1 Decreasing throughput with distance from base station

Technology	Peak throughput	Average throughput	Cell edge throughput
LTE 4x4 MIMO (Release 8)	107.9 Mbit/s	12.5 Mbit/s	3.8 Mbit/s
LTE-Advanced 8x8 MIMO (Release 10)	199.4 Mbit/s	12.5 Mbit/s	3.8 Mbit/s

Source: Pietrzyk, 2012.

Figure 3.9 shows the decline in cellular throughput when the base station is shared among several users: if there are 10 concurrent users per sector (as 3GPP assumes in their "indoor hotspot" and "dense urban" microcell scenarios (2017a), each gets about one-tenth the available throughput. So, a third reason for reducing cell size in 5G is to reduce the number of users simultaneously sharing each cell's capacity.

Figure 3.9 Relationship between speed and number of concurrent LTE users



Source: Pages and Pe for Delta Partners, 2013.

A fourth reason for densification is to increase the geographic re-use of frequencies. Shrinking average cell size has already enabled cellular networks to absorb increased data traffic in the past decade with relatively modest increases in allocated spectrum. Re-use expands network capacity, improves spectrum efficiency and adds to the value of every channel.

Fifth, the only blocks of spectrum large enough to accommodate the data traffic expected in coming years are in the microwave range, which means the signal reach and building penetration will be much less than in earlier generations of cellular and coverage will be less uniform. Densification must compensate for these shortcomings.

3.2.2 Fixed Network Options

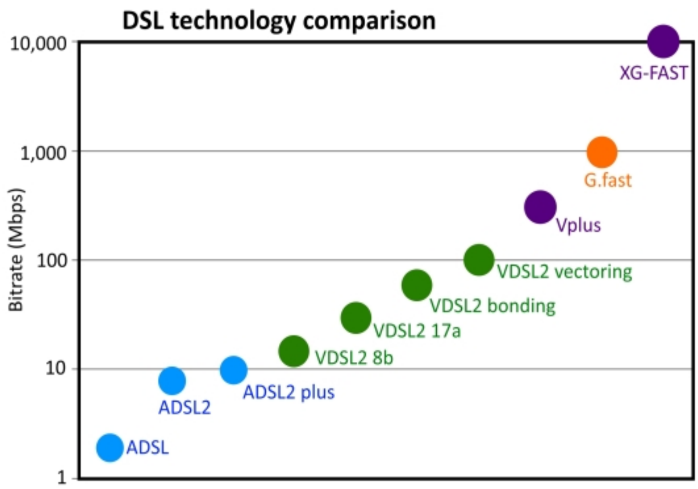
What are the possibilities for using existing fixed networks to reduce the cost and time needed to densify mobile networks? Obviously it makes a big difference if the infrastructure is supposed to support Gigabit Society targets (1 Gbps peak), the 5G specifications (20 Gbps peak) or more modest goals. Backhaul technologies capable of supporting the throughputs required by 5G are mainly fibre. Gigabit Society targets would seem to be limited to optical fibre or microwave, but that could change in a few years (see Figure 3.10). Coax cable and twisted pair copper wires are still potential alternatives thanks to emerging technologies like G.FAST and DOCSIS 3.1 Full Duplex. xDSL

G.FAST is a new variant of xDSL. Equipment based on that standard entered the market in 2016 (ITU-T, 2014). G.FAST can deliver gigabit speeds when the street cabinet is less than 70-100m from the subscriber's terminal, and 100s of Mbps when the cabinet is 300m from the terminal. More recently, XG.FAST – not yet standardized – has been shown capable of delivering up to 11 Gbps over twisted pairs of copper wire – the kind of infrastructure originally deployed for telephony – but only over short distances (30-50m) (Telekom Austria Group, 2017). ITU-T has launched a standards development project (G.mgfast) for further enhancements of copper wire technologies (Mariotte, 2017). Commercial offerings are expected by 2020.

That, however, is not the end: Marcus Weldon, Nokia's CTO and the President of Bell Labs, says, "I'm sure we'll find a way of doing 30 Gbit/s or 40 Gbit/s… We're getting to the point where copper is almost outpacing fiber in the access domain" (Morris, 2015). Affirming that faith, John Cioffi recently claimed that terabit performance is possible with bundles of copper wire: 1 Tbps over runs of 100m, 100 Gbps at 300m and 10 Gbps at 500m (Cioffi et al., 2017; Chirgwin, 2017).

However, these technologies all suffer from problems endemic to xDSL: energy radiates through the insulation, sapping signal strength and causing interference to nearby wires, while flaws in the wiring that did not impair analog voice do impair data transmission. Yet the cost advantages of these solutions are so large they cannot be ignored, particularly for serving small cells mounted in or on buildings already connected to fixed telephone networks. Jaber et al. (2016) note that the total cost of ownership for small cells using G.FAST for backhaul is 24-46% lower over five years than microwave or fibre.

Figure 3.10 DSL standards' speed limits improving over time

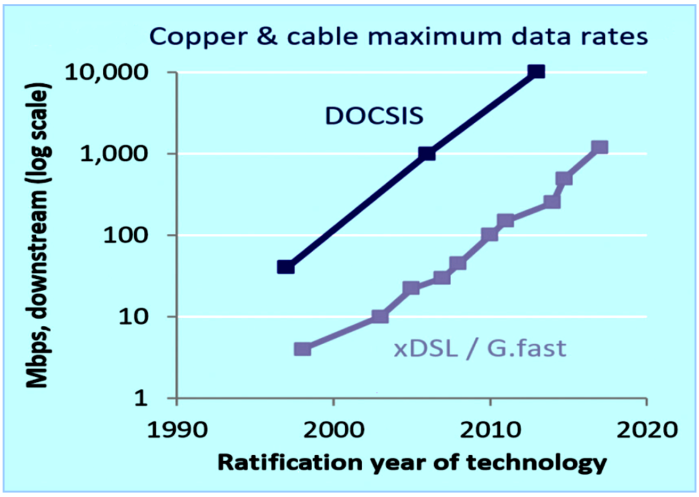


Source: Alcatel-Lucent, 2015.

DOCSIS

Introduced at the end of the 1990s, the Data Over Cable Service Interface Specification (DOCSIS) enabled cable TV networks to offer subscribers two-way broadband through existing infrastructure with relatively minor upgrades for handling upstream data. DOCSIS 3.1 increased throughput enough to rival fibre: 10 Gbps downstream and 2 Gbps upstream. That, however, is under ideal conditions. Network configuration (particularly the ratio of fibre to cable in hybrid systems, the number of people that each cable connects, and contractual commitments to broadcasters) limits the speeds experienced by end-users. As SamKnows found in a 2014 study for the European Commission, the average cable broadband connection in Europe is faster than fibre (66.57 Mbps for DOCSIS vs 53.09 Mbps for fibre) but still far below what is possible (see Figure 3.11).

Figure 3.11 DOCSIS vs xDSL



Source: Liberty Global, 2016.

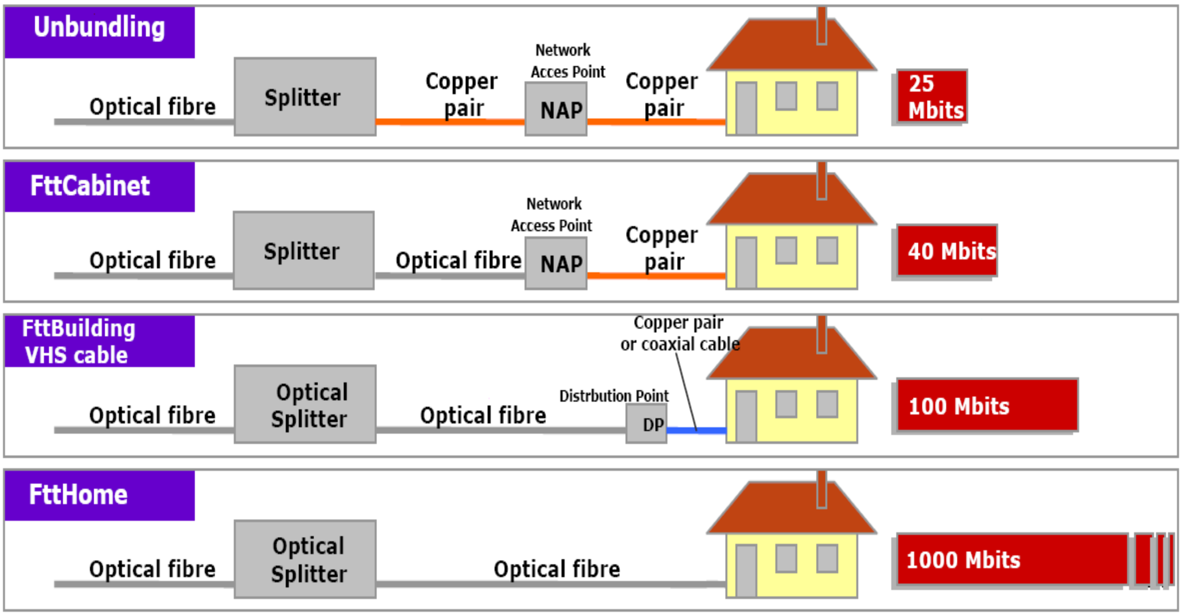
The German government set a goal of making 50 Mbps broadband available to every household in the country by 2018. An analysis by TÜV Rheinland found that goal could be achieved with a cost-optimized mix of DSL, DOCSIS and LTE-Advanced for about €20 billion, with DOCSIS supplying 59% of the connections. Achieving that goal with fibre alone was estimated to cost about €90 billion (Andritzki et al., 2013).

Cable TV networks reach fewer people than wired phone networks so they are not a universal solution for broadband access. But their contribution to the spread of high-speed broadband in Europe has been significant nonetheless, because cable networks "can be upgraded at relatively low cost to NGA levels of connectivity... NGA coverage has been slow to develop… in countries that lacked extensive cable in their legacy networks" (European Commission, 2016c).

Optical Fibre

So far we have discussed wire, cable and fibre as if they are separate – perhaps even rival – media. This is common in telecom policy discussions but it is an oversimplification that hides an important fact: fibre has been the high capacity "backbone" medium for cable TV, cellular mobile and wired telephone networks for more than a decade. When we refer to a network as "cable" or "wire," we are using the connection medium seen by end-users to describe the whole network. But actually, all broadband delivery networks today make extensive use of fibre. Thus, they have more in common technically than policy debates generally acknowledge. "Fiberization" has progressed gradually from network core to final link, replacing or shortening copper segments to increase throughput (see Figure 3.12).

Figure 3.12 Progressive fiberization



Source: ARCEP, 2006.

The final link in the service chain – the one that brings broadband to the user's premises – often acts as a "bottleneck". That we still have bottlenecks is due to the fact that replacing the final link to create an all-fibre path is usually difficult and costly. Installation may be expensive, but repurposing installed fibre can be as easy as plugging a different appliance into an electric outlet. This is because, unlike wire or coax cable, fibre's throughput is mainly determined by the attached equipment and service management practices (bandwidth allocation decisions, throttling, etc.). The maximum theoretical throughput for a single-core optical fibre has been calculated as 1.2 petabits per second[15] with very low path loss, so any installed fibre can support higher throughput simply by replacing the equipment at the end-points. For this reason, fibre is regarded as "future-proof," which increases its appeal. In addition, fibre installations are expected to operate with minimal maintenance for up to 20 years, consuming minimal power, while electricity based systems (microwave, DOCSIS and xDSL) depreciate over 5-7 years, require active maintenance and electricity eventually proves to be a major cost burden.

According to the FTTH Council's European forecast, nearly 62.8 million fibre "lines" will be deployed by 2018 (Finnie, 2016). This is probably an underestimate as there is also an unknown amount of unused and unreported "dark fibre." Dark fibre in Europe is mainly owned by telephone incumbents who lease out access. City governments and utilities (gas and electric) compete with them to some extent, but in many places network coverage does not overlap so price competition is limited. Private investors increasingly see this inefficient market as a good chance to profit from the consolidation of ownership across national borders so they have begun financing mergers and buyouts. That could make the market for dark fibre access even less competitive just as it becomes more important for meeting the bandwidth requirements of 5G and supplying a growing number of small cells with backhaul.[16]

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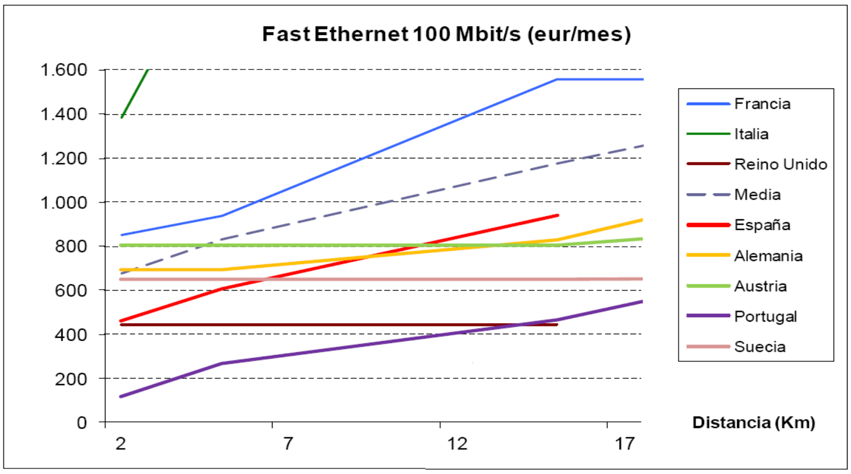
[15] 1 petabit = 1000 terabits = 1 million gigabits = 10^{15} bits. See Vance, 2013

[16] Directive 2014/61/EU of the European Parliament and of the Council of 15 May 2014 on measures to reduce the cost of deploying high-speed electronic communication networks does not encompass access to dark fibre. See Article 2(2).

Consequently, some MNOs asked telecom regulators to define dark fibre as a wholesale product needed for mobile backhaul and to determine if some suppliers are unfairly exercising "significant market power" over access (BEREC, 2017). (It is not unknown for telcos with dark fibre to give their own mobile subsidiaries discounts or preferential treatment while overcharging or denying service to rivals.) A finding of unfair exercise of SMP could lead to harmonized price regulation and the standardization of access conditions.

Copper leased lines can also be used for backhaul, though they might not be an MNO's first (or second or third) preference. Leased lines are subject to ex ante regulation in some Member States but offers are generally not closely scrutinized so prices vary greatly, often for no apparent reason. Figure 3.13 shows the diversity of prices for the same service in nine EU Member States.

Figure 3.13 Monthly prices of 100 Mbps leased lines in 9 EU Member States



Source: Comisión del Mercado de las Telecomunicaciones (Spain), 2013.

BEREC's recent survey and report on these issues (2017) are so relevant that they should be quoted at length:

> Some MNOs are calling for regulated wholesale products to cater for their needs to connect mobile base stations, including options such as active leased lines access, dark fibre and duct access… A majority of MNOs indicated that the existence of regulated offers is important; allowing them also to negotiate better commercial terms when they bought unregulated products…
>
> Some operators also expressed concerns on the sustainability of current pricing practices of backhaul services, given the expected growth in mobile data per mast site, the growth in the number of mast sites required and the declining revenue environment for mobile services… A number of respondents lament a general lack of regulated services specifically defined for mobile backhaul, asking for dark fibre access products instead… In this context, some NRAs plan to impose on the incumbent the obligation to give access to dark fibre…
>
> [But ten] NRAs do not think that regulation on mobile backhaul needs to evolve in the medium term… some respondents, especially incumbents, consider that regulatory interventions are not necessary since the market is already competitive… Therefore, the need for the creation of a separate regulated mobile backhaul market has not been clearly identified yet. Nevertheless, given the advent of 5G networks and increasing demand for capacity by mobile operators, it is important for NRAs to continue monitoring the needs of mobile backhaul transmission and fine-tune their regulatory toolbox accordingly.

Microwave

Despite all the interest in fibre for mobile backhaul, it is still a secondary option in practice, held back by costs and long waits for connection to the backbone network. Nearly two-thirds of all mobile backhaul is implemented now with point-to-point (P2P) or point-to-multipoint (PMP) microwave, and Ericsson (2017) believes that will not change anytime soon.

Twenty-five years ago, P2P microwave mainly supported fixed telephony and broadcasting with intercity links. But the cellular boom produced an explosion of demand for in-city backhaul. The fixed bands between 6 and 42 GHz in Europe got so crowded that channels wide enough to accommodate the high capacity links required by LTE are no longer available in large cities.[17] CEPT responded by increasing the maximum permitted channel sizes in fixed allocations at 40-57 GHz, see Table 3.2.

The 60 GHz "millimetre-wave" band is unusual in that oxygen absorbs the radio energy. Initially it was thought that would make the band worthless for communication, but tests proved the opposite: every signal is hushed but absorption also suppresses interference, so very dense deployments are possible. The Wireless Gigabit Alliance promotes the use of this band with a version of Wi-Fi called WiGig. Based on the IEEE 802.11ad specification, WiGig delivers throughput at rates up to 7 Gbps. Demand for 60 GHz equipment for LTE backhaul in city centres is already growing (Hetting, 2017).

Table 3.2 Microwave bands where CEPT recently introduced wider channels

FREQUENCY BANDS WHERE HIGHER CHANNEL WIDTHS HAVE RECENTLY BEEN INTRODUCED

Date	Frequency band	Channels before ECC REC revision	Channels after ECC REC revision	Remarks
May 2014	40.5 - 43.5 GHz (42 GHz)	112 MHz, 56 MHz, 28 MHz, 14 MHz and 7 MHz	224, 112 MHz, 56 MHz, 28 MHz, 14 MHz and 7 MHz	
January 2015	48.5 – 50.2 GHz (50 GHz) 51.4 - 52.6 GHz (52 GHz)	56 MHz, 28 MHz, 14 MHz, 7 MHz and 3.5 MHz	112 MHz, 56 MHz, 28 MHz, 14 MHz, 7 MHz and 3.5 MHz	This January 2015 update of ERC/REC 12-11 includes a possible pairing of the 50 GHz and 52 GHz bands providing inter alia 7 channels of 224 MHz and 14 channels of 112 MHz
January 2015	55.78 – 57.0 GHz (56 GHz)	56 MHz, 28 MHz, 14 MHz, 7 MHz and 3.5 MHz	112 MHz, 56 MHz, 28 MHz and 14 MHz	

Source: Radio Spectrum Policy Group, 2015.

71-76 GHz and 81-86 GHz are not absorbed by oxygen so their signals reach farther (although rain reduces range). Because signals in these bands can be focused into pencil-thin beams, interference can be avoided by aiming the beams precisely at the target antenna. However, that also means the beams need a clear line-of-sight to the receiver. CEPT (2005) introduced new rules for these bands when their value for cellular backhaul was recognized. As the largest global allocation in the fixed service, the so-called "E-band" provides 40 channels 250 MHz wide, each capable of carrying up to 10 Gbps for several kilometres (Frecassetti, 2015). IHS predicts that globally, $5.1 billion will be spent on small cell backhaul between 2016 and 2020, 60-80% of that on microwave links, led by 60 GHz, and E-band products (Webb, 2016).

[17] Standard channels in the fixed service allocations between 6 and 42 GHz are 7, 14, 28 or 56 MHz wide. But few if any 28 or 56 MHz channels are still available. Fixed channels below 6 GHz are typically 20 or 40 MHz – not wide enough to supply LTE base stations with backhaul.

3.2.3 Findings

The main conclusion of this analysis is that mobile network densification using small cells to implement LTE and/or 5G can be accelerated by using existing fixed networks for backhaul but opportunities to reduce costs are likely to be limited, except where the cells are deployed in or on buildings already connected to the fixed telephone network with fast xDSL or served by coax cable networks running DOCSIS 3.1.

This is good news, since in-building "hotspots" will probably constitute 80% of all the small cells needed for densification (according to the Small Cell Forum and Rethink, 2017, p. 5).[18] The most recent edition of Europe's *Digital Progress Report* (May 2017) says 94% of all residences in the EU have xDSL access and 44% have cable broadband (EC, 2017). However, only about 16% of the DSL connections promise to deliver 100+ Mbps (Digital Scoreboard, 2016) and of those only 63.3% reportedly achieve the "headline" speed (SamKnows, 2014). Though still the most common delivery platform for fixed broadband, DSL subscriptions are declining, as is DSL use for cellular backhaul, which must make telcos reluctant to invest more in upgrading their copper infrastructure, despite the new high speed technologies on the horizon. DOCSIS, as noted earlier, is faster and delivers "headline" speeds more often than DSL, but it is less widely available.

Another positive aspect of indoor deployment is that the cells can be built and installed more cheaply than outdoor cells – weatherproofing, site preparation and vandal resistance being less necessary. And since backhaul for Wi-Fi is normally paid by the end-user or facility-owner, "offloading" the cost of indoor cellular backhaul might find more public acceptance than has been the case so far with femtocells – if the small cell combines cellular with Wi-Fi.

For small cells deployed outdoors, the situation is not so good. As noted by Boch (2014), "In the outdoor environment, fiber 'close' to a micro-cell site doesn't generally mean that there is a point-of-presence which allows cost effective or timely deployment of a fiber spur-line to the micro-cell site (located on a store front, or lamp-pole for example)." Deployments of "fibre to the street lamp" or "fibre to the traffic light" are rare and even a gap of a few metres significantly increases costs and delays activation as the link must be trenched. Breuer et al. (2015) told Deutsche Telekom:

> Fibre backhaul in FTTC areas is only economical at locations next to existing fibre and power infrastructure assets, as *e.g.* at street cabinets. However, the cabinets might not always be the optimal location from the radio propagation and demand perspective…
>
> A higher small cell density… would lead to a significant scalability problem… because of the limited amount of spare fibres per cabinet, especially in FTTC areas, and the huge amount of dedicated interfaces at the IP edge node. New fibres or additional wavelength filters in the cabinets would be required...

The diagonally-hatched and turquoise bars in Figure 3.14 represent the relative cost of fibre backhaul for a small cell mounted directly on a street cabinet (centre), compared to the same cell mounted on a nearby house wall (left) or the pole of a street lamp (right).

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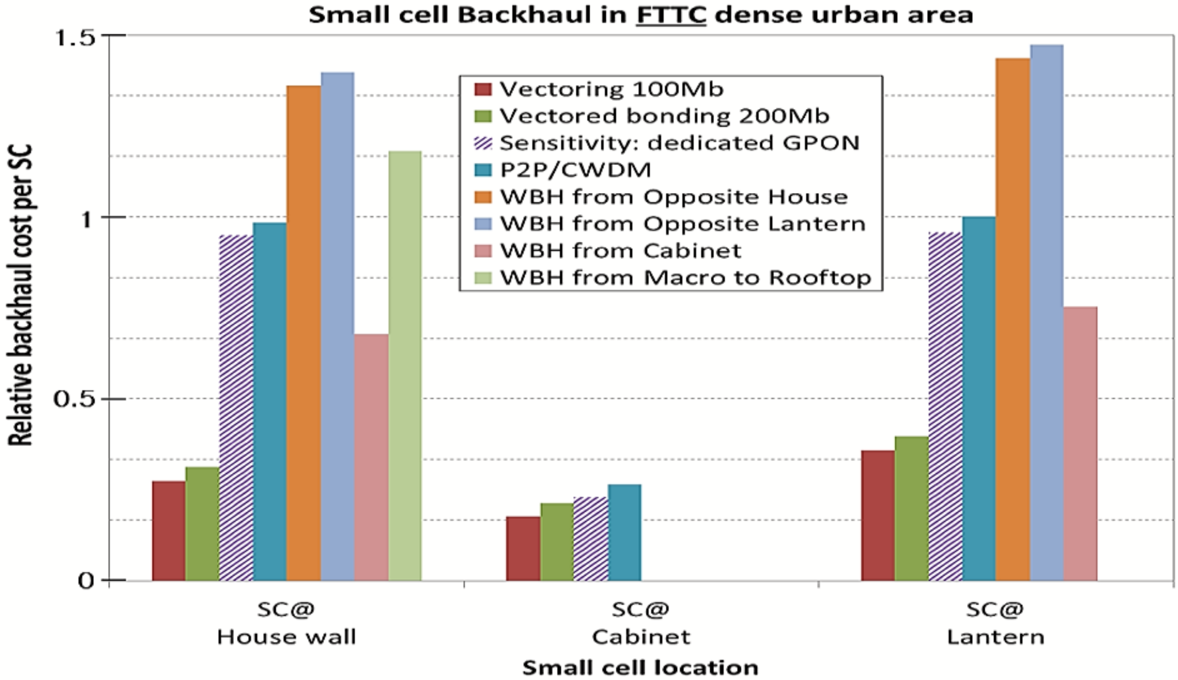
[18] The reasons for such a high percentage of indoor deployments are that the vast majority of mobile data traffic originates and is consumed indoors, especially at home, and the high frequencies likely to be used by small cells have very poor outer-wall penetration capability. See the discussion of Verizon's experience with broadband delivery at 28 GHz (below).

Figure 3.14 Relative backhaul costs of fibre, DSL and microwave for dense urban deployment of small outdoor cells



Note: "WBH" stands for wireless backhaul, "Vectoring" and "Vectored bonding" refer to VDSL. "P2P/CWDM" stands for point-to-point coarse wavelength division multiplexing, a fibre technology often used for macrocell backhaul.

Source: Breuer *et al.,* 2015.

The problem with microwave is that the outdoor small cell is most likely to be connected to a nearby macrocell which will be mounted high – on a roof or tower – while the small cell is at or near street level. "Assuming installations at/near roadway intersections, only 5% - 15% of these locations have clear LoS [line of sight] to the elevated macro PoP locations" (Boch, 2014).

BEREC makes additional points in their 2017 report on backhaul in the context of fixed/mobile convergence (BoR(17)187). Having surveyed large MNOs in the Member States, they found:

> The majority of these operators, forty-one, declared that they are able to satisfy most of their mobile backhaul service needs – more than 75% of the traffic – by means of self-supply on their own fixed and/or mobile infrastructures. In particular, seventeen operators declared to rely exclusively on their own infrastructures…
>
> A key factor obtained from the survey is the growing need of operators to have full control over technical conditions; this could explain why the operators rely mostly on self-provided mobile backhaul solutions. As a general rule, operators however at least partly rely on services provided by other companies when the deployment of a proprietary network results to be too expensive.

But when the "services provided by other companies" are also too expensive, that solution does not work. Yet there are mobile operators who depend on other companies for backhaul, particularly when they are not part of a converged fixed/mobile enterprise. The advantages of self-provision suggest that converged operators will find 5G networks easier to develop while mobile-only networks are disadvantaged:

> If products suitable for mobile backhaul are not available, the likely consequence will in the near future be a reduction in the ability of non-integrated mobile operators to compete on a level playing field in relation to high speed LTE services, to the detriment of end-users (Allen, 2014).

3.2.4 Fixed Cellular

Another topic that is part of this task is to examine the potential economic contribution of fixed cellular. Fixed cellular has been marketed with some success elsewhere in the world (notably in North America), and one mobile executive claims that "a fixed deployment of 5G technology could be profitable enough to provide the carrier a complete return on its investment in the technology, irrespective of a mobile 5G service" (Dano, 2016). That optimism seems based on two beliefs:

- That a fixed 5G network would be substantially cheaper to build and operate than a mobile network; and
- Fixed cellular can capture a large share of the potentially vast "Internet of Things" (IoT) market.

Mike Dano, the author of the article just quoted, wrote a follow-up in July 2017 that was much more equivocal. Although AT&T's fixed LTE service was expected to emanate from 400,000 locations by the end of 2017 (and 1.1 million locations by 2020), the download speeds were said to be just 10 Mbps and subscription costs are considerably higher than DSL or cable. So their service seems viable only in places without wired broadband alternatives. Dano does not give any information about the economics of AT&T's network, but he quotes the owner of a smaller Internet provision business in the rural western US, who mentioned that his fixed LTE sites cost "tens of thousands of dollars" each. Nevertheless, his network "cost a fifth to a tenth what it would cost to build a comparable wired service." This ISP delivers data to customers 3-4 miles from the towers at speeds up to 100 Mbps using the 2.5 GHz and 3.65 GHz bands. He says he needs at least 100 subscribers per base station to break even. A service radius of 4 miles translates into a service area of ~41 km^2; note that 2.4 customers per km^2 is quite a low threshold for economic viability.

Meanwhile, Verizon plans to launch a residential fixed broadband service in the second half of 2018 in up to five US cities using pre-standard 5G equipment (Verizon, 2017). Apparently urban settings were chosen because foliage blocks the network's 28 GHz microwave beams: "The idea of this solving the rural problem is folly. There are too many trees," according to Tod Sizer of Nokia, which developed the equipment for Verizon (Jones, 2017b). 28 GHz also does not penetrate brick or concrete walls or low-emissivity glass windows, so the receiver must be mounted outdoors with Wi-Fi used indoors to distribute content. No information has been released yet about cost or speed.

These American projects suggest fixed LTE can be profitable – and some market participants think fixed 5G can be, too, although in a different environment. However, it must be said there are cheaper solutions offering comparable performance (e.g. WiMAX). Cellular networks were developed to serve communicators travelling fast enough to pass out of the range of one base station and into the range of another within the duration of a single phone call. "Handoffs" from one cell to another are cellular's hallmark. But when handoffs are not needed – in fixed services, for example – the complicated user tracking and continuity features of cellular are superfluous. Using this technology to serve "things" and people at fixed locations is rather like using a motorcycle as a chair.

Thus the significance of Karandikar's suggestion for "Frugal 5G" which the IEEE is now exploring (Karandikar, 2016). This would be a version with simplified architecture and reduced capital requirements to facilitate 5G roll-out in areas without prior deployments of 4G or LTE, and allow the use of access media suited to rural areas, like TV white spaces in the UHF band. Karandikar proposes a more inclusive 5G to "connect the unconnected."

As for IoT, even the usually optimistic GSM Association expects no more than 10% of device data to be delivered via cellular (GSM Association, 2016). The average ARPU for an "operatorless" IoT device will be much lower than for a human subscriber, they add, noting that the ARPU for IoT now is as low as one euro per month. The French firm Sigfox offers IoT connectivity at prices ranging "from 1 EUR per device per month to 1 EUR per device per year" using their proprietary [non-cellular] long range/low power radios (SigFox, 2016). Nokia/Bell Labs is also pessimistic about MNO participation, expecting that "cellular traffic generated by IoT devices will only account for 2% of the total mobile traffic by 2020" (Nokia, 2016).

3GPP is a latecomer to the IoT scene and it will be hard for them to find a niche not already filled by much lower cost unmetered technologies like Zigbee, Bluetooth, Weightless, SigFox, LoRaWAN and Wi-Fi. Competing successfully against these will require operating with little or no profit. Consequently, if LTE or 5G find ways into this market, it may be without the mobile network operators (Deutsche Presse-Agentur, 2017).

3.2.5 Wi-Fi and Cellular

Wi-Fi began as a wireless networking product for homes and offices but it now serves many purposes. It is a primary "on ramp" to the Internet and is commonly found in public venues. After years of dismissing Wi-Fi as a "toy" technology, the cellular industry now recognizes that it has saved them billions of Euros by absorbing most of the increased data traffic resulting from the addition of web browsers to mobile handsets.

Not many realize it but LTE was conceived by the cellular industry as "the answer to the threat posed by Wi-Fi" (Chitrapu *et al.*, 2012). Until a few years ago, 3GPP and IEEE, the standards bodies responsible for cellular and Wi-Fi, worked independently. As a result, Wi-Fi and cellular are minimally compatible. Incompatibility was not a problem when they used different frequency bands, but now that LTE is moving into Wi-Fi spectrum and mobile network operators want to control their customers' use of Wi-Fi, cooperation has become imperative.

Formal cooperation between 3GPP and IEEE began in 2015 with Licensed-Assisted Access (LAA). Requirements for "fair" band sharing and "acceptable" levels of interference between LTE and Wi-Fi were explored, as well as bandwidth aggregation techniques combining Wi-Fi and LTE data streams. IEEE expressed interest in working with 3GPP in developing 5G. Liaison statements were exchanged as 3GPP responded positively (Dutta *et al.*, 2016). Then in July 2017, IEEE created a new workgroup (1932.1) to develop standards enabling 5G/Wi-Fi interoperability and joint use of spectrum.[19]

Will End-users Suffer as a Result of SDO Pre-emption of WLAN Choice?

Wi-Fi is now seen as essential to 5G – to the extent that 5G networks are being designed to control handovers to and from Wi-Fi, and to balance and allocate data traffic between the two network types according to the 5G network operator's criteria. This is called "traffic steering" and it is described in purely technical terms as "load optimization" which needs to be handled algorithmically. There is a real danger that in the process, end users will be excluded from these decisions and denied the right and/or opportunity to choose which

[19] http://sites.ieee.org/sagroups-1932-1/.

WLAN they want to use, or if and when to use Wi-Fi instead of cellular.[20] The IEEE, which one would think should understand the importance of protecting Wi-Fi users' right to choose, is inclined to give 3GPP complete authority in these matters. In their Roadmap for "5G and Beyond" the IEEE 5G WG state:

> **6.4 3GPP-as-a-Control-System** …Notably, one needs to research the architectural and protocol approach to have 3GPP act as a control channel/system for all wireless systems available globally. Going well beyond today's licensed assisted access (LAA), cellular would be responsible to coordinate various IEEE 802.11™ "Wi-Fi®" and other systems to ensure best possible link performance while offering mobility/roaming, as well as billing. This work is already gaining increased interest in the context of fixed and mobile converged networks in 5G, where the broadband forum and the 3GPP architectures are merged to obtain the best of each technology. (IEEE 5G Working Group, 2017)

As a consequence, it may fall to the European Commission and the Member States to articulate and protect (through regulation, legislation like the EECC or mandates to appropriate regional entities) the right to choose among available electronic communication networks including WLANs. This is a necessary complement to EU citizens' "freedom to provide electronic communications networks and services, subject only to the conditions laid down" in the Authorisation Directive (2002/20/EC), and reiterated in Article 12 para. 1 of the draft European Electronic Communications Code:

> Member States shall ensure the freedom to provide electronic communications networks and services, subject to the conditions set out in this Directive. To this end, Member States shall not prevent an undertaking from providing electronic communications networks or services, except where this is necessary for the reasons set out in Article 52 (1) of the Treaty…" (European Commission, 2016d)

Because 5G is still being defined, the "traffic steering" principles are incomplete and it is not too late to ensure that they reflect the basic principles of European society.

Most significantly, the number of Wi-Fi "homespots" – where half the bandwidth (partitioned by a firewall) is offered for use by outsiders while half is retained for private use – is expected to increase six-fold from 2016 to 2021 (Cisco, 2017): "Homespots are proliferating fast and have the potential to radically alter Wi-Fi's social impact while shifting the boundaries between public and private." Most cellular subscribers switch between Wi-Fi and cellular multiple times each day, generally choosing Wi-Fi when that option is available. The experience of 4G suggests this will not change with the introduction of 5G.

Since doubts have been raised about the business case for 5G even within the cellular industry, what is the way forward? Fixed-mobile convergence based on easy handoffs between cellular and Wi-Fi "homespots" *that reflect the users' network preferences* seems an obvious solution because:

- Blanket coverage of the EU with 5G cellular only would be extremely expensive.
- The scope for re-using existing fixed networks to reduce the cost of network densification and 5G build-out is limited.
- Wi-Fi's success with millions of end users voluntarily investing in and managing their own access points ("bottom up broadband" as the Commission calls it) suggests the

[20] See clause 22A ("LTE-WLAN Aggregation and RAN Controlled LTE-WLAN Interworking") in 3GPP TS 36.300 V14.4.0 (2017-09) for a high-level description of LTE-WLAN integration in 5G - http://www.3gpp.org/ftp/Specs/archive/36_series/36.300/36300-e40.zip.

> feasibility of linking Wi-Fi home-spots to cellular networks to create a cost-optimized blanket of small cells interconnected for public and private use.[21]

3.2.6 Applications Enabled by Converged High Performance Networks

Many new applications have been proposed by 5G researchers and promoters to justify the giant leap in performance associated with that label. So many, in fact, and of such diversity, that there is great confusion about what a 5G network could or could not do. In fact, 5G is still being defined, so one cannot be sure about its capabilities. But what is clear is that 5G abandons the idea of a monolithic network architecture defined by its hardware components. Instead the focus is on:

> scalable assignment of network resources [to provide] multiple combinations of reliability, latency, throughput, positioning, and availability [for] optimized support for a variety of different services, different traffic loads, and different end user communities… Flexible network operations are the mainstay of the 5G system (3GPP, 2017a).

The key strategy is "network virtualization", in which software entities representing network functions that were implemented previously by telecom equipment perform the same or similar tasks on generic computing hardware as instructions for processing data. Modifying software is a lot easier than replacing equipment. The advantages of virtualization are that the software has fewer material constraints and the platform it runs on is made of easily procured parts. Cost reduction and greater flexibility are the rewards.

Something similar has begun in radio, with software replacing functions that had required special hardware. This is "software defined radio" and cellular base stations are full of it. Initially SDR allowed upgrades and modifications to be implemented without maintenance visits to replace parts. 5G will take this further, by moving software from the base stations into a network management "cloud".

Another important innovation is "network slicing," in which resources are assigned to subgroups of users as needed. Each "slice" has the functionality of a complete end-to-end network with a defined "minimum available capacity" – and beyond that, "capacity elasticity" is assigned to the subnet according to its priority. This allows a video camera, a law office and a nuclear reactor all to be served by the same network yet each perceives the network as customized just for them.

So the capabilities of 5G networks are hard to characterize, not just because the specifications are still being drafted, because the network is planned to be an evolving cloud of options.

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[21] Recital 127 of the EECC speaks directly to these points and we support its assertions: "Massive growth in radio spectrum demand, and in end-user demand for wireless broadband capacity, calls for solutions allowing alternative, complementary, spectrally efficient access solutions, including low-power wireless access systems with a small-area operating range such as radio local area networks (RLAN) and networks of low-power small-size cellular access points. Such complementary wireless access systems, in particular publicly accessible RLAN access points, increase access to the internet for end-users and mobile traffic off-loading for mobile operators. RLANs use harmonised radio spectrum without requiring an individual authorisation or spectrum usage right. Most RLAN access points are so far used by private users as local wireless extension of their fixed broadband connection. *End-users, within the limits of their own internet subscription, should not be prevented from sharing access to their RLAN with others, so as to increase the number of available access points, particularly in densely populated areas, maximise wireless data capacity through radio spectrum re-use and create a cost-effective complementary wireless broadband infrastructure accessible to other end-users. Therefore, unnecessary restrictions to the deployment and interlinkage of RLAN access points should also be removed…"* (emphasis added).

Use Case: The Connected Car – the Challenge of Reliability

A family wishes to travel to see friends on the other side of the busy city. The city has many narrow streets and a complicated geography, interspersed with elevated sections of multi-lane autoroutes. Nobody in the family can drive. They summon their pre-booked self-drive hybrid vehicle, which arrives with batteries fully charged. Once all the family is aboard, they give their destination as an address, via a spoken command in response to the car's question: "where are we going today?"

As they drive away, the family cat jumps off the garden wall into the narrow lane on which the car is travelling. At the same moment, a neighbour's car suddenly turns out of a driveway. However, the family's car detects the cat's movement using its Doppler side and front radars and brakes gently. Simultaneously it sends a priority 5G message to the master collision avoidance system of the neighbour's car, with which it has been communicating since it arrived, just as it has been with other vehicles in a 200-metre radius. That message activates brakes and drive train controls on the neighbour's car to halt it gently, as it should give way according to the highway code.

<u>Implementation: Driverless cars demand FMC and ubiquitous coverage</u>

Current concepts for safety-enhanced cars rely on sustaining both vehicle-to-vehicle communication and vehicle-to-object positioning in group management patterns. As identified in the EC C-ITS platform[22] vehicle information, hazard notification and signage applications, including adaptive/modifiable speed limits (European Commission, 2016b), will constitute an integrated mobile environment. That will enable future road vehicles to become components of a coordinated traffic scheme that no longer depends fully on driver competence. This implies a need for universal road coverage by wireless networks, perhaps including driveways, parking lots, dirt tracks etc. (It is necessary to prevent situations where a vehicle is unable to move because it has lost access to remote guidance and control systems.) The main priorities are ubiquitous availability, safety, then traffic efficiency, then connectivity for the passengers (phone, alerts, streamed video, etc.). The system is likely to use four connection modes for device-to-device interaction, plus WAN based communications (see Figure 3.15):[23]

- **Vehicle-to-Vehicle** (**V2V**): steering coordination for collision avoidance with other suitably equipped vehicles and road objects. Short range car radar at 76-81 GHz may also be employed (per ERC Rec. 70-03, Annex 13) (Standeford, 2017).
- **Vehicle-to-Roadway Infrastructure** (**V2I**): interaction with smart fixed roadway units and furniture for location awareness, road use fee metering, etc.
- **Vehicle-to-Person/Pedestrian** (**V2P**): direct unscheduled communication without a need for network relay, in a mode analogous to ad hoc IEEE 802.11p (5G Automotive Association, 2016).
- **Vehicle to network** (**V2N**): for access to a local base station and then to a remote (cloud) server, perhaps using existing WAN mobile and fixed networks.

Key parameters and performance indicators, with constraints, are described in Table 3.3. The primary parameter for delivering *driving safety services* is a guaranteed maximum end-to-end radio network delay of 5 ms (including wireless device detection, connection setup and radio transmission but excluding delay for vehicle processing and message

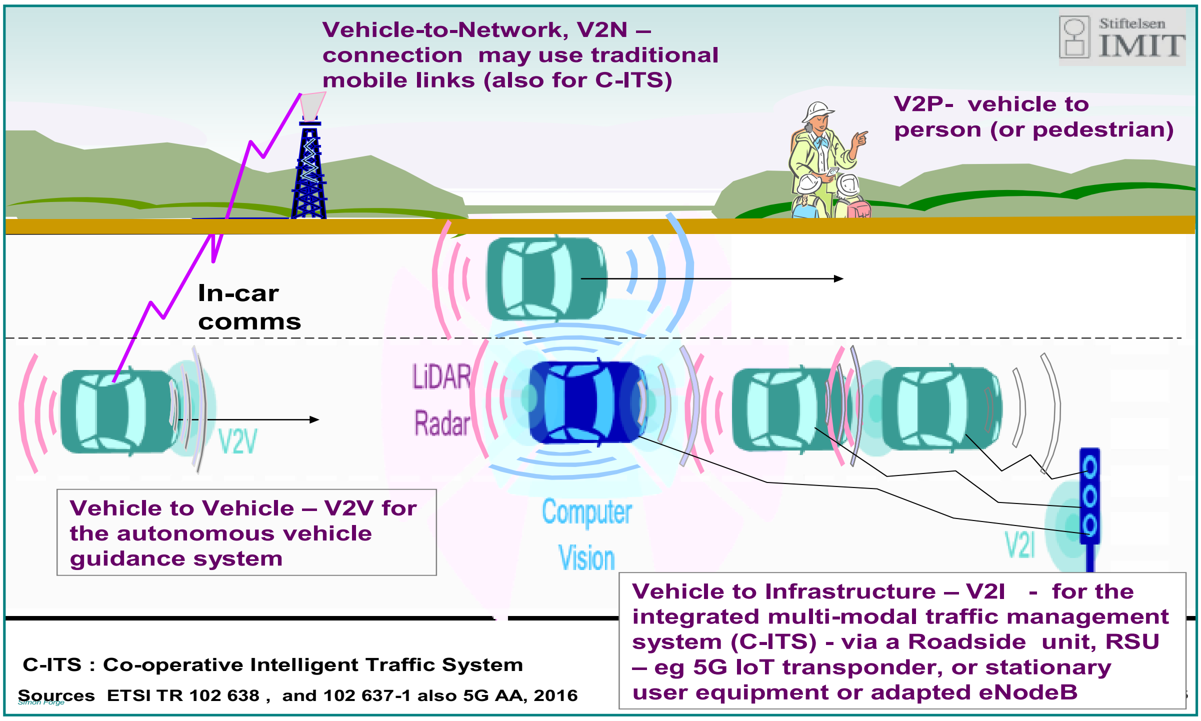
[22] Cooperative, connected and automated mobility (C-ITS), https://ec.europa.eu/transport/themes/its/c-its_en.

[23] 3GPP Release 14 (the ETSI PC5 interface dataset providing location and speed) for Vehicle-to-Anything" (V2X).

generation), with transmission reliability of 99.999% (METIS II, 2016). This is a major challenge as:

- Vehicle to anything (V2X) communication needs to be established across different network infrastructures and operators with the same requirements and performance guarantees as within a single network.
- Close to 100% network availability along the entire roadway and into the adjacent landscape (sidewalks, parking lots, garages, etc.).[24]

Figure 3.15 Cars connect to other vehicles and the roadside infrastructure



Source: ETSI and 5GAA.

Table 3.3 Needs analysis and KPIs showing adequate QoE for V2X

Parameters	Value range
Reliability (including coverage of all points along road)	For safety, all vehicle positioning systems = 99.99% to 99.999%. For V2V communications systems, 99.99% to 99.999%
Device Density	Devices per km^2: High ≥10000; Medium 1000–10000; Low <1000
Network accessibility	• Limited: No infrastructure available or only macro cell coverage • Only limited and short range: Small amount of small cells • Highly available infrastructure: Large number of small cells
User-available bandwidth	Very high: ≥20 Gbps; High: 1000-100 Mbps; Medium: 50–100 Mbps; Low: <50 Mbps
Latency	5 ms guaranteed for safety services needing 99.999% reliability. For other services: Long >50 ms; Medium 10–50 ms; Short 0.5–10 ms
Supported data types	• Isochronous: ad hoc, continuous, periodic

[24] It is not clear how the metered-use business model preferred by mobile network operators could work in the context of traffic safety services. In addition to worrying about "running out of fuel," will we have to worry about "running out of credit for our collision avoidance radars"?

	• Non-isochronous: bursty, event driven, all types simultaneously
Mobility	Static users to pedestrians (0-3 km/h); Medium to slow vehicles (3–50 km/h); Fast vehicles, cars and trains (>50 km/h)
Communication range	Up to 1 km in autoroute environments; up to 500 m in rural settings; up to 50 m in urban scenarios
Positioning accuracy	Less than 0.5 m; GPS may not always be available/sufficient, so local landmark/triangulation techniques must be options.
Constraints	
Multiple network operators: V2X communication must operate across several different networks with standardized interfaces, latency and service guarantees as for a single network.	
Data traffic by type (some values cited here are less challenging than the latest proposals): • **Periodic broadcast traffic:** at least 1600 payload bytes for transmissions for 10 detected objects from local environment perception and vehicle information, with repetition rate 5-10 Hz. Update rate selected to minimize vehicle velocity variation between updates. Traffic data is delivered to neighbouring vehicles within the specified range. • **Event-driven broadcast traffic:** at least 1600 payload bytes at repetition rate of at least 5-10 Hz for transmission related to 10 detected objects resulting from local environment perception and information related to vehicle. • **Communication between vehicles and other devices** (e.g. smartphones): payload of 500 bytes (for information transmitted to/from consumer device, e.g. audio alerts, data from device sensors, etc.).	
Mobility environments: • **Urban:** maximum absolute velocity of 60 km/h, 120 km/h relative velocity between vehicles • **Rural:** maximum absolute velocity of 120 km/h, 240 km/h relative velocity between vehicles • **Autoroute (highway):** maximum absolute velocity 250 km/h, 500 km/h relative velocity between vehicles • **Vulnerable road users present:** velocities ranging from 0-3 km/h (pedestrian) up to 30 km/h (bicycle).	
User/device densities (depend on the environment and scenario): • **Vehicle devices:** In urban environments, the density can be up to 1000 users/km^2; in rural and highway environments, the density can be up to 100 users/km^2 • **Vulnerable road users' devices:** In rural and highway environments, density up to 150 relevant users/km^2; in urban environments, density can be up to 5000 relevant users/km^2	

Sources: ETSI TC ITS; Mecklenbräuker et al., 2011; METIS-II, 2016.

Use case: Digital Health – the Challenge of Constant Availability

The European Digital Agenda, the mid-term review of the Digital Single Market and many Member States identify digital transformation in health and care including eHealth as a priority for the following reasons:

- Current spending in the healthcare sector averages around 10% of GDP in Europe (5G Infrastructure Association, 2015).
- Healthcare costs are expanding as a percentage of GDP faster than growth in the MS.
- Digitization of health records and digitally-supported care are now seen as major drivers in the transition of healthcare from a hospital-based, specialist-driven system to a distributed, patient-centred model with care shifting to the periphery – towards eHealth.

But what is eHealth? According to the EU's eHealth Action Plan 2012-2020 (COM/2012/0736 final):

> eHealth is the use of ICT in health products, services and processes combined with organisational change in healthcare systems and new skills, in order to improve health of citizens, efficiency and productivity in healthcare delivery, and the economic and social value of health. eHealth covers the interaction between patients and health-service providers, institution-to-institution transmission of data, or peer-to-peer communication between patients and/or health professionals.

The health industry and standards organizations are exploring various broad areas for the application of wireless medical tools and practices. These include FMC networks to support remote patient monitoring via implanted or wearable medical devices; ambient assisted living for the aged and frail; embedded pharmaceutical systems; robotics for surgical procedures; outpatient monitoring and follow-up after acute events; remote preventative monitoring of health, lifestyle and wellness; remote management of assets and interventions (5G Infrastructure Association, 2014).

5G systems as currently envisaged offer attributes useful for eHealth, specifically ubiquitous coverage, high bandwidth, low latency, low power consumption, high density of connected devices, support for shared infrastructure via multi-tenancy, and seamless handover between different radio access technologies. However, security against malicious attacks (e.g. remote reprogramming of insulin pumps, ransomware attacks on health services) and prevention of service interruptions and outages must be increased. Even more than with vehicle safety management, lives are at stake in eHealth, and the service continuity provided by commercial mobile networks today is not adequate. They must aim for at least a "four nines" level of no more than 53 minutes of downtime per year, preferably "five nines" availability, i.e. no more than 5 minutes of downtime per year, in order for medical professionals to trust them in life-threatening situations.

Table 3.4 Major KPI parameters for eHealth

Parameter	Value Range
Reliability	Maximum packet loss rate in the application layer: 10^{-5} tolerates at most 1 in 100,000 packets not received within the maximum latency, or 99.999%
Latency	Maximum tolerable end-to-end latency from source application to destination (ms)
Positioning	For specific applications: 0.01mm maximum positioning error tolerated
Resilience	Dual alternative path network routing; backup UPS power for 1-2 hours
Other constraints:	
• Heterogeneity of networks for multiple radio systems; Scalability of numbers of connected devices; Robust security (AAAA) with isolation of networks and devices, by application; Patient data privacy rules	
• Resilience of all services needed during disaster events; Energy minimization for battery life	
• Coverage (rural, as well as dense hospital)	

Source: 5G Infrastructure Association, 2015.

Use Case: Media and entertainment – the Challenge of Throughput

Content distribution requires more than a link between a media server and a consumer. QoE depends on QoS across multiple relay networks to minimize jitter, lost packets, skipped and frozen frames, maintaining a steady flow of data. Such demand challenges existing cellular networks in their unicast mode; 5G may provide the bandwidth and QoS to satisfy mobile video demand for large numbers of people. The networks are also expected to support access control with distributed storage of media by edge servers close to consumers. New business models for media distribution via 5G are likely to emerge (New European Media and 5GPPP, 2016; METIS II, 2016).

<u>Convergence for hybrid media networks</u>
5G is expected to enable at least six main groups of media and entertainment use cases in the 2020s with a user experience exceeding that of 4G and other legacy networks. It may well achieve the holy grail of ATAWAD (anytime, anywhere, any device):

- **Ultra High Fidelity Media:** Exploiting progress in capture technologies and high resolution displays for new viewing experiences with ultra-crisp, panoramic pictures, deep colour contrast and three-dimensional sound. But note that the screen resolution of mobile devices imposes limits on the utility of high bandwidth transmission. However, content can also be streamed to either large, home-theatre UHD TV screens at fixed locations or portable devices like Virtual Reality goggles. Both linear (streamed live programming) and non-linear (on-demand) content will fuel the future media experience. In order to guarantee a high QoE for UHFM, 5G networks must have high bandwidth data transport capabilities, efficient network management and local content caching.
- **Holographic video calling:** Audiovisual media could become more immersive and interactive, perhaps enabling high bandwidth holographic type video (Su-hyun, 2017). This could have business applications for collaborative working, through VR conferencing that simulates a face to face experience.
- **Cooperative Media Production**: Many media products are produced by teams. Content in the future may be captured and shared immediately, utilising 5G enabled cameras and microphones, with metadata automatically attached e.g. location, date, authors etc. The content may be processed by different players including end-users. Quicker access to content can reduce media production timescales.
- **User Generated and Machine Generated Content:** People and objects will be able to capture more audio/video content than today and share it with others via cloud services. Future 5G networks should support on-demand high upload bandwidth and streaming from millions of devices (cameras, health sensors, building sensors, vehicle data, etc.).
- **On-site Live Event Experience:** Large event venues such as cinemas and stadiums are increasingly connected for attendees to share their experience with those not attending (replays, commentary, etc.).
- **Collaborative Gaming:** Gaming as a fully immersive multi-sensory environment could provide a more intense experience, with improved interaction within the game and fewer limitations on the number of simultaneous users, perhaps incorporating augmented reality and the physical surroundings. Game development is already becoming more cooperative with “beta testers” directly interacting with designers during play (Folmer, 2017).

Table 3.5 KPIs for the QoS and QoE needed for media delivery

Eight main parameters for media QoE, closely related to network QoS:	
Availability in terms of coverage	Geographic area in which media streams can be sent and received at acceptable levels of reliability, speed, latency, etc. Indoor reception may be crucial for some entertainment.
Reliability	Maximum tolerable packet loss rate at the application layer, within the application’s maximum tolerable end-to-end latency.
Data Rate	Bit rate required at the user device for the application to function correctly.
Latency	Maximum tolerable delay from data packet source to destination. For infrastructure mode that equals upload delay, routing & interfacing delay plus download delay.
Data traffic volume limits in terms of simultaneous sessions	Density of operation as maximum numbers of active 5G capable devices per unit area, either in a transmission/reception session or actively polling for services.
Numbers of users/channels per base station unit	Distribution pattern by line-of-sight link to customer premises with multiple channels (up to 4 per family) and multiple dwellings (up to 25 per base station).
Mobility	Maximum speed of movement at which the specified reliability is achievable.
Positioning accuracy	Maximum positioning error tolerated by the application for viewing

Sources: METIS 1 and II.

Use Case: Smart Cities – the Challenge of Heterogeneity

The smart city is a dense future urban Information Society configuration, based on ubiquitous connectivity throughout the city. This connectivity can be used by citizens as well as the city's infrastructure and supports city administration with communicating devices. Metropolitan transport, energy distribution systems and lighting are integrated with the needs of 'smart workplaces' in retail, manufacturing, logistics, business, healthcare and social services.

Network coverage must be pervasive, having the same QoE indoors and out. Data traffic flows across the city but servers may be hosted anywhere in the EU as they are cloud– and fog-based. 5G may contribute along with services utilising legacy mobile networks and NGN. One key infrastructure application that will benefit from 5G is the city's smart electricity grid. It will have feed-in from renewable resources spread across the landscape (including outlying suburbs), capturing solar, geothermal and wind energy while regulating storage in and discharge from batteries.

Device-to-device (D2D) communications in dense urban environments enable the offloading of traffic as well as the shortening of data paths using proximity based discovery techniques. The infrastructure is designed for both human-to-machine and machine-to-machine (M2M) communications. These are present in a variety of forms, including ultra-reliable systems to support autonomous road and rail vehicles. The citywide management system weaves them together as a single co-operative and intelligent transport system (C-ITS). All critical infrastructures are monitored along with air pollution and building security, with video surveillance and intrusion detection. M2M communications connect millions of devices and sensor networks.

One of the main 5G smart city services is community healthcare. 5G communication support will be especially useful in three major areas:

- Highly instrumented dwellings for aged and infirm citizens, including support robotics and the automated allotment of medications.
- Vulnerable citizens (those with physical or mental disabilities) with carers, arranging for their transport and therapy.
- Outpatient support including medical monitoring and remote examinations/consultations.

This will be important in reducing the budget burden of health services as the average age of the European population rises.

Unlike the other use-cases, KPIs have a wide spectrum of values because so many different systems are needed to manage the city. Some of them interact, many stand alone, many must be inaccessible to unauthorized persons. Some require massive bandwidth but many are narrowband and only occasionally active (METIS II, 2016).

Table 3.6 KPI parameters for the Smart City (too varied to profile)

Parameter	Value Range	Parameter	Value Range
User Density	Low - very high	**Latency limit tolerable**	Variable by application
Data Rate	Low - high	**Reliability**	Medium - very high
Mobility	Medium (<60km/h)	**Availability**	Medium - very high
Infrastructure	Dense, much backhaul	**Energy consumption**	Varied

Source: Authors; METIS II, 2016.

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3.3 Task 3: Analysing Regulatory Coverage Obligations in Member States

3.3.1 Introduction

Task 3 reviews and analyses the differences in, and effects of, regulatory coverage obligations as previously used by EU Member States and indicates key elements for coverage obligations to be considered at the EU level that are critical to meet the connectivity goals.

The key outputs are: (1) an overview and analysis of mobile coverage obligations in the EU MS, based on a dataset including, for all EU MS, their coverage obligations and, as far as possible, coverage criteria, measurement approaches and means of enforcement, (2) an analysis of the effects of coverage obligations in terms of connectivity improvements and the market impacts, and based on this (3) an identification of broadly applicable key elements, which could serve as guidelines for future coverage obligations for reaching connectivity goals. Task 3 is divided into three subtasks (STs), summarized in Table 3.7 with their inputs, analysis and outputs.

As already mentioned, one of the outputs of Task 3 is a comprehensive dataset of the coverage obligations in the 28 EU MS. The information has been collected from: (1) interviews with and questionnaires completed by NRAs (National Regulatory Authorities); (2) the ECC 231 report (ECC, 2015a) and to some extent BEREC & RSPG (2012); (3) additional data has been gathered from websites and NRA documents, industry newsletter websites and other web sources.

Table 3.7 Task 3 overview: breakdown of subtasks, inputs, methods and outputs

Sub-task: objective	Input / methods	Output
3.1: Overview and analyse similarities and differences of mobile coverage obligations used by EU MS	• Interviews and survey of NRAs • Previous overviews: ECC 231 (2015a), BEREC-RSPG (2012) • Desk research: NRA websites, official documents, industry news and reports	• Data-set with coverage obligations in the EU MS • Overview of coverage obligations in the EU, dimensions, commonalities and differences • Input to ST 3.2/3.3
3.2: Analyse effects of the different coverage obligations in terms of connectivity improvements and impact on the market	• Information from ST 3.1 • Analysis of six country cases • Interviews/survey • Experiences from non-EU countries • Findings from literature	• Contribute to analysing the effects of coverage obligations on connectivity and market and serves, • Input to ST 3.3
3.3: Indicate key elements for coverage obligations to consider at EU level as critical in meeting EU connectivity goals	• Relate to connectivity goals • Analysis of ST 3.1/3.2 • Analysis of others (NRA opinions, other reports, etc.)	• Key elements for coverage obligations to consider at EU level as critical to meeting EU connectivity goals

3.3.2 Coverage Obligations of the EU Member States

The objective of this section is to overview and analyse similarities and differences among the mobile coverage obligations used in the EU MS. It begins with a brief introduction to the diversity of MS' approaches with respect to connectivity and other relevant indicators. The next sub-section includes an overview of the coverage obligations and associated criteria in the EU-28 MS. Subsequently, it reviews the criteria in use for voice and data coverage respectively. This is followed by an overview of how coverage obligations are monitored, measured and the procedures applied if coverage obligations are not met. It concludes with a summary of emergent similarities across MS and over time.

Characteristics of the Member States

The analysis of coverage obligations needs to take differences among European Member States into consideration. All Member States are covered with basic data about coverage obligations, but our survey of NRA (and MNOs) covers a sub-set.[25] The tables below illustrate the diversity of the EU Member States in terms of general characteristics (Table 3.8) as well as in terms of various connectivity-related indicators (Table 3.9).

Table 3.8 Selected characteristics of the EU-28 Member States

Country	Pop. (mn)	Area (1000 km^2)	Pop. / km^2	Average Elevation (m)	Pop. in mountain municip. (%)	Pop. in rural areas (%)	Pop. in urban areas (%)	GDP / Cap (€)
Austria	8,6	84	104	910	49,8	40,5	33	36 000
Belgium	11,2	31	370	181	0,8	8,6	67,5	34 200
Bulgaria	7,2	111	66	480	45,6	40,4	14,9	5 700
Croatia	4,2	57	75	331	N/A	N/A	N/A	10 400
Cyprus	0,8	9	93	91	14,3	0	0	20 800
Czech Republic	10,5	79	136	433	23,4	33,6	22,4	16 000
Denmark	5,7	43	132	34	0	43,0	21	45 300
Estonia	1,3	45	30	61	0	48,5	0	13 300
Finland	5,5	337	18	64	12	43,9	25,4	34 100
France	66,4	644	105	375	14,3	29,3	34,6	31 500
Germany	81,2	357	227	263	10,1	27,6	42	34 200
Greece	10,9	132	83	498	49,6	44,2	45,5	17 000
Hungary	9,9	93	106	143	6,9	47,9	17,4	11 000
Ireland	4,6	70	68	118	2,6	70,5	29,5	49 300
Italy	60,8	301	201	538	32,6	20,9	35,4	25 600
Latvia	2,0	65	32	87	0	39,3	47,2	10 700
Lithuania	2,9	65	47	110	0	44,4	24,4	11 600
Lux.	0,6	3	215	325	1,5	0	0	80 800
Malta	0,4	0.3	1352	N/A	0	0	100	19 400
Netherl.	16,9	42	501	30	0	0,7	71,1	38 700
Poland	38,0	313	124	173	5,8	38	28,3	10 900
Portugal	10,4	93	113	372	26,5	38,8	47,7	16 600
Romania	19,9	238	87	414	24,9	46,2	9,9	7 200
Slovakia	5,4	49	111	458	48,6	50,3	11,4	14 100
Slovenia	2,1	20	102	492	64,9	44,1	24,9	18 000
Spain	46,4	505	93	660	38,5	13,8	48,2	23 000
Sweden	9,7	450	24	320	6,9	23	20,9	41 700
UK	64,9	245	266	162	4,3	2,9	71,3	31 100
EU-28	**508,4**	**4325**	**117**	**363**	**17,8%**	**24,2**	**40,4**	**26 500**

[25] For the selection, the following criteria were initially applied in discussion with the European Commission services: (1) to include the "Big Five" (France, Germany, Italy, Spain, UK); consider diversity in geographical, demographic and socio-economic characteristics; consider diversity in broadband connectivity (e.g. coverage of fixed and mobile broadband, rural coverage, 4G development), broadband policies; include MS not profiled in previous reports, mainly ECC (2015a) survey of mobile coverage obligations (Bulgaria, Greece, Hungary, Poland and Romania); convenience (expected ease of collaboration of access to data, e.g. Sweden, Czech Republic and the UK); and specific requests from the European Commission services (e.g. Estonia).

Note: 2015 or latest year available. Some EU-totals and averages have been calculated. EU-28 is EU-27 when no data for Croatia

Source: Population, population density and GDP/Capita from Eurostat, land area and average elevation (mostly) from Wikipedia, people in mountainous areas from http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/montagne/mount4.pdf (accessed 30 July 2017), people in rural and urban areas from http://ec.europa.eu/eurostat/statistics-explained/images/0/06/Share_of_land_area_according_to_the_original_OECD_classification_and_the_new_urban-rural_typology_new.png (accessed 30 July 2017).

Here we may note the large differences in various dimensions, for example:

- Large population of the Big Five (above 45 million) vs. e.g. Luxembourg, Malta, Cyprus and Estonia (below 2 million);
- Vast land areas of France, Spain and Sweden (above 400 thousand km^2) vs. Cyprus, Luxembourg and Malta (less than 10 thousand km^2);
- Densely populated Member States such as Belgium, Malta, the Netherlands (above 300 inh./km^2) vs. sparsely populated ones like Estonia, Finland, Latvia and Sweden (less than 35 inh./km^2);
- Mountainous countries like Austria, Bulgaria, Greece, Slovakia, Slovenia vs. (mostly) predominantly flat countries like Belgium, Denmark, Estonia, Latvia, Lithuania, and the Netherlands;
- Predominantly rural countries like Ireland vs. predominantly urban countries like Belgium, the Netherlands and the UK;
- Countries with high GDP/cap like Denmark, Ireland, Luxembourg and Sweden vs those with substantially lower like Bulgaria and Romania.

Table 3.9 Selected connectivity indicators of the EU-28 Member States

Country	BB cov. above 100 Mbps (%)	Fixed BB cov. (%)	HSPA (%)	LTE (%)	BB cov. (rural) (%)	Fixed BB cov. (rural) (%)	LTE (rural) (%)	LTE launch year	LTE data rates (Mbps)	LTE availability (%)
Austria	53	99	99	99	98	94	93	2013	27	66
Belgium	96	100	100	100	100	98	99	2013	27	70
Bulgaria	19	95	100	77	100	81	19	2015	34	63
Croatia	25	97	99	90	98	89	56	2012	29	63
Cyprus	84	100	99	74	100	100	0	2016	N/A	N/A
Czech Rep.	44	99	97	99	99	97	96	2013	23	73
Denmark	89	99	100	100	100	97	100	2012	31	71
Estonia	59	91	99	99	100	73	96	2013	22	75
Finland	33	97	100	100	100	84	100	2013	24	76
France	34	100	100	94	100	100	62	2011	24	49
Germany	65	99	92	97	99	94	88	2010	20	57
Greece	0	99	99	93	99	97	71	2014	26	60
Hungary	68	95	98	99	99	86	96	2014	41	80
Ireland	45	96	99	97	99	93	91	2012	22	44
Italy	19	99	99	98	98	94	85	2011	26	54
Latvia	81	96	99	99	99	87	98	2013	28	73
Lithuania	87	93	100	93	100	83	86	2016	29	85
Lux.	90	100	99	98	100	100	91	2012	32	65
Malta	99	100	100	100	100	100	51	2013	N/A	N/A
Netherl.	98	100	100	100	100	100	98	2012	34	84

Poland	57	86	100	98	100	82	88	2015	21	57
Portugal	89	100	99	99	99	98	92	2011	22	66
Romania	80	89	100	75	100	82	50	2012	36	58
Slovakia	64	88	91	90	92	91	66	2013	26	64
Slovenia	72	98	98	97	99	92	91	2014	20	74
Spain	79	95	100	94	99	92	73	2011	28	67
Sweden	69	99	100	100	100	91	100	2011	23	81
UK	24	100	99	100	100	100	95	2013	22	58
EU 28	51	98	98	96	99	93	80	2011	27	67

Note: coverage data at the end of June 2016. Fixed broadband coverage includes DSL, VDSL, FTTP, DOCSIS 1.0/2.0, DOCSIS 3.0, WiMax. XY% LTE (or 4G availability), means that on average that country's 4G users can find an LTE signal XY% of the time.

Source: Adapted from European Commission (2017b). LTE data rate and LTE availability (rounded) are from OpenSignal "The State of LTE" (November 2016), https://opensignal.com/reports/2016/11/state-of-lte, as reported elsewhere in this report. LTE launch year is from a.o. Magi (2016).

Similarly, there are large differences among the MS in terms of connectivity:

- % of households with more than 100 Mbps broadband coverage higher than 95% (Belgium, Malta, the Netherlands) vs. Bulgaria, Greece and Italy with less than 20%;
- LTE rural coverage close to 100% in e.g. Belgium, Denmark, Finland, the Netherlands and Sweden vs. 50% or less in Bulgaria, Cyprus, and Romania.

Having pointed out these differences, it is worthwhile repeating that we have covered all EU MS in this overview although only some of them were interviewed or answered our questionnaire. These were: Austria, Croatia, Czech Republic, Estonia, Finland, France, Ireland, Italy (partly), Malta, Netherlands, Portugal, Romania, Slovenia, Spain, Sweden and the UK.

Types of Coverage Obligations

This section includes an overview of the mobile coverage obligations in the EU-28 MS. Most (26) MS have attached some coverage obligations to the right to use spectrum to provide mobile public communication services in at least one frequency band. Looking at the number of bands in each MS where licences have been awarded, there are 145 such Member State/band combinations in total. A majority (111) of those come with coverage obligations, while 27 do not (see Table 3.10). In seven cases, the situation is either unclear or there are old obligations in place, which do not apply to renewed licences. While it is more common than not with coverage obligations for all frequency bands, it is even more common in the lower bands, i.e. 800 MHz and below.

Table 3.10 Coverage obligations in the EU MS per frequency band

Band (MHz)	Obligation					No obligation	Unclear or ambiguous	Total
	Voice only	Data only	Both voice & data	Not specified or N/A	Total			
450	1	1		2	4		1	5
700		3			3			3
800		16	5	4	25	1		26
900	4	2	10	6	22	5	1	28
1500		1		1	2	1		3
1800	2	3	10	5	20	6	2	28
2100		6	6	9	21	5	2	28
2600		7	3	4	14	9	1	24
Total	7	39	34	31	111	27	7	145

Note: Numbers refer to the use of coverage obligations for each of the eight investigated frequency bands for each country. For instance, the 800 MHz band has been licensed in 26 MS of which 25 with attached coverage obligations (for at least one block of frequencies in that band).

In a few cases (mainly the "older" frequency bands) coverage obligations are for voice only. Most common is however to set coverage obligations for data or for both voice and data. Data only coverage obligations are more common (as a percentage of the total) in the bands most commonly used specifically for LTE, i.e. 700, 800 and 2600 MHz. In several cases (e.g. the Netherlands) voice or data is not specified, but the obligation may instead refer to a "communications service".

Coverage obligations are often specified either as (1) population coverage where the operator should cover a percentage of the population or (2) area coverage, where a certain percentage of the territory (normally land area) needs to be covered. Population coverage obligations are more commonly used than area coverage while in some Member States and bands both apply. In some cases (e.g. Spain) an investment amount is stipulated instead of (or in combination with) other criteria. Indoor coverage or outdoor coverage, or both, are specified in obligations in around half the MS. Outdoor coverage specification is far more frequent. However, indoor coverage requirements have recently become more common (used in e.g. Austria, Czech Republic, Hungary, Romania and the UK) particularly for data services. Some MS, such as Sweden and France, do not explicitly specify indoor coverage, but require operators to present coverage in a way so that indoor coverage is implicitly assumed to be attained (by applying correction factors) (see BEREC 2017b).

Coverage obligations for mobile services by frequency band are shown in Table 3.11.

Table 3.11 Type of coverage obligations in the EU per frequency band

Band (MHz)	Population	Area	Both	Other	Unclear	Total
450	1	3				4
700	1		2			3
800	15	8	2			25
900	9	4	4	1	4	22
1500	1	1				2
1800	10	4	4	1	1	20
2100	10	5	3	1	2	21
2600	10	3		1		14
Total	57	28	15	4	7	111

Note: Some administrations do not have coverage obligations directly connected to a specific frequency band. In the 900 MHz band, old obligations are sometimes mixed with new ones, and are in such cases difficult to classify. "Other" may refer, for example, to old obligations in Spain, where cities above a certain size had to be covered, or a certain number of base stations in specified areas.

Some coverage obligations are quite specific and have been developed in response to MS policies, often to extend rural coverage. To exemplify:

- Sweden: in one block in the 800 MHz band the licence holder had to cover uncovered permanent homes and business places to a rollout cost of a least SEK 300 million (circa € 30 million).
- Germany: licences for 800 MHz included obligations for each federal state – mandating build-out (in four stages) in listed communities in areas with no or very low broadband coverage before being allowed to build out in more populated areas.
- In France, for the LTE deployment, areas of high priority were defined, i.e. areas with a low population density (representing 63 % of the territory and 18 % of the population). The operators have an obligation to cover a certain (population) percentage of these areas (40 % in January 2017 and 90 % in January 2022).
- In Portugal, each mobile operator has the obligation to cover 160 parishes using the 800 MHz and 900 MHz bands.
- In the Czech Republic, in the 800 MHz band, obligations for residential areas at the district level are divided into two groups according to their population density, where districts with low density (Group A) involves stricter obligations: within 2.5 years the license holders had to cover 30 (of 32) Group A districts; after 5 years: all Group A and 22 Group B districts (as well as 50% of transit railway corridors, motorways and express roads) and after 7 years all of the above.
- In Italy, in the 800 MHz band a number of municipalities are listed for each frequency block, of which 30% should covered within 36 months (2015), and 75% within 60 months (2017), using any frequency held and specifically, for the 800 MHz band: 37.5% after 84 months (2019) and 75% after 108 months (2022).

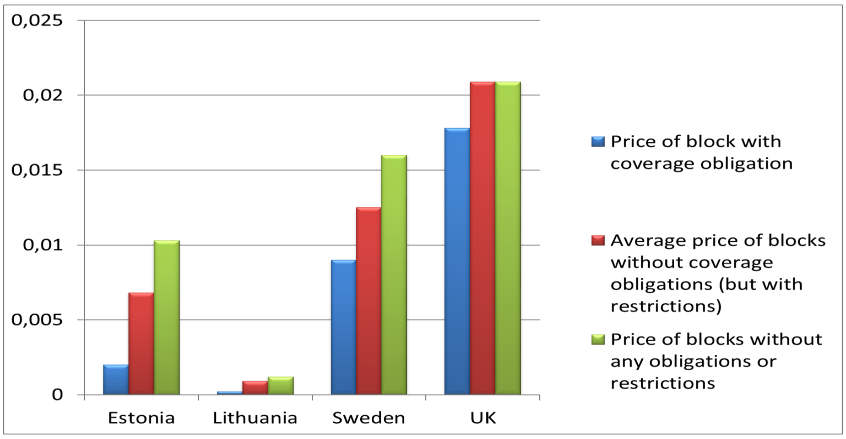
As can be seen in the Czech case, sometimes obligations relate to key national infrastructures such as roads and railways. In France for the 700 MHz and 800 MHz bands where all main roads (ca 50 000 km) and certain percentages of rail networks (only for 700 MHz band) have to be covered at certain dates. The Netherlands (2100 MHz), Finland (700 MHz), and Hungary (450 MHz) also have obligations for main roads and other infrastructures (including waterways and ports in the case of the Netherlands).

The coverage obligations often become stricter over time as in the Czech Republic in the 800 MHz band, where both the number of districts and transport infrastructures to be covered and the data rate requirements increase after 2.5, 5 and 7 years. In some cases, new entrants are imposed different conditions than incumbents, where obligations are generally more relaxed for new entrants. This has been the case in e.g. Austria, Belgium, Italy and Slovenia.

Coverage obligations may also differ within the same frequency band. In some cases, only one block (and hence one licensee) is subject the obligations or to stricter obligations than the other ones, as for example in the Swedish case (800 MHz, mentioned above). Such differences allow for identifying the indirect cost (as “lost” revenues) of mobile coverage obligations and which can be quite substantial, as shown in Figure 3.16.

Figure 3.16 The cost of coverage obligations

Price/pop/MHz/GDP (Purchasing Power Parity) per capita of 800 MHz band frequency blocks in MS with obligations for one licence only (€*1000)



Source: Magi (2017).

In some cases, coverage obligations are specific to certain frequency band or technology, while in several other cases, obligations apply to the license holder of a specific band, but can be fulfilled with a combination of frequency bands or technologies. This applies mostly to data services (ECC, 2015a) but it can also apply to voice services. In Slovenia, for instance, obligations in the 1800 MHz, 2100 MHz and 2600 MHz bands can be fulfilled by using any of these bands.

Coverage obligation criteria can also be combined, like in Denmark for the 800 MHz band, where certain specified post code areas should be provided with 98 % geographical coverage and 99.8 % population coverage of 10 Mbps outdoor download data rates (ECC 2015a, data set).

The level of coverage obligations also varies in other dimensions, e.g. in terms of how ambitious they are in level and timing. As noted by RSPG (2011), lower frequencies (below 1 GHz) have typically been used to ensure wider coverage. Population coverage obligations are often set well over 90% in those cases. In higher bands (1.8-2.6 GHz) the primary objective of the coverage obligations appears to have been, according to RSPG (2011), to stimulate network deployment and avoid spectrum hoarding. Following this, coverage obligations are sometimes modest in the scope (usually between 25-50 % population coverage), and often below the level expected to be achieved. This is then done in order to ensure competition, which in turn would then drive more ambitious network rollout. RSPG (2011) mentions Germany and Ireland as examples. Germany set its coverage obligations at 50% for the 1.8 GHz, 2.1 GHz and 2.6 GHz bands with the expectation that actual roll-out would be significantly higher.

Some MS, including the Nordic countries, Belgium, UK, Spain and Portugal (RSPG, 2011, confirmed by our research), have no coverage obligations in the 2.6 GHz band. Some other MS have established obligations in the 2.6 GHz band with the objective of targeting specific locations (RSPG, 2011) notably cities, e.g. Lithuania (50% population coverage of certain number of cities) and France (coverage of metropolitan areas.)

Criteria Associated with Coverage Obligations

This section reviews the current criteria in use for specifying fulfilment of voice and data coverage respectively.

Voice coverage criteria

Most MS use field strength or signal strength (11 and 17 counts respectively in ECC 2015a),[26] which to some extent are indirect indicators. The benefits of using those measures is that they allow for NRAs to easily verify voice coverage and to make theoretical calculations. One drawback is that other factors, such as cell load, will have an impact on the actual QoS. Threshold values for field strength range from 38 to 58 dBµV/m and signal strength from -106 dBm to -75 dBm. In some cases, additional specifications are made including height above ground (from 1.5 to 3 m), probability at cell edge (50-75%) and probability of cell load (ECC, 2015a).

In France, the possibility to make a phone call is specified as a criterion. It can be defined as (depending on if 2G or 3G and which license holder it concerns) that success rate for making a 2-minute uninterrupted call on first attempt should be above 90% using a 1 or 2W handset). Clearly one advantage of this criterion is that it provides a realistic measure of the actual availability of the service. At least one country (Belgium) uses a quality measurement for voice service: RxQUAL which needs to be equal to or lower than 4. In a few cases (according to ECC, 2015a) a specific bitrate is used as an indication for voice coverage (12.2 to 144 kbps). (ECC, 2015a).

Finally, it could be noted that some MS (e.g. France) have included the SMS QoS in their coverage obligation criteria (the rate of messages received within 30 seconds should be at least 90%).

Data coverage criteria

Various criteria for data coverage have been introduced in the coverage obligations, to some extent for 2G and 3G, but even more so after the introduction of 4G/LTE, including a few indoor and outdoor metrics. By far the most common criterion is minimum downlink data rate (often between 144 kbps and 30 Mbps but can be higher or lower). So far, the data set counts 20 NRAs that use this criterion, although using widely differing definitions, which makes them difficult to compare (Table 3.12).

Table 3.12 Overview of data rate coverage obligation criteria (in relevant MS)

Member State	Criteria
Austria	800/900/1800 MHz: Complex requirement: For some blocks and certain municipalities, and if licence holder has been awarded two blocks: 2 Mbps downlink and 0.5 Mbps uplink otherwise 1 Mbit/s downlink and 0.25 Mbit/s uplink. Mix of indoor and outdoor. Certain % of population and # of municipalities to covered within certain time-frames. 900/1800 MHz: An old narrowband obligation of 12.2 kbps 2100 MHz: UMTS, 144 kbps 2600 MHz: 1 Mbps downlink, 256 kbps uplink.
Belgium	800 MHz: Download speed of at least 3 Mbps (24/24, 7/7, max. 2 hours per day (peak hours) when speed cannot be reached.
Cyprus	900/1800/2100 MHz: 30 Mbps obligation linked to LTE.
Czech Republic	800/1800/2600 MHz: 2 Mbps within 7 years, 5 Mbps afterwards. 95% of a given district population. 75% probability of indoor coverage.
Denmark	800 MHz: 10 Mbps in the postcode areas specified in the licence. 1800 MHz: 30 Mbps downlink and 3 Mbps uplink in 245 underserved areas

[26] For many MS/frequency band combinations, it has not been possible to identify which criteria the NRAs use to evaluate the availability of voice coverage. To some extent, therefore, we rely on the overview given by ECC (2015a).

	2100 MHz: a certain signal strength value corresponding to 12,2 kbps data rate, at cell edge, 50% probability
Estonia	800/2600 MHz: 5Mbps downlink 2100 MHz: 144 kbps in town and 64 kbps outside
Finland	800 MHz: One operator has obligations to ensure 1 Mbps data rate in the mobile network before switching off the copper network. For the others it only specified that they should provide outdoor and "reasonable" indoor coverage.
France	700/800/1800/2600 MHz: 60 or 30 Mbps theoretical speed depending if 2*10 MHz or 2*5 MHz 900: MHz: Old GSM obligation with low speeds (e.g. 20 kbps) 2100 MHz: UMTS. Various obligations following beauty contest (e.g. 144 kbps)
Germany	700/900/1500/1800 MHz: Min. 50 Mbps per sector that ensures a "general downstream rate" of 10 Mbps. Not specified for 800 MHz band.
Greece	800 MHz: 10 Mbps (downlink) within 3 years & 30 Mbps (downlink) within 5 years.
Ireland	There is an old obligation for UMTS in the 2100 MHz band referring to a minimum bearer rate of 144 kbps.
Italy	800/1800/2600 MHz: "Minimum single user rate" of 2 Mbps 2100 MHz: 144 kbps
Lithuania	800 MHz: 4 Mbps or 2 Mbps. Varies depending on location and time 900/1800 MHz: 30 Mbps. Measured as signal strength.
Portugal	800 MHz: Data transmission speed must be equal to the highest speed (in the lowest quartile of such offers when ranked according to the maximum speed subscribed to) provided by the operators' commercial offers. In practice, this means 43,2 Mbps, 4 Mbps and 7,2 Mbps respectively for the three operators. 900 MHz: For GSM 9,6 kbps 2100 MHz: Old UMTS obligations 144/384 kbps. From 2018 in specific parishes: 30 Mbps (maximum, theoretical rate for one user, outdoor)
Romania	800/900/1800/2600 MHz: 2 Mbps downlink. (in some cases, temporarily 1 Mbps) 800/900 MHz: Specific localities with 384 kbps
Slovakia	800 /1800/2600 MHz: Outdoor, 2 Mbps for downlink, 256 kbps for uplink. 1800 MHz: Old requirement also for GSM: 12.2 kbps
Slovenia	800 MHz: For one lot: 10 Mbps outdoor (corresponding to 1 Mbps indoor)
Spain	800 MHz: 30 Mbps downlink (to 90% of population in pop. centres with less than 5000 inh.
Sweden	800 MHz band: Specific locations: 1 Mbps, indoor (in at least one room) 700MHz (not in force since auction was cancelled): 10 Mbps. Outdoor.
United Kingdom	800 MHz: indoor, sustained downlink speed of at least 2 Mbps, when cell is lightly loaded, with 90% confidence 2100 MHz: Outdoor, at least 768 kbps in lightly loaded cell, 90% probability

Note: Some of the very low values for GSM/UMTS may not necessarily relate specifically to data services.

Some observations:

- Downlink data rates often refers to different things, if defined at all. France for instance refers to theoretical maximum data rates (60 or 30 Mbps), while Germany mentions minimum 50 Mbps per sector, that ensures a "general downstream rate" of 10 Mbps. In most cases the obligations seem to refer to QoS experienced by users.
- While data rates over 1 Mbps are typically applied in bands where LTE are used, there are many older obligations ranging from 12 (or 12.2) kbps (in Austria, Denmark and Slovakia) to 0.786 kbps (UK) intended mainly for GSM or UMTS.

- In some cases, certain areas are to be covered with a higher downlink data rate than others. For example, in Austria, where it is 2 Mbps downlink and 0.5 Mbps uplink for specific municipalities, and 1 Mbps downlink and 0.25 Mbps for the rest.
- Portugal applies operator specific requirements, which in turn depends on the level of service of the operators' commercial offers elsewhere than where the obligation applies.
- Some MS evolve the obligations (Greece, Czech Republic and to some extent Lithuania) with time, increasing the required downlink data rate after some years.
- Sometimes data rate obligations depend on how much spectrum the licensee receives (e.g. France).
- The UK used additional criteria such as probabilities (90%) and cell load ("light").
- In some cases, outdoor coverage (e.g. Slovenia and Slovakia) and indoor coverage (e.g. UK and Sweden 800 MHz) are explicitly mentioned while in some cases not.
- In some cases, the data rates are linked to certain percentages of the population, while some countries required coverage of specific location before extending the coverage to other places (Germany).
- In many cases data rates are indicated by indirect criteria such as RSRP, SINR and signal strength values.

Monitoring and Enforcement

In line with ECC (2015a) this study identifies four main types of methods for monitoring coverage obligations: (1) operators providing (typically theoretical) coverage information; (2) theoretical studies run by the administrations/NRAs; (3) field measurements by NRAs and (4) crowdsourcing. These can then, in turn, be divided into subcategories and combined.

In this study, and in line with RSPG (2011), we find the most common way to monitor coverage obligations includes two steps: (1) some form of self-declaration from operators in which they provide evidence of their coverage (or that they have met the coverage obligations as set out in their licences or their progress towards that goal). Typically, this is theoretical coverage data based on their network planning. (2) Authorities follow up through some form of validity check either through field measurements (most common) and/or their own theoretical simulations (less common), in some cases complemented with crowdsourced data or other reports from users.

<u>Operator-provided information on coverage</u>
Radio networks are planned using computerized tools. Based on detailed maps, data on the location of base stations, their radiated power, radiation patterns, and propagation models, the field strength at any location can be predicted. The areas being covered or not covered can then be calculated quite accurately, if the maps are detailed enough and the propagation model and the assumed minimum field strength required by commercial terminals are realistic (ECC, 2016b).

In many cases operators are required to report, typically annually, on their network coverage and/or the fulfilment of their obligations, sometimes separately for each band or by technology. Typically, these reports are based on theoretical models/simulations conducted by the operators, and provided in formats agreed upon in advance. Information provided can include maps (at suitable resolution level) and/or geo-coded data files showing coverage (according to some criteria) for the coordinates and/or on the maps. They can also include lists of locations of base-station transmitters, and other information on methods/tools that have been used to calculate coverage (e.g. propagation models, link budget parameters, terrain models, clutter definitions, traffic figures, capacity utilization levels for cells, and indications of the frequency blocks used for each cells/sector). In some cases (e.g. Slovenia), detailed information about base stations is required (ECC, 2015a).

In a few countries (e.g. in Ireland) operators are required to perform field-tests as well and provide their results to the NRAs.

Simulations / theoretical studies run by the NRAs
The administrations may use either coverage directly provided by operators or deduce coverage levels by linking them to e.g. population data themselves. They may also, based on data from the operators, conduct their own simulations. Member States doing the latter include Croatia, Czech Republic, Italy, Latvia, Lithuania and the UK (ECC, 2015a).[27]

The administrations can then simulate coverage based on assumptions or actual data regarding a number of parameters including: propagation model; lognormal location variation with a specified standard deviation; a specified terrain database (DTM); a specified clutter database; specified population locations and settlement identifiers; specified use of equipment noise figure and antenna gain; theoretical base station antenna azimuth and elevation radiation patterns; network load; time and location probability; received signal strength or field strength level; and antenna receiver height. (ECC, 2015a).

ECC (2015a) points out that these kinds of theoretical studies require specific tools, particular expertise and are generally quite expensive.

Field measurements
In many countries, theoretical studies are verified by field measurements (spot or drive tests) (ECC, 2015a). We found no source that provides a good overview of the different types of test conducted by NRAs (neither ECC, 2015a nor RSPG, 2011). However, ECC (2015a) does provide a list of answers to the relevant survey questions and in addition we have collected some complementary answers from our survey. From this it can be concluded that most (but not all) MS do perform some field measurement tests. These tests can be conducted either on a regular (e.g. yearly) basis, in relation to the date when coverage obligations have to be met, or when/if theoretical simulations suggest that information provided by operator is not valid (difference between operator calculated coverage and NRA's calculated coverage) as was the case of the Czech Republic (ECC, 2015a).

Field measurements are typically conducted as drive-tests and/or spot tests, and usually outdoors. Tests are using either commercial (consumer) equipment (e.g. in Austria, Belgium) or specialized test-equipment (such as the Rohde & Schwartz ROMES platform) (e.g. in Croatia, Finland and Lithuania).

Crowdsourcing
In most Member States, there are possibilities to use crowdsourcing to measure coverage. Various systems and software exist for this, in some MS provided by the NRAs (e.g. RTR *NetTest* in Austria and *Tjek dit net* in Denmark), by independent associations (e.g. Bredbandskollen in Sweden) some being more international in scope (e.g. m-Lab). Typically such tools provide, for each measurement occasion: (a) upload and download speed; (b) latency (ping); (c) time and location of measurement; (d) type of device and operating system;(e) type of connection (GSM, UMTS, LTE); (f) name of service provider

[27] ECC (2015a, p.10) gives example of a list of information needed in such cases (in turn based on responses from Slovenia and Latvia).

and sometimes (g) additional information such time of loading a reference webpage and signal strength (ECC, 2016b).

The pros and cons of these types of measurement are discussed elsewhere, but there are some issues to consider. One advantage is that measurement is closer to the actual experience of users. However, outer conditions are usually not documented (height, inside-outside building). Neither are restrictions in the subscriptions (e.g. volume limits being reached) being accounted for. In addition, the population of test users and observations are likely not representative.[28]

Enforcement / penalties in case of non-compliance

There are two types of sanctions commonly available to the MS, when it comes to procedures when license holders fail to comply with coverage requirements. These are:

- financial penalties – the ability to fine operators
- revocation of licences (or in some cases shortening of license term).

These are typically preceded by a warning or notice. In some cases, both types of sanctions are available. In a few cases, quite complicated penalty schemes have been elaborated. In Austria penalties will be imposed depending the "degree" of non-compliance:

- For basic coverage: €15-25 million depending on degree of coverage for each frequency band where coverage is not
- €40.000 for each municipality not covered;
- Data rates: different levels of penalties (usually between €15-25 million) depending on data rate, band and levels of coverage.

There are very few documented cases where such actions were implemented (apart from some cases where operators voluntarily handed back their rights). One example is from the UK, where Vodafone failed to reach the 3G obligation to cover 90% of UK homes by June 2013. Vodafone subsequently agreed plans with Ofcom to bring itself into compliance with the 3G coverage obligation by the end of 2013. Ofcom found in January 2014 that Vodafone had met its obligation, and thereby avoided fines (Ofcom, 2014).

Conclusion

This section concludes the overview of coverage obligations in the EU MS by identifying some general patterns of their use.[29] To begin with, most EU MS have used coverage obligations for quite some time. Although we lack systematic evidence, it seems obligations have been specified, following consultations with stakeholders, in response to policy needs, which, in turn, have differed across the MS and over time. Early obligations (as well as later ones), have typically been specified as percentages of the national population or of its geographical area, and seem to have promoted basic coverage in the MS. The release of additional frequencies (and rollout of new network generations) improved network capacity, coverage and enabled the introduction of basic data services. Sometimes obligations then included coverage criteria related to such data services.

In recent years, with the release of the 800 MHz and 2.6 GHz bands (and in a few cases 700 MHz) accompanied by the launch of LTE/4G, several MS saw an opportunity to address further policy needs, e.g. (1) to improve mobile coverage in rural and other underserved

[28] See further ECC (2016), BEREC (2015b) and OECD (2014).

[29] An attempt was made to categorize the MS use of coverage obligations, but this was not fully possible to do.

areas, (2) to provide mobile broadband to these areas, (3) to improve coverage for transport paths and (4) improve indoor coverage. Accordingly, coverage obligations for these bands often reflect these needs: (a) in many MS the NRAs identified specific underserved areas and included coverage of those areas in the new obligations (in different ways). (b) Similarly, several MS have included a broadband QoS criterion in the obligations (typically downlink data rates above 1 Mbps). (c) A few countries have included coverage of major transport infrastructures in the obligations (notably in the 700 MHz band). (d) Indoor coverage was specified in some cases, but typically monitored only indirectly through assuming attenuation of signals as compared to outdoor.

Concerning enforcement, the MS broadly apply similar principles. Coverage is often monitored by a combination of (1) self-declaration from operators in which they provide evidence of coverage, typically calculations of outdoor signal strength using network planning data; (2) regulators follow up with through field measurements. However, methods, procedures and equipment used vary considerably across Europe. In cases where licence holders fail to achieve the coverage required of them, regulators have two types of sanctions available: financial penalties and revocation of licences. In practice, sanctions are rarely applied and usually proceeded by a warning or notification period.

Finally, there are indications that future licences (e.g. in the 700 MHz band and for 5G) may address additional needs including support for new applications and services. This could mean inclusion of obligations for e.g. interrupted coverage along transport paths and in other places where people (and things) communicate as well as additional QoS parameters (low latency, reliability, etc.).

3.3.3 Effects of Coverage Obligations on Connectivity

The objective of this section is to analyse the effects of the different coverage obligations in terms of connectivity improvements and market impacts. It starts with a summary analysis of the role of coverage obligations on connectivity in six country mini-cases. Then, it discusses these findings in comparison to other parts of the world. The next section briefly relates the finding to received research on factors (including government mandates) driving mobile network diffusion. The final section concludes with identifying a number of success factor and best practices with respect to mobile coverage obligations.

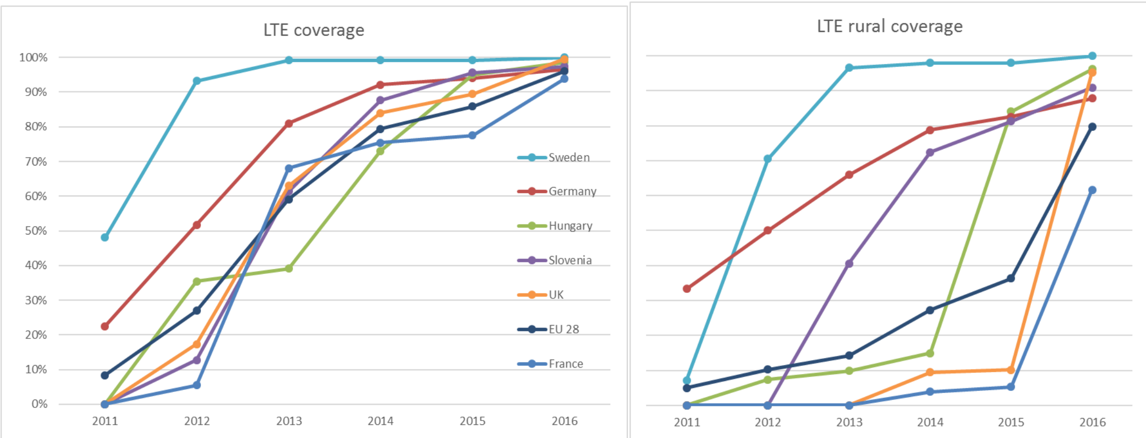
Country Case Studies

This sub-section uses six country mini-case studies (Sweden, Germany, UK, France, Slovenia and Hungary) to further the analysis of the role of coverage obligations on connectivity. The cases focus on mobile broadband related obligations, mainly (but not only) used for LTE in the 800 MHz band. Since the objectives of introducing obligations in this band have mainly been to expand mobile broadband connectivity to rural and remote areas, emphasis is placed on analysing such impacts. Table 3.13 synthesizes and contrasts experiences from the cases.

Table 3.13 Summary observations from the six cases

	Sweden	Germany	UK	France	Hungary	Slovenia
Band (MHz)	**800**	**800**	**800 & 2600**	**800 & 2600**	**800**	**800**
Year	**2011**	**2010**	**2013**	**2011**	**2014**	**2014**
Obli-gation	(Gradually) cover list of locations up to a cost of 300 MSEK.	4 priority area stages. *Bundesland* level. Deployment in next stage, can only begin when 90% of the previous stage covered. All stages to be achieved in 5 years.	98% of population by end 2017 (in 3.5 years)	Divided into metropolitan, departmental and priority area (e.g. 40% of priority areas in 2017)	Different packages: across municipal boundaries (in 12 months), localities with pop. 1000-6000 12 months after TV-shutdown	General obl. + one band: 95% within 3 years, plus 75 of Special Coverage Areas each year
Crite-ria	1 Mbps (indoor)	Not specified	In-door 2Mbps	Theoretical 60/ 30 Mbps	Min. signal strength value	10 Mbps (outdoor)
# MNOs	One	All	One	All	All, but with different obligations	All (but different for new entrants and for one band)
Impact	High impact on remote locations, but does not fully explain high coverage.	High impact on rural coverage. Fulfilled already in 2011, but rural coverage continued to increase, although slowly.	Limited	Recent impact when approaching millstone	High impact of coverage obligation on rural coverage	Positive, but coverage good already before obligation went into force. Likely impact on rural coverage
Lessons	Economic incentives, network sharing and earlier build-out matters	Incentives and specificity of coverage obligation	General national % of pop. obl. unlikely to have major impact on rural coverage.	Timing important	Specificity of obligations, timing matters as does network sharing	Difficult to state, since level of coverage was high anyway

Figure 3.17 Total and rural LTE coverage
% of households in six MS and EU 28 (2011-2016)



Note: 2011-2014: end of years. 2015-2016: mid-year.

Source: 2012-2016: European Commission (2017b); 2011: European Commission (2014c).

A few observations can be made from Table 3.13 and Figure 3.17. First, Sweden was quick to achieve high total and rural LTE coverage. Among the big MS, Germany stands out with early build-out of rural coverage in particular, while France and the UK were lagging and only recently improved rural coverage from very low levels. Finally, Slovenia and Hungary have experienced early, rapid and sudden increases in coverage.

In the case of Sweden, the current very specific coverage obligation scheme used for 800 MHz – including specific addresses and economic incentives – appears to have had a clear impact and achieved its objectives (with some delays) although this impact was on the margin concerning the last uncovered households and businesses. Instead earlier coverage obligations (including those resulting from beauty contests) and long-term follow-up of those obligations by the NRA seem to have provided the pre-requisites for rapid build-out following the early introduction of LTE.

In Germany, white spots and rural areas were covered very rapidly (as compared to in many other EU MS) – three years ahead of the obligation deadline. The coverage obligation design, providing commercial incentives to cover unprofitable areas before more profitable areas could be built out, was successful in this respect (despite rather vague specifications of what was meant by coverage), although the pace of roll-out seems to have slowed after obligations were met.

In the UK, mobile coverage has been a problem and coverage obligations were not enough to address this problem. The coverage obligation design appears not to have stimulated coverage in rural areas until 2015, which was generally well below the EU average. One reason could have been that, although Ofcom defined comprehensive measurement parameters and methods, the formulation of the obligations provided only small incentives for MNOs to cover rural areas. Following this, the government negotiated a change in obligations in 2015 with operators. These recent changes have, at least according to European Commission (2017) data, led to radically improved coverage.

France was early in introducing LTE in the digital dividend band, including elaborate coverage obligations. Nevertheless, it has taken a long time before these obligations translated into any substantial rural coverage – which indeed was very low up until 2015, increasing only recently. We conclude that coverage obligations have indeed impacted connectivity in France, but this effect started to show itself only when the first coverage obligation milestone was approached. Hence timing of obligations milestones is important for coverage.

Hungary stands out insofar that coverage obligations in the 800 MHz band seem to have had a swift impact on coverage, which can be seen as a vigorous increase in rural coverage in the first 6 months of 2015 only. The extensive network sharing agreements in place between the two largest operators have likely amplified this effect. It could also be noted that coverage obligations are well specified in terms of how they are defined and measured.

Finally, Slovenia performs well terms of LTE coverage, both in terms of total and rural household coverage. While the coverage obligations have had an impact in this respect, since this build-out was well under way even before coverage obligations went into force, it appears other factors have played a major role as well, including Slovenia being a relatively small country.

In addition to the case studies, a few other observations emerged from the NRA survey that are useful to point out here:

- The Czech Republic introduced, in 2013, coverage obligations for 800MHz (4G) with relatively strict deadlines and with priority given to districts with low population density. Connectivity improved as a result, not the least in areas with no or limited 3G coverage. LTE coverage reached above 96% of population and 92% of the territory within three years, which was significantly faster than UMTS/3G coverage (built out over more than 10 years and reaching less than 80% of population and less than 40% of territory). Mobile download/upload speeds have also risen significantly.

- In Ireland, although coverage obligations have promoted rollout, retail competition also has driven coverage to levels higher than the coverage obligations.

- In Finland, coverage obligations have contributed (together with network and spectrum sharing, allowing for more cost-efficient network build-out) to improving connectivity in the sparsely populated north-eastern parts of the country.

- In Estonia, the obligations following from the spectrum assignment procedure (combined auction/beauty contest) in the 800 MHz band has led to a very rapid build-out of 4G.

In conclusion, while mobile connectivity and coverage depend on several factors, of which many are specific to the MS (e.g. geography, density of population and socio-economic factors) including practices of network sharing and earlier build of complementary infrastructure, our research shows that coverage obligations can be an effective tool to increase coverage. The success factors for the use of mobile coverage obligations are summarized in the final sub-section, but first we turn attention briefly to what can be learned from practices outside the EU and from previous research.

Practice in Other Parts of the World

This section contrasts the findings on the use of coverage obligations (with a focus on mobile broadband) in the EU with those in other parts of the world. It is based on desk-research of a selection of countries: US, Canada, India, China, Japan, South Korea, Australia, New Zealand, Singapore, Norway and Switzerland.[30]

Coverage obligations are quite commonly used also outside the EU – but are not omnipresent. Of the 12 countries surveyed at least 7 have some coverage obligation in at least one band. Typically, these obligations are less strict than in many EU countries. In some countries (e.g. China and Japan) the absence of coverage obligations follows from the procedures used in awarding licences. In some cases, notably Australia (with vast sparsely populated areas), public funding seems to have been the preferred policy tool to stimulate coverage. Public funding has been used also in Chile and to some extent in India and Norway (and possibly in more countries). Network sharing has also been allowed and promoted in several cases. Some further selected country specific observations include:

- In the USA, just as in EU, stricter obligations have been used in the digital dividend band, reflecting its suitability for expanding service to rural areas. Typically, licenses are awarded on a regional rather than national basis; failing to meet requirements will lead to either reduction of licence terms or the licence holder being denied renewal of the license.
- The situation in Canada resembles that of the USA. Licences were generally granted on a regional basis, with stricter obligations for a portion of spectrum in the 700 MHz band. In addition, just as in the USA, strong renewal conditions were enforced. Several network sharing agreements are in place in Canada.
- In Singapore, licenses were granted on a national level, often with quite specific coverage obligations (specifying indoor and outdoor coverage, underground coverage etc.). The obligations do not include any percentages of population or area to be coverage, likely implying 100% coverage.
- In New Zealand, as in many European countries, the digital dividend band is linked with ambitious coverage obligations, while the higher frequencies were not. The terms of the obligations are a bit different from the European standard, because they are varied depending on the amount of spectrum purchased.
- In Europe, Switzerland has, compared many EU Member States, relatively less strict coverage obligations, with the aim to ensure that assigned frequencies are being used. Norway has (in the 800 MHz band) used a scheme similar to that of some EU countries (one band with stricter obligations) combined with the use of public funding for build out in very remote areas.

Research on Factors Behind Mobile Network Diffusion

How do the empirical findings so far relate to what is known, from previous research about factors driving mobile (coverage and) diffusion? A brief literature summary was performed to answer that question. It showed that there is much evidence of the socio-economic benefits of connectivity, not least for economic growth (see the next section). While some of this economic impact stems from the build-out of the infrastructure, more relevant effects come from the diffusion and use of services delivered over broadband. The relationship between mobile coverage and diffusion and usage has not been studied explicitly in the literature we have found. However, one may assert that it is a logical conclusion that better coverage does drive diffusion (in the sense of take-up of services), as does the quality of service.

However, with the current state of technology, it is unlikely to be economically feasible for all operators to build out their networks so that they are accessible to everyone, so choices in coverage (within the licence obligations) may be made. Investment in coverage would therefore tend to be sub-optimal from a social perspective, if left to the market (implemented as comparative underinvestment for unprofitable areas). Intervention is therefore needed to provide better mobile broadband coverage. The relevant government intervention tools are mainly (1) coverage obligations, (2) the promotion of network sharing and (3) public funding to expand coverage in unserved areas. Thus, mobile coverage obligations in combination with the promotion of network collaboration agreements and possibly other forms of public funding (designed to avoid distorting market competition) seems to be the way forward. This confirms our empirical results. However, the literature has little to say about the design of such arrangements, which is the topic of the final section.

Success Factors

It is difficult to identify reliably a set of success factors or best practice for the use of mobile coverage obligations. This is because of the wide variety of factors that affect coverage, the diverse set of practices in place, the divergent dimensions of policy objectives they address and a lack of data to quantitatively link coverage obligation practices to actual coverage improvements. Still, based on the mini-cases investigated above and other observations, it is possible to distil a few aspects of what could be considered best practice regarding the use of coverage obligations.

First, the use of mobile coverage obligations can generally be seen as a successful tool to improve coverage in the EU MS. Second, and perhaps needless to say, obligations should be designed to address policy needs. To exemplify, if the objective is to ensure broadband coverage in previously poorly served locations, it makes little sense to specify a 9X% population coverage obligation. Instead, if needs are specific (e.g. better coverage of certain communities, roads, indoor, or similar) the obligations need to be specific as well.

A long-term perspective is also useful, where coverage (obligations) of one generation can build on and complement coverage (obligations) of earlier generations. Sweden can serve as an example of this, where the 800 MHz band obligation could draw on earlier obligations, including: (a) the one for UMTS in the 2100 MHz band from 2001-2007 which stimulated roll out of infrastructure, providing a base for later roll-outs; (b) 450 MHz coverage obligation improved geographical area coverage in remote areas and provided universal service for households lacking that and (c) the 900 MHz coverage obligation which stimulated coverage (mainly voice) along roads and in remote areas.

In addition, timing (relative to level of obligation) is also key. For example, in France, roll-out in priority areas appears to have taken place relatively late, largely when deadlines were approaching, which suggests that deadline dates could have been set earlier. On the other hand, obligations should not be too strict (e.g. degree of coverage of remoter areas, schedule) so that they become unattainable for operators. In particular, if obligations applied to all operators are too strict, then they are likely to impose high costs for build-out (and may lead to high enforcement costs).

Furthermore, incentives need to be high enough for operators to fulfil their obligations in a timely manner. This was the case in Germany, where build-out in commercially more attractive areas was conditional on build-out in less attractive ones. Other options include, as in Sweden, that one operator was required to invest a certain amount that could be reclaimed or simply specifying financial penalties at levels that are high enough to provide incentives for the MNOs to adhere to the obligations. Ensuring that authorities have the necessary power to verify and enforce the obligations, as proposed in Article 30 of the EECC (European Commission, 2016d) is also important in this respect.

Finally, regulators need to strike a balance between keeping obligations simple enough for operators to interpret and for NRAs to enforce, while at the same time making them specific enough to avoid conflicting interpretations.

3.3.4 Key Elements for Coverage Obligations

This final section for Task 3 aims to indicate which key elements for coverage obligations to consider at EU level as being critical to meeting EU connectivity goals. It therefore starts by recapitulating the EU connectivity goals and their relation to mobile broadband and mobile broadband coverage. Coverage obligations are then identified as one of several possible interventions that may be needed for the EU (and its MS) to meet connectivity targets. This is taken as a starting point for a discussion on the potential for a European harmonized approach regarding coverage obligations. It concludes with some tentative ways forward.

Connectivity Goals and the Role of Coverage Obligations

The need for better broadband connectivity is well anchored both in the literature and European policies. In the academic literature, there is ample evidence of socio-economic benefits of connectivity, not the least for economic growth, for mobile telephony (e.g. Gruber and Koutroumpis, 2011) and broadband (e.g. Czernich et al, 2009; Katz, 2012). Some recent literature (e.g. Rohman and Bohlin, 2012) suggests that higher quality broadband yields higher benefits. A recent communication from the European Commission (European Commission, 2016a) also confirms the importance of connectivity for Europe’s growth and jobs, and for competitiveness and cohesion. Connectivity, then, means not only ubiquitous access to basic Internet (coverage) but also much higher quality in terms of much higher speeds and other key performance dimensions (e.g. responsiveness, uninterrupted access, reliability) (European Commission, 2016a; 2016b)

To define more precisely what Europe's future Internet connectivity should be, the Communication establishes a set of objectives for network deployment by 2025 (European Commission, 2016a). The objectives build on and extend the connectivity goals of the Digital Agenda for Europe (DAE) (European Commission, 2010b), which were (i) to bring basic broadband to all Europeans by 2013, and to ensure that (ii) all Europeans have access to internet speeds of above 30 Mbps by 2020 and (iii) at least 50% of households subscribe to internet connections above 100 Mbps.[31] While the 2010 connectivity objectives remain valid up to 2020, the new communication calls for complementary, longer term objectives (European Commission, 2016a). In short:

- Gigabit connectivity for all main socio-economic “drivers” e.g. schools, transport hubs, digitally intensive enterprises and main providers of public services (by 2025)
- High performance 5G connectivity:
    - 2018: Commercial introduction of 5G
    - 2020: Commercial 5G service in at least one major city in each MS,
    - 2025: All urban areas and all major terrestrial transport paths to have uninterrupted 5G coverage.
- Improved connectivity in rural areas: 2025: All European households, rural or urban, shall have access to Internet connectivity offering a downlink of at least 100 Mbps, upgradable to Gigabit speed.

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[31] These goals are also reflected in national broadband plans (NBP) of the member states, where in fact many of the member states have more ambitious targets than the DAE ones.

The Communication also stipulates that in 2017 the MS should update their National Broadband Plans in line with the strategic objectives set in the Communication and the 5G Action Plan (European Commission, 2016a; 2016c). Earlier in 2017, a few Member States had already done so (e.g. Sweden[32]).

These recent and quite ambitious connectivity goals have at least two important implications (for this section of the report). First, they imply that mobile/wireless high-speed broadband coverage will be needed where fixed broadband is not feasible, to cover all areas where people live (and work) and in addition where people or businesses (or connected things) can be found – including roads, railways and other transportation paths, and, for example, recreational areas. Some criteria related to QoS service of such networks are needed – the prime target in the first phase being speed (data rates). Second, there are objectives specifically related to 5G – which, as shown in Task 2 include a different and expanding set of relevant performance dimensions (speed, low latency, reliability, Jitter, traffic – and connection density, power consumption, payload, etc., depending on use case and applications). Some of these dimensions may, depending on the business models for how services are introduced, be considered as criteria in license obligations.

Starting with the first implication, better mobile broadband coverage is needed. Given the availability of adequate technologies, spectrum etc., competitive markets can be expected to deliver such connectivity, but only in areas and with a quality that the providers (most often MNOs) deem as profitable – e.g. urban areas with high demand. Network sharing agreements can lower the network costs of the MNOs, thus further expanding the areas for which there is a business case to cover, which could therefore be promoted by governments. Governments may also provide different forms of public funding to further stimulate build-out (RSPG, 2011; Frontier Economics, 2015). They could also consider promoting other technological solutions such as satellite technologies, wide-range Wi-Fi and high-altitude balloons etc. While these measures have their virtues, their implementation will not be discussed further here. Instead we turn attention to the main topic at hand – coverage obligations.[33]

As shown in earlier sections, coverage obligations are already widely used among the EU Member States and come in a range of forms with respect to their specifications, measurement and enforcement. While such obligations appear to have been efficient tools in some cases to address coverage, they need to be better tailored towards future needs for improved connectivity and the objectives of the European Commission (2016a), particularly (according to the communication) regarding main transport paths and rural areas (European Commission, 2016a), but also perhaps by taking additional quality measures into consideration, specifically for indoor measurements for which novel approaches may be necessary.

Key Elements of Future Coverage Obligations for European Harmonization

The EU MS need to address a number of issues relating to coverage obligations including: (a) whether coverage obligations could be imposed at all and if so, how they could be formulated/specified; (b) how criteria should be defined; (c) how could licence holders' performance with regard to obligations and their associated parameters be measured and

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[32] "Sverige helt uppkopplat 2025 - en bredbandsstrategi" (Sweden completely connected 2025 – a broadband strategy, our translation) updates and raises the ambitions stated in the earlier one from 2009 (Government of Sweden, 2016).

[33] Coverage obligations could be regarded as a special form of public support in the form of forsaken revenues as compared to the case with no such obligations (Frontier Economics, 2015).

monitored; and (d) what the effective means of enforcement could be. Potentially all those issues could be subject to European harmonization. A tentative analysis of pros and cons for harmonization at these four levels is provided in Table 3.14.

Table 3.14 Elements of harmonized obligation: Some pros, cons and implications

Level (explanation /example)	Pros	Cons	Implications
Specification / design (to include or not, definition, time-frame etc.)	Could facilitate cross-border services	MS diversity Different policy targets No "one size fits all" obligation	Remain at MS level Knowledge sharing to be encouraged
Definition of criteria (what is meant by e.g. coverage, downlink data rate, reliability?)	Reduced uncertainty in interpretation of policy objectives and coverage obligations Better information and improved comparability across Europe.	Switching cost Changes in definitions could lead to de facto changes in the meaning of existing obligations	To be considered for harmonization (for future obligations) Define for 4G /data rate, implement on voluntary basis New criteria for 5G Standard format for describing obligations
Measurement procedures/methods	Above + economies of scale in measurement	Switching cost Some MS may have to use what they would consider as inferior methods	Above: + consider trade-off between precision and cost of measurement
Enforcement - procedures if not fulfilled?	Not analysed	Not analysed	Remain at MS level. Sharing of experiences.

Note: The analysis above is not exhaustive.

Concerning the first two issues, we need to consider national specificities, as illustrated in Section 3.3.2. EU MS are very diverse in terms of geographical, socio-economic and other characteristics, with both densely and sparsely populated MS, mountainous and flat alluvial plains, pre-dominantly rural countries and pre-dominantly urban countries, major differences in per capita GDP, etc. In addition, the MS display very different levels of connectivity. For instance, in 2016 in Belgium, Latvia, Malta, the Netherlands more than 95% of the households had access to broadband of at least 100 Mbps, while in Bulgaria, Greece and Italy these figures were below 20%. Mobile broadband coverage also shows very large differences, especially in rural areas.

These and other specificities of the MS suggest a quite diverse range of policy objectives and targets, which in turn could be addressed with quite different policy interventions. In terms of coverage obligations, it is unlikely that the EU and its MS would benefit from European level harmonized specifications, at least not in terms of whether or not coverage obligations should be used and how they should be specified in terms of specific shares of the population, geographical areas, transportation infrastructures or specific locations, or the timing when obligation should be met. Therefore, one may argue that the specification of coverage obligations should continue to be made at MS level. This also seems to be the prevalent opinion among the NRAs that we interviewed and seems to be broadly in line with the EECC proposal (European Commission 2016d), e.g. Articles 18, 19, 30 as well as Article 45 that sets out general objectives for coverage and Article 47 (3) intended to promote convergence in the criteria used to frame such coverage obligations (e.g. methods for designing coverage obligations) without imposing uniform conditions (see European Commission, 2016f).

Still, the definition of coverage obligations is subject to many trade-offs, options and uncertainties. In recent years, there has been a lot of "experimentation" among the Member State authorities with varying results. Clearly, sharing these experiences, knowledge gained and disseminating best practice among the NRAs is important, and it is already taking place to some extent, e.g. through BEREC. This should be encouraged and supported by the EU.[34] Some tentative best practices were sketched out in this respect in Section 3.3.3, but more is needed, for example regarding indoor coverage, coverage in poorly served areas and for road and rail transport (see also BEREC, 2017b). Note that the use of coverage obligations specified in terms of population percentages are likely to miss the target in this respect, since they are typically defined as outdoor coverage where the population lives, while in fact most usage takes place either inside homes or in other places than outside those homes (see e.g., Jungermann, 2017).

The inclusion of quality parameters, their definition and measurement, could however potentially benefit from European harmonization. In Section 3.3.2, it was shown that many Member States use a two-stage approach to monitoring and measurement: (1) theoretical coverage data combined with (2) field measurements conducted by the NRAs, of which both could be harmonized.

In principle, harmonized definitions, measures and procedures for measurement, could lead to benefits for consumers, producers, regulatory agencies, policy makers and society in general, were they to be standardized. Common measurement could lead to economies of scale in the enforcement activities of the NRA, and possibly for operators as well in their network planning, to reduced uncertainties in how to interpret policy objectives and coverage obligations, and better information and improved comparability across Europe for consumers and others.

However, for definitions, metrics and procedures for measurement, there are also downsides and barriers to harmonization and standardization that need to be overcome. The NRAs surveyed, while recognising the potential benefits of harmonization, also express some scepticism regarding the practical possibilities to implement it. Beside the difficulty in agreeing on a standard, most MS already have obligations and measurements methods in place and have made investments and developed expertise in relation to those. Imposing a standard may require them to make changes, which in some cases could be costly. In this respect, countries that implement coverage obligations and measurements for the first time may very well be more inclined to adopt a standard.

Definitions will benefit from harmonization and standardization. One NRA expressed a need for guidance in interpreting policy objectives and targets, e.g. what is meant by "all Europeans should have access to Internet speeds above 30 Mbps"? One should note however, that changes in definitions may have unintended implications for existing coverage obligations.

But even simple definitions become quite complicated to implement. Take voice calls for instance. The ability to make a voice call is fairly simple to define. However, since 24x7x365 everywhere testing is not possible, it needs to be translated into some indicator which can be modelled. And although, in principle, the ability to make a phone call can be translated into a field or signal strength, this also assumes that there is no co-channel interference. Additionally, for theoretical studies, assumptions regarding the propagation model chosen need to be specified. Furthermore, availability of the signal, as calculated

[34] Some aspects of such exchange of knowledge and best practices are proposed in the EECC (European Commission 2016d) Article 35, "Peer Review Process".

by the tool, does not necessarily mean that phone calls can be made in a specific location. Calculation of data coverage is more complicated than for voice, even when using a seemingly simple criterion such as a certain throughput (data rate). Data rates depend on other factors, not only signal strength - e.g. cell load and user speed. However, with theoretical studies, including the relevant assumptions, combined with field test measurements, it may be possible to approximate reality (ECC, 2015a).

Assuming however that there are significant benefits from a harmonized measurement of coverage obligations, we may tentatively see some potential ways forward. One solution could be to specify an approach to defining criteria and measurement approaches for LTE coverage (data rates and perhaps voice over LTE), for instance, building on the work already conducted in ECC (2016b) and other best practices. This approach could then be implemented in a Member State on voluntary basis. Note that emphasis on *indoor* measurements is needed. This is not the primary pre-occupation of the current obligations, and should be added.

A second possibility relates to the coming introduction of 5G. As mentioned above, some of the policy objectives concerning connectivity as stated e.g. in European Commission (2016a) relate specifically to 5G, which as shown in Tasks 2 and 5, includes a different and expanding set of relevant quality parameters. One or more of those parameters may, depending on the 5G business models, be considered for spectrum license obligations, and for a harmonized approach to definitions and measurement. Parameters related to transport, connected cars and autonomous driving could be especially relevant here.

Finally, as proposed by at least one NRA, a useful starting point towards a potential standardization of criteria and measurement coverage obligations, could be to develop a standard format for describing different criteria and their measurement. The work conducted in the Mapping of Broadband Services in Europe study[35] could contribute to such a venture.

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3.4 Task 4: Measuring Quality of Service and Experience in the EU Member States

3.4.1 Understanding QoS and QoE

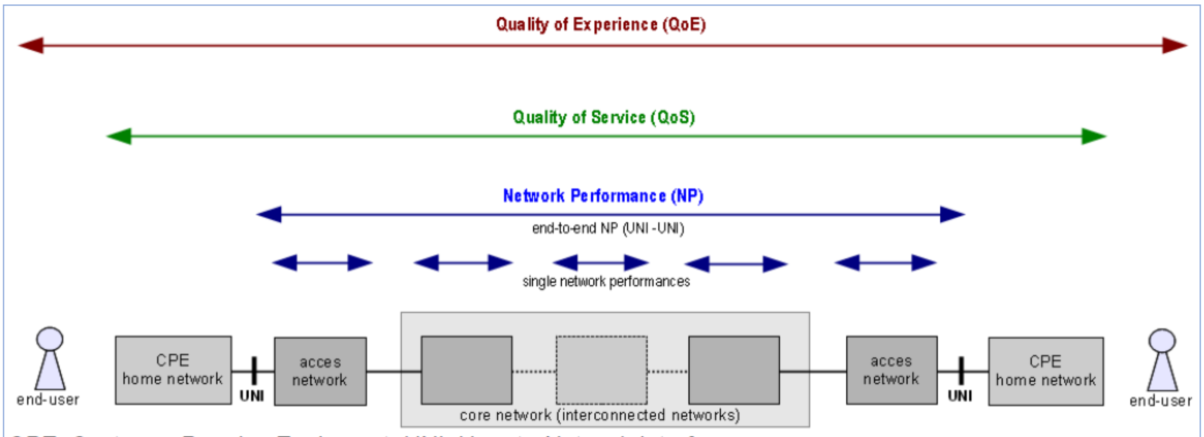
The aim of Task 4 is to analyse the comparability of different QoS and QoE measurement approaches, taking into account the datasets available in the EU Integrated Platform (SMART 2014/0016) and the work carried out by BEREC. Many different approaches to measuring QoS and QoE used by MS and private initiatives have been identified. The BEREC Expert Working Group on Net Neutrality is working towards identifying a common approach at the MS level. Based on this, Task 4 aims to analyse the advantages and disadvantages of other approaches and how far they could be compared. Task 4 can thus be split into four subtasks:

1. Identify the different approaches to QoS and QoE used by EU MS;
2. Analyse the comparability of those approaches, their advantages and disadvantages;
3. Lay the groundwork for the identification in Task 5 of a common approach to the measurement of QoS and QoE at the MS level; and
4. Review the output of BEREC, the Broadband Mapping Project, private initiatives and regulators in other parts of the world with regard to QoS and QoE measurement.

3.4.2 Network Performance, Quality of Service, Quality of Experience

Quality of Service (QoS) refers to the effective performance of a system in support of end-user needs or that contributes positively to another system's performance. QoS is distinguished from Quality of Experience (QoE) by encompassing the system only to the user interface. Performance *at* the interface is key for QoS. Network performance (NP) is more limited in scope because it excludes user interfaces, while QoE is broader because it includes the interfaces, the users and their perceptions. Figure 3.18 shows the relationship among these terms.

Figure 3.18 Relationship of NP, QoS and QoE



CPE: Customer Premise Equipment, UNI: User-to-Network Interface

Source: BEREC, 2011, p. 14.

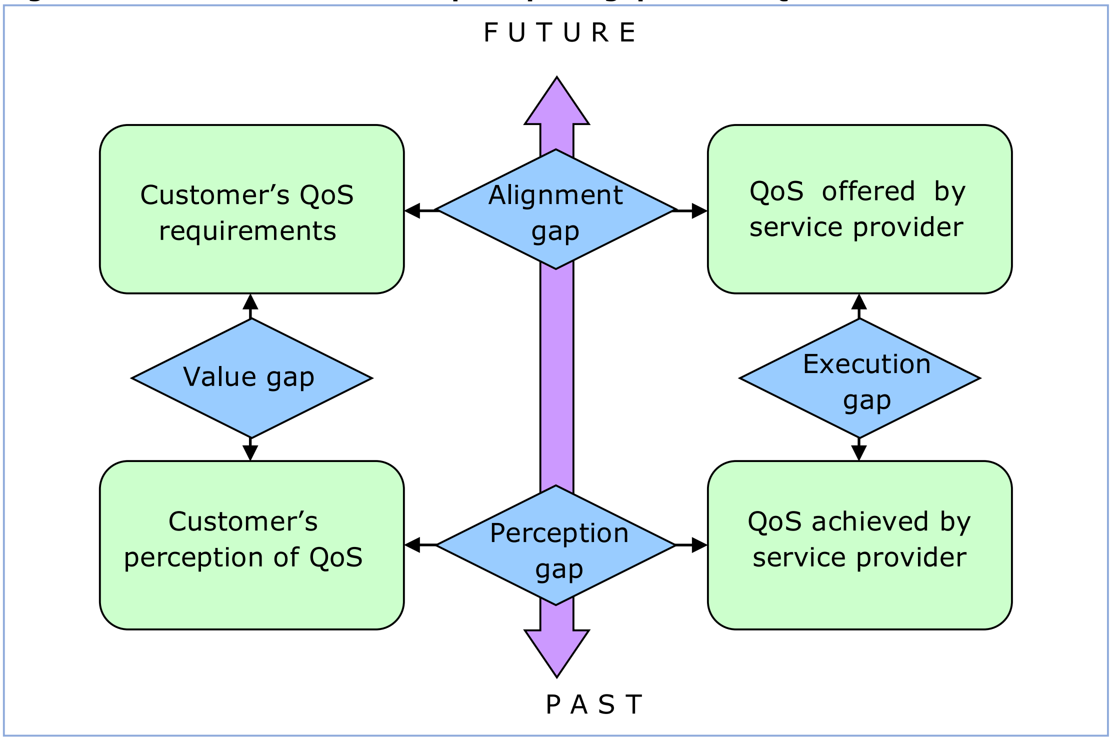
NP is mainly of interest to network managers. QoS, on the other hand, tries to separate attributes that are the responsibility of network managers from the subjective responses of the users. Complete separation is not possible since "quality" is itself a judgment based on comparisons that reach beyond the network.

Quantification and measurement are important for comparing service offerings objectively. They are also valuable tools of management for system operators and regulators, and the basis for specifications that guide designers. But objectivity does not mean that customers, regulators, network managers and designers perceive QoS in the same way. Often there are persistent gaps, as Figure 3.19 illustrates. Customers' perceptions of the QoS offered by a network may differ from what they require (the "value gap"). The QoS they perceive may differ from what the network actually offers (the "perception gap"). The QoS offered may differ from what the customer wants (the "alignment gap"), and it is all too common for a network's claimed performance to differ from its actual performance (the "execution gap"). For these reasons, regulators are called upon to intervene with independent assessments. (The arrow of time in this diagram indicates that QoS perceptions and achievements are based on experience in the recent past while requirements and offers may change in the future).

QoE, on the other hand, accepts user perceptions as primary. It does not stop at the network interface but encompasses personal impressions, expectations and judgments about fitness to purpose. It is "user-centric" rather than "network-centric". "Mean opinion scores", ratings and surveys are typical quantification tools for QoE measurements. Nontechnical variables are also prominent, like the readability of service contracts and the responsiveness of help desks. The Broadband Mapping project refers to QoE as QoS-3.

Among EU regulators, Ofcom UK is perhaps the most committed to QoE. When their "Broadband Checker" mobile app measures download speeds, it asks the user if they are satisfied with their network and which applications have the most impact on their judgments about service quality. In 2016 they refocused their network assessments on the processing of subscriber complaints. ARCEP in France made a similar move, shifting their reliance on audited measurements submitted by network operators to "crowd-sourced" measurements by end users.

Figure 3.19 Persistent structural perception gaps within QoS



Source: Adapted from Oona et al, 2003.

Variables and Purposes

No single number represents the entirety of QoS or QoE (that is to say, one never sees something like QoS = 1). Rather, specific variables or attributes are measured as indicative of overall performance: download speed, for example, is often cited as the principal indicator of broadband link quality. Variables tend to be chosen either because of their relevance to user experience or because their measurement is relatively straight forward. Such choices (convenience of measurement vs. relevance to experience) explain many differences among Member States in the indicators monitored and reported.

Whose needs are served by an indicator – the subscriber's, prospective subscriber's, network operator's, business partner's, regulator's or policy maker's – influences what is measured and how. The choice and design of indicators also depend on *purpose* – whether the aim is to:

- Show regulators that license conditions are being met;
- Discourage operators from misrepresenting their network's performance;
- Reduce the number of subscriber complaints;
- Help officials assess progress toward Digital Agenda goals;
- Enable the public to decide which service best meets their needs;
- Let subscribers know if their network is delivering the performance promised in their service contract; or
- Increase recognition of the best operators' achievements.

All these explanations have been given in various contexts and they are all legitimate. Indeed, diversity among indicators reflects the diversity of purposes they serve. If the diversity of QoS indicators is reduced, some purposes served now might not be served in the future. However, that does not justify Member States' using different measurement protocols for the same indicator, just because they had the freedom to choose different protocols.

Whatever the purpose, and whatever is measured, QoS indicators always have these elements:

- *A definition* – this might come from a regulator, an international standards organization, a private initiative, a network operator or an equipment vendor. Regardless of the source, the definition's clarity and completeness are essential for measurement results to be consistent, comparable, replicable and fair;
- *At least one measurable parameter* – most of today's indicators consist of a single variable, even though there are many applications that depend on combinations of variables, like video streaming, voice over IP and online gaming. Decomposing these combinations into multiple single-parameter indicators is another reason why many are needed;
- *An agreed unit of measurement* – since translating one unit into another is often trivial – seconds into milliseconds or MHz into GHz – agreement on a unit of measurement is of secondary importance. Nevertheless, it reduces the risk of misinterpretation;
- *A transparent, reliable and suitable measurement method* – much of the work of standards development addresses this requirement. But even when a method is defined rigorously, a variety of implementations may still be possible, reintroducing questions about comparability;
- (Optional) *A performance target or acceptable limit for the measured variable*. Targets are generally less strict than acceptable limits because they represent aspirations rather than hard boundaries. Failing to reach an acceptable level can trigger an

enforcement response: a penalty or compensation claim, perhaps even license suspension. Both targets and acceptable limits are considered *benchmarks.* Less than 30% of the QoS indicators that must be regularly measured and reported by electronic communication service providers in Europe now come with benchmarks.

3.4.3 QoS in Europe

QoS indicators emerged with telephony and became more prominent in the 1990s with the de-monopolization and privatization of fixed telephony. Specifically, the new notion of "universal service in a competitive environment" required the definition of a "minimum set of services of specified quality which is available to all users…" (Council of the European Union, 1994).

A key step in this process was "Directive 95/62/EC of the European Parliament and of the Council of 13 December 1995 on the application of open network provision (ONP) to voice telephony", which stipulated that:

> quality-of-service parameters and achieved performance levels should be published for the benefit of users; …harmonized quality-of-service parameters and common measurement methods are required in order to assess Community-wide convergence…

This Directive asked ETSI "to draw up European standards for common definitions and measurement methods" in QoS while recognising that:

> the principle of subsidiarity [means] the national regulatory authority of each Member State should play an important role in the implementation of this Directive, particularly in matters relating to the publication of targets and performance statistics [and] the supervision of conditions of use…(Recital 10)

Appended to that Directive was this Annex:

> The following list specifies areas where quality-of-service indicators are required for telecommunications organizations…:
>
> - supply time for initial network connection,
> - fault rate per connection,
> - fault repair time,
> - call failure rates,
> - dial tone delay,
> - call set up delay,
> - transmission quality statistics,
> - response times for operator services,
> - the proportion of coin and card-operated public pay-telephones in working order,
> - billing accuracy.

This list was carried forward with minor changes through a series of EU directives stretching over a decade and it still defines QoS parameters for fixed voice telephone networks in many countries.

To sum up, minimum QoS standards were needed to define universal service obligations in competitive environments. "Common definitions and measurement methods" were seen from the start as essential for internetwork compatibility and to promote convergence toward a single European market. Subsidiarity was interpreted as making MS responsible for publishing performance targets, compiling statistics facilitating the comparison of service offers from competing networks and overseeing conditions of use (licence-based QoS requirements). But the scope of subsidiarity was unresolved back then, and to some extent, remains so today. In its current form the Treaty on the Functioning of the European Union gives subsidiarity more scope than the 1995 Directive, e.g., Article 288 now says:

> A directive shall be binding, as to the result to be achieved, upon each Member State to which it is addressed, but shall leave to the national authorities the choice of form and methods.

"Methods" would seem to include QoS measurement methods – which the 1995 Directive said should be "common" throughout the EU – while "form" would seem to cover indicator definitions and reports.

Skipping forward, Directive 2009/136/EC, which amended the Universal Service Directive of 2002, proposed a process of inter-layer consultation that carefully balanced subsidiarity rights and regional recommendations, achieving wide acceptance among the Member States.[36]

The salient point is that the EU Member States adopted and modified their QoS regulations in waves corresponding to regional policy initiatives, generally accepting regional guidance so long as the harmonized aspects could be considered voluntary – even if subject to regional review, with departures from the regional recommendations needing defence and justification. The wave of acceptance that followed the 2002 Universal Service Directive was especially consistent, perhaps because QoS was embedded in an insightful and far-reaching policy package and the directive included a distilled list of indicators based on ETSI standards. Member States' responses to the 2009 update of the Directive were less consistent. This might have been because the 2009 amendment directed Member States to extend QoS obligations beyond universal services – but how and how far were left to national discretion. Article 22 of Directive 2009/136/EC says in part:

> 2. National regulatory authorities may specify, inter alia, the quality of service parameters to be measured and the content, form and manner of the information to be published, including possible quality certification mechanisms, in order to ensure that end-users, including disabled end-users, have access to comprehensive, comparable, reliable and user-friendly information. Where appropriate, the parameters, definitions and measurement methods set out in Annex III may be used.
>
> 3. In order to prevent the degradation of service and the hindering or slowing down of traffic over networks, Member States shall ensure that national regulatory authorities are able to set minimum quality of service requirements on an undertaking or undertakings providing public communications networks.
>
> National regulatory authorities shall provide the Commission, in good time before setting any such requirements, with a summary of the grounds for action, the envisaged requirements and the proposed course of action. This information shall also be made available to the Body of European Regulators for Electronic Communications (BEREC). The Commission may, having examined such information, make comments or recommendations thereupon, in particular to ensure that the envisaged requirements do not adversely affect the functioning of the internal market. National regulatory authorities shall take the utmost account of the Commission's comments or recommendations when deciding on the requirements.

A close reading of the above shows flexibility in who specifies the measurement methods: the Commission suggests methods in Annex III but the national regulatory authorities decide if they are appropriate – or the regulators can propose methods that the Commission evaluates, offering recommendations of which Member States "take the utmost account". In both alternatives, the Commission has the upper hand but the States have the final say.

[36] However, BEREC criticized its vagueness and proposed some procedural details to correct this in Section 7.2 of BoR (12) 131.

After the 2009 amendments, the updating of QoS obligations was driven not by newer directives but by the regulators' interest in expanding public access to accurate performance data for mobile broadband. The burgeoning popularity of smartphones equipped with browsers and the gradual replacement of 2G cellular networks with 3G and now LTE, made mobile Internet access speeds the hottest issue in QoS, particularly as regulators got an ongoing stream of complaints about mobile networks not delivering the broadband speeds promised. But because the mobile data speeds actually delivered depend crucially on the user's location, the efficiency of individual handset antennas and the number of simultaneous data sessions handled by the same base station, real-time link testing by subscribers using their own equipment became the measurement solution closest to the user experience. However, the fact that mobile licenses increasingly include both coverage and minimum download speed requirements means regulators need performance testing capabilities that are authoritative and user-independent as well as testing capabilities that are user-specific and based on experience. The splitting of measurement solutions for mobile broadband into calibrated multi-network probes and ad hoc "crowd-sourced" tests reflects a diversification of measurement needs.

3.4.4 Current Approaches to QoS/QoE Measurement in the EU

To understand the current sprawl of indicators, measurement methods, standards and obligations, as well as possibilities for consolidating and harmonising them, we undertook an extensive survey of QoS/QoE reporting obligations imposed on electronic communication networks and services in the EU Member States. We began by reviewing previous inventories, most notably:

- Annex 1: "Responses to a questionnaire on QoS frameworks and practices in case of retail Internet access sent on September 2011", in *ECC Report 195: Minimum Set of Quality of Service Parameters and Measurement Methods for Retail Internet Access Services* (2013).
- BEREC's Annex to Monitoring Quality of Internet Access Services in the Context of Net Neutrality, BoR (14) 117 (BEREC, 2014b).
- Commission Staff Working Document, Implementation of the EU regulatory framework for electronic communication, 2015, SWD(2015) 126 final; and
- "2017 COCOM 112 implementation report: Key Performance Indicators", Annex to "Working Document: Implementation of the European emergency number 112 – Results of the tenth data-gathering round", COCOM 17-01 (DG CONNECT/B2).

We drafted two questionnaires to survey NRAs, based on the tasks assigned for this study, which included some of the same questions CEPT asked for ECC Report 195, to spot changes since that report. BEREC helped distribute our questionnaires and collect the returns. We also interviewed regulators from the EU Member States. Regulators' websites proved highly informative, offering access to the texts of legislation, licence conditions, decisions, rules, standard interconnection agreements, records of public consultations and periodic reports about measured QoS. Eighteen Member States sponsor websites and offer free smartphone apps for the public to test their broadband links; two more are procuring this capability now; see Table 3.16. These websites document what they test and explain how the results are calculated. In addition, specifications for the procurement of measurement probes and drive testing equipment helped in clarifying the NRAs' needs.

This research showed that minimum performance levels and targets, service benchmarks, and state-imposed obligations to measure and report QoS/QoE indicators are scattered across many types of regulatory instruments, from regional directives and national laws to cellular licences to interconnection agreements to universal service and leased line contracts, etc. So it is possible that our inventory of such indicators and benchmarks is incomplete.

We found this field to be more dynamic than is generally recognized, with many regulators making in-depth reviews every few years and modifying their QoS monitoring agendas as a result. Some benchmarks are updated, others that yield the same results year after year are quietly retired. We started this study with the impression that QoS measurement obligations were more or less static and thus might be difficult to change, but that is not so: there is evidence of widespread flexibility.

However, change is also a challenge when counting the indicators:

- Should an announced minimum broadband speed requirement for a cellular network that has been licensed but is not yet operating be counted?
- Finland and Sweden require networks *to be able* to measure certain parameters, but they do not actually require that the measurements be made unless the information is needed. Should these be included?
- Should a universal service provider's QoS obligations be counted when no universal service provider has been designated? (Eight Member States currently have no universal service providers offering electronic communication services.)

With such uncertainties in mind, along with the probability that there are measurement obligations we failed to find, we estimate that the 28 EU Member States require their electronic communication networks and services to measure and report regularly on the value of at least 858 QoS/QoE indicators, an average of 30.6 per country.

Averaging, however, hides the fact that some countries (e.g. Germany, Luxembourg, Malta, the Netherlands and Slovakia) hardly monitor QoS at all, while others (e.g. Bulgaria, Greece, Italy, Latvia and Lithuania) monitor it extensively, see Table 3.15.

Table 3.15 Numbers of QoS indicators mandated by Member States

Member State	QoS indicators with bench-marks	QoS indicators without bench-marks (report only the level achieved)	Total number of QoS indicators mandated
Austria	16	12	28
Belgium	6	30	36
Bulgaria	25	58	83
Croatia	10	37	47
Cyprus	13	10	23
Czech Republic	2	13	15
Denmark	11	5	16
Estonia	2	9	11
Finland	7	24	31
France	12	18	30
Germany	6	1	7
Greece	2	63	65
Hungary	21	19	40
Ireland	16	10	26
Italy	14	60	74
Latvia	13	49	62
Lithuania	21	52	73
Luxembourg	2	6	8
Malta	1	16	17
Netherlands	1	7	8

Poland	3	16	19
Portugal	4	27	31
Romania	9	17	26
Slovakia	3	5	8
Slovenia	7	6	13
Spain	9	20	29
Sweden	5	7	12
United Kingdom	1	19	20
TOTALS	**242**	**616**	**858**

Source: Inventory of NRA regulations.

3.4.5 Comparability of Member State Approaches to QoS/QoE

EU Member States generally adopt QoS requirements in response to regional initiatives, so it is surprising to find large differences in practice among them. A possible explanation can be found in their different attitudes toward markets and regulation:

- At one end of the spectrum, there are countries like Estonia, Sweden and the Netherlands that are willing to let market forces work with minimal regulatory intervention.
- There are countries like Slovenia that see *self-regulation* as a solution: a "self-regulatory code on compensation for inaction or inferior performance by public communication service operators" (Samoregulacijski kodeks, 2014) was drafted with help from AKOS, the official regulatory agency. The code was added to the co-signers' corporate charters, making it as binding as any regulation.
- A further variation is *co-regulation*, which Poland tried. For two years, the regulator UKE and network operators negotiated a set of QoS indicators and measurements, but the effort failed when mobile operators "were not willing to establish a single measurement methodology. At the beginning of last year we got up from the table", said UKE's president (UKE press release, 2016). UKE then implemented a plan, based on drive testing and crowd sourcing, that did not require MNO cooperation.
- A more common arrangement is that the regulator determines the indicators but responsibility for the measurements is split: either the regulator verifies the operators' measurements or they work in parallel, measuring different parameters.
- In still other countries regulators define the indicators and outside auditors check the operators' measurements.
- Finally, there are countries like Latvia where the regulator determines the indicators, makes the measurements and reports the results.

Thus, one can see a continuum from Member States favouring a regulator-led process – and many mandatory QoS measurements – to those favouring a market-led process and few mandated measurements. This range of policy preferences represents a creative diversity but could be a problem in moving toward a common set of indicators.

On the other hand, it is a mistake to think that just because a country implements a certain strategy now, it has always done so and always will. ARCEP of France, for example, have made several major changes in their measurements programme for QoS in a relatively short period of time before moving to greater reliance on broadband testing by end users.

Extensive overlap among the parameters to be measured confirms that many countries' indicator choices are similar. This is certainly the case with emergency call centres and universal services, but it is also true of telephony and, to a less extent, other media categories as well. Overlap suggests that further convergence toward a common set of indicators and measurements is possible.

One area where there is a notable lack of commonality is in standards for network reliability: Bulgaria, Finland and Sweden have benchmarks designed to reduce the probability of service disruption in networks serving large segments of the population. But most other states do not have such benchmarks, even though the Framework Directive (2009/140/EC) stipulates that "Member States shall ensure that undertakings providing public communications networks take all appropriate steps to guarantee the integrity of their networks, and thus ensure the continuity of supply of services provided over those networks". (Article 13a, para. 2).[37]

Perhaps the most conspicuous trait that EU Member States have in common is the extent to which they rely on ETSI's guidance for measurement methodologies, definitions, descriptions, criteria for statistical analysis and sampling. They might differ on whether to limit sampling to the 20th and 80th percentiles or the 5th and 95th percentiles, or set a 48 hour instead of a 72-hour deadline on repairs, but they all accept ETSI's QoS indicator definitions and methodologies.

The growing acceptance of crowd-sourced data and link testing by end users as QoE indicators is another important area of convergence, even though the testing sites use a variety of different software. Adaptations of M-Lab, Ookla and Austria's NetzTest were noted as the basis of several sites sponsored by national regulators:

Table 3.16 Regulator sponsored websites for end user testing of broadband speeds

Member State	Public broadband link-speed testing site	Start date
Austria	NetzTest: https://www.netztest.at/	2012
Belgium	None found	-
Bulgaria	None found	-
Croatia	HAKOMetar (based on NetzTest): https://www.hakom.hr/default.aspx?id=1144	2012
Cyprus	2B2T (based on MLab): http://2b2t.ocecpr.org.cy/	2011
Czech Republic	Netmetr.cz (based on NetzTest): https://www.netmetr.cz/	
Denmark	Tjek dit net (based on Ookla): https://tjekditnet.dk/	2015
Estonia	None found	-
Finland	None found	-
France	Mon Reseau Mobile : http://monreseaumobile.fr/	2017
Germany	Breitbandmessung: http://breitbandmessung.de/	2015
Greece	Hyperion (based on MLab): http://www.hyperiontest.com	2011
Hungary	Szelessav.net (based on Ookla): http://www.szelessav.net	2015
Ireland	Procurement planned, no platform chosen yet	
Italy	Misura Internet: https://www.MisuraInternet.it/	2008
Latvia	iTest: https://itestn.sprk.gov.lv/	2009
Lithuania	Matuok (based on Ookla): http://matuok.lt/	2010
Luxembourg	None found	-

[37] Article 50 of the draft European Electronic Communication Code says that in deciding whether to renew a radio license the regulator should take into account the licensee's consideration of "the need to avoid severe service disruption." The EECC discusses "resilience" only in the context of radio receiver resistance to interference.

Malta	None found	-
Netherlands	None found	-
Poland	Procurement underway	
Portugal	NET.mede: http://www.netmede.pt/	2013
Romania	NEToGRAF: http://www.netograf.ro/	2014
Slovakia	Merac Internetu (based on NetzTest): http://www.meracinternetu.sk	2017
Slovenia	AKOStest (based on NetzTest):https://www.akostest.net/	2015
Spain	None found	-
Sweden	None found	-
United Kingdom	Broadband Checker (partnership with SamKnows): http://www.broadbandspeedchecker.co.uk/	2016

3.4.6 Hard and Soft Indicators

The analysis here includes "soft" QoS indicators, for which no minimum or target value has been set by law or regulation: only the achieved value must be reported. Of the 858 QoS indicators identified in this inventory, 616 (71.8% of the total) are "soft". If we consider only "hard" indicators, the 28.2% for which a minimum or target value has been set, we find that Bulgaria, Hungary and Lithuania are "hard" regulators, mainly because of obligations imposed on their universal service providers. Indeed, throughout the EU, over half of all "hard" QoS indicators apply only to universal service providers (129 out of 242).

Overall, the largest group of QoS measurement obligations (191 of them, of which 95.3% are "soft") concern call handling by "112" emergency phone-in centres. These "soft" indicators support an annual survey produced by DG CONNECT Unit B2 for the Communications Committee (COCOM) which tracks Member State implementations of 112. States must report numerical values for 9 KPIs, which obliges the call centres to measure them. Their presence is our inventory is large because *these are the only indicators currently implemented in all of the Member States with uniform definitions and the same methods of measurement.*

The reason these "soft" indicators do not constitute 100% of the call centre measurements is because one Member State, Ireland, imposes an additional 9 "hard" benchmarks on their call centres, due to a funding arrangement that requires the regulator to collect fresh evidence of "value for money" each year (ComReg, 2017). This might prompt one to ask why COCOM does not also use their indicators to set "hard" performance targets for other emergency call centres. After all, lives are at stake and by now the centres know what levels of performance are achievable. That measuring the centres is a *regional* initiative might explain why only "soft" indicators are used: in that way differences of opinion among the MS about appropriate values for each indicator were avoided, and flexibility about performance may have facilitated agreement on the consolidated list of KPIs.

The Value of Standards Without Benchmarks

There may be a lesson here: not setting target values for QoS or KPIs might make it easier to reach an initial agreement on a regionally harmonized list of indicators covering a wider range of parameters. In fact that is today's norm in Europe: 71.8% of the QoS indicators mandated do not have specified target values or minimum acceptable levels of performance, and if one excludes those specifically aimed at universal service providers and the 9 aimed at call centres in Ireland, that raises the percentage of indicators without benchmarks to 85.4%. COCOM's annual emergency call centre reports show that even without minimum values, call handling at the centres is improving thanks to publicity for the measurement results (and the growing competence of the call centre staff, of course).

But if it is found that the Member States are not converging on a single set of target values for the agreed indicators, this permissive approach can be reconsidered.

Analysis of Current QoS Indicators in the EU

Here is a further breakdown of current QoS indicators in Europe:

- **Just 2.8% of the indicators apply to all electronic communication networks.** In Sweden's case this includes minimum standards for network resilience and continuity of service for systems serving large numbers of people. Backup power supplies and redundant infrastructures are the main requirements. (PTS, 2015) In other countries, indicators applying to all networks typically set minimum acceptable levels for customer services (e.g. time needed to complete repairs or to respond to help-desk inquiries).

- **6.2% of the indicators relate to customer care.** The real percentage is in fact higher because many regulators classify customer care service obligations by the type of network. Thus, many parameters listed under "fixed voice networks" actually regulate the customer care quality of fixed networks rather than the technical quality of the network.

- **13.6% of the indicators apply to mobile voice and 10.4% apply to fixed voice, for a total of 24% directed at voice networks**. This is in addition to the 22.3% of all indicators that relate to the handling of "112" emergency calls and the 18.2% that are specific to universal services. The latter are all supplied by voice networks though some also have obligations to provide broadband. In other words, *64.5% of all mandated QoS indicators apply to voice networks*, a fact not widely recognized. This suggests that the list could use some modernization. It still includes indicators like the percentage of working payphones (implemented in 10 countries) and support for dial-up modems by several universal service providers.[38]

- **16.6% of all QoS indicators apply to mobile Internet while 9.7% apply to fixed Internet, so a total of 26.3% applies to Internet access.** It is interesting to note that despite all the attention given to minimum download speeds and latency, only 17.8% of the indicators for Internet access are benchmarked, compared to 34.4% for voice networks. That means 82.2% of broadband indicators require only the reporting of measured performance, with no particular targets or minimum levels defined.

What Does this Imply?

It is hard to interpret the significance of this lack of performance targets for broadband. It may be that "fast enough" broadband is regarded as a moving target by regulators and law makers, even though specific speed targets have been set by the European Commission. (There has been a similar reluctance among regulators to define "high speed" broadband.) Or maybe the trend away from specific benchmarks and toward general performance monitoring is exaggerated by the Internet being a new medium. (Table 3.17 shows that benchmarking is still associated with universal services, an older category.) Or it may be an artefact of our research methodology, so further exploration may be useful.

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[38] The draft Electronic Communications Code proposes the removal of universal service obligations that are no longer relevant, such as requirements to maintain public payphones and supply printed directories unless the need to ensure the availability or affordability of such services is duly demonstrated.

Table 3.17 QoS indicators with and without benchmarks
(average distribution per country)

QoS indicators per country	112 call centres	Universal Services	Mobile Internet	Fixed Internet	Mobile voice	Fixed voice	Customer services
Average number	6.8	5.6	5.0	3.0	4.2	3.2	1.9
Average number with benchmarks	0.3	4.6	1.1	0.4	1.1	0.8	0.4

Apart from the "112" indicators and the number of working payphones, these are the most widely mandated QoS indicators in Europe (i.e. by at least 10 Member States). They should probably become the core of any future common approach:

- Time needed to activate a communication service at a fixed location
- The frequency of faults reported per subscriber line
- Average time to troubleshoot, repair and eliminate faults
- Average response time for calls to customer services
- The proportion of mobile phone calls dropped or interrupted prior to normal completion
- Frequency of complaints about inaccurate billing
- Data transfer rate in the download direction

All the indicators on this list are cited here with descriptive names in English. But for implementation it is normal for Member States to identify the indicators in their national language – either translated from the name used in the original definition document or a phrase thought to be more accurately descriptive. For our inventory, the local names were translated back into English. Unfortunately, the linguistic "round trip" sometimes made it hard to know if we were dealing with the same indicator under different names or with different indicators. Some examples (these are all the same indicator):

- Austria: "Frist zur Bereitstellung eines Anschlusses" *(Deadline for the provision of one connection)*
- Belgium: "Délai de mise en service" *(Delay of setting in service)*
- Bulgaria: "Време за първоначално свързване към мрежата" *(Time to initially connect to the network)*
- Czech Republic: "Průměrná doba realizace připojení (zřízení + zprovoznění) služby přístupu účastníkovi" *(Average connection realization time [establishment + setting-up] of access service to subscriber)*
- Estonia: "Elektroonilise side seaduse» § 93 lõikes 1 toodud avalduse esitamise hetkest kuni lõppkasutajale sideteenuse kasutamise võimaluse loomiseni keskmiselt kulunud aeg, kui sideteenuse osutamiseks ehitatakse välja füüsiline ühendus" *(The average time taken to create the possibility of utilizing the communication service, from the moment of submission by the end user of the application provided for in subsection 93 (1) of the Electronic Communications Act, if a physical connection is established for provision of communication services)*

This illustrates that some apparent differences among the national QoS measurement agendas are simply the result of language differences and styles of expression rather than substantive differences. That is not to minimize the substantive differences (some were described above), but to assert that not all differences are substantive.

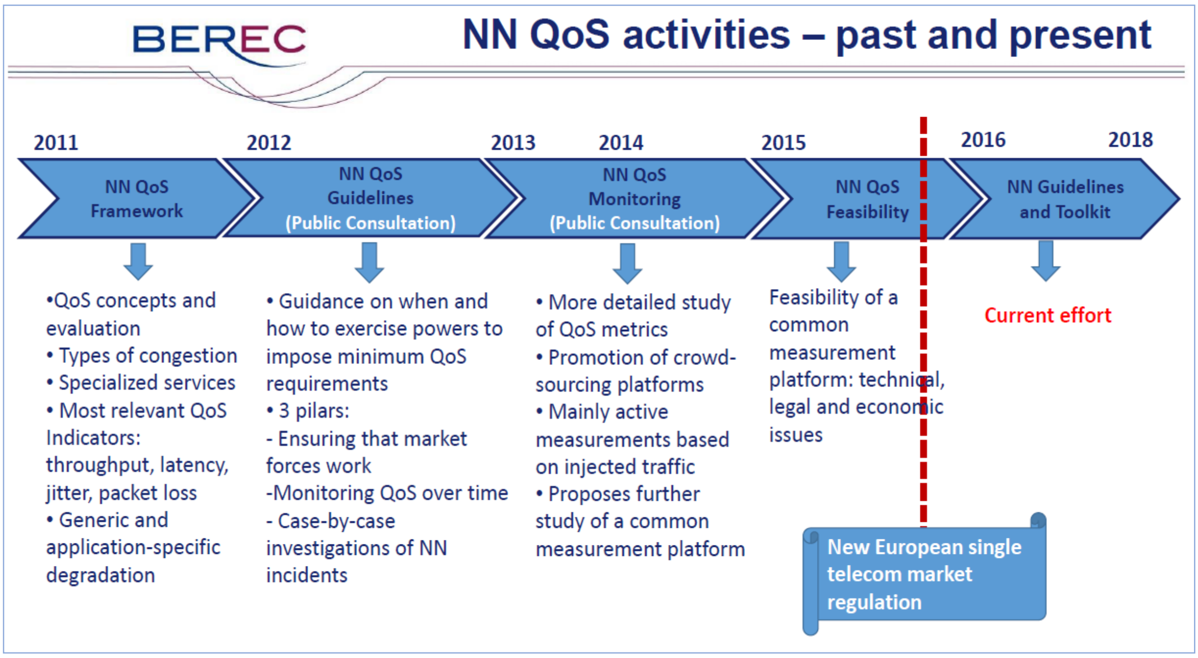
3.4.7 Other Approaches

The requirements for this study included reviewing the output of the BEREC Expert Working Group on Net Neutrality, the Broadband Mapping Project, private initiatives and regulators in other parts of the world with regard to QoS and QoE measurement. Here is a brief summary of our findings:

BEREC

BEREC has been working on QoS mainly in the context of net neutrality, because "traffic shaping" – which, generally speaking, is the opposite of net neutrality – can affect QoS.

Figure 3.20 Timeline of BEREC's QoS and Net Neutrality projects (2011-2018)



Source: Aldabbagh (2016).

BEREC's interest in these topics led them to survey the national QoS initiatives of EU Member States in 2014. This was summarized in the Annex to BoR (14) 117 (BEREC, 2014b), which also examined private initiatives like M-Lab's Network Diagnostic Tool (NDT), Glasnost, Shaperprobe, etc. Our inventory began as an update to this survey.

In 2015, as Figure 3.20 shows, they drew attention to the possibility of:

> a future opt-in quality monitoring system, where individual regulators can participate on a voluntary basis common measurement platform for QoS. BEREC's work beginning in the second half of 2016 would consist of specifying the system requirements and describing a framework for NRAs to collaborate in the opt-in system… The collaborative functionality proposal would include enhanced features such as cross-border performance measurements and multi-country monitoring data analysis. The common system could also function as a platform for collaboration between regulators and facilitate development and testing of new monitoring methods and measurement tools which can be gradually phased in by individual participating regulators (BEREC, 2015).

BEREC's "Net Neutrality Regulatory Assessment Methodology" BoR (17) 178, published in October 2017, specifies a "best practice methodology based on the combined goal of maximising measurement accuracy balanced against the need to be able to facilitate easy access to the measurement tool for the general public ensuring that the measurement results are comparable between different member states”. This provides a solid foundation for a converged set of indicators and measurements reaching beyond net neutrality.

Thus, one of the strategic priorities in BEREC’s draft work plan for 2018 (BoR (17) 176, 2017) is subcontracting the development of a net neutrality measurement tool. This is expected to combine three elements: open source software, a reference system and an information portal. An extension to the portal concept is a plan to make public more of the nonconfidential data collected by BEREC which network operators, other stakeholders and the public might find useful. This dovetails with our recommendation in Section 3.6.2 below for a regional public database of key quality indicator measurements, searchable by operator and location.

BEREC also plans to publish a report in 2018 on “best practices” in the use of license conditions to set mobile coverage obligations, and another report on the use of license conditions for “market shaping”, which should include QoS and QoE targets.

Looking further into the future, the draft Electronic Communications Code stipulates in Article 97 that 18 months after the Code comes into force, “BEREC shall adopt, after consultation of stakeholders and in close cooperation with the Commission, guidelines on the relevant quality of service parameters, including parameters relevant for disabled end-users, the applicable measurement methods, the content and format of publication of the information, and quality certification mechanisms.“ Since their work plans are implemented by Expert Working Groups, our proposal for an Expert Working Group on QoS Indicators seems fully compatible with the policy direction outlined in the EECC and charted by BEREC.

Broadband Mapping Project (SMART 2014/0016)

Launched two years ago, the Broadband Mapping Project is producing a website[39] that offers zoom-in maps of Europe and individual MS enabling site visitors to learn about the speed, technology and availability of broadband at any location. Built on data contributed by over 30 country-level mapping projects, it complements our own study of broadband coverage obligations in cellular licenses, reported under the rubric of Task 3.

However, they partition service quality space somewhat differently. While we accept the traditional distinctions between network performance (NP), quality of service (QoS) and quality of experience (QoE), the Mapping Project distinguishes between QoS-1 (theoretical or calculated availability of service), QoS-2 (actually measured provision of service) and QoS-3 (measured experience of service quality), as summarized in Figure 3.21.

[39] https://www.broadbandmapping.eu/.

Figure 3.21 The Broadband Mapping Project's QoS framework

		Internet / IAP / End User
QoS-1: Calculated availability of service	**What:** Theoretical network performance of existing infrastructure **How**: Assessment / calculation / marketed speeds by providers	Calculated availability of Service
QoS-2: Measured provision of service	**What:** Line qualification **How:** Measurement through panel probes or speed tests with filter to <u>exclude</u> end user's environment	Measured provision of Service
QoS-3: Measured experience of service	**What:** Actual user's experience when using Internet Access Service (IAS) **How:** Measurement via online speed tests <u>including</u> end user's environment	Measured experience of Service

Source: TÜV Rheinland Consulting (2016).

Creating the mapping website brought a crucial problem into focus: maximising its value to users requires maximising the resolution and reliability of the maps' geographic data – and that magnifies the problem of keeping the data accurate and up to date. Reality checking and frequent updating are essential to the site's value.

Public awareness of the state of broadband access in Europe is enhanced by this resource and it could help plan and integrate new infrastructures like 5G. The Commission asked us to suggest indicators that the Broadband Mapping Project might add to their platform, to further increase its value. Our suggestions are given in Table 3.20.

USA (Federal Communications Commission, FCC)

In the United States, the FCC is responsible for regulating commercial and non-federal telecommunication services. It recently adjusted to the pro-business orientation of the current administration by cancelling most QoS regulations. In July 2017, it stopped requiring telecom carriers to certify their compliance with national QoS standards and ended the carriers' annual reporting obligations for network outages, unfulfilled requests for services, numbers of complaints received and service pricing (FCC, 2017). This was done despite the fact that the FCC is mandated by the Telecommunications Act of 1996 to assess and ensure the availability of high quality services for transmitting voice, data, video and graphics.

More recently, mobile network operator Verizon submitted comments to the FCC arguing that, "The Commission Should Eliminate Unnecessary Reporting Requirements for Mobile Broadband and Voice Deployment" (Verizon, 2017). They objected to the kind of reporting that underpins the EU's Broadband Mapping Project and that supports the FCC's "service availability maps".[40] Other carriers filed similar comments, claiming that the FCC's request for more accurate coverage information would be burdensome without producing any public benefit (Goovaerts, 2017).

In 2015, the FCC reclassified broadband Internet access as a telecommunications service (no longer an "information service"). That change invoked rules which enable the application of quality standards (Wigfield, 2015). The move was specifically aimed at preserving net neutrality because Title II of the law treats data transfer speeds as a quality

[40] https://www.fcc.gov/reports-research/maps/.

parameter. But the current administration saw net neutrality as a concept promoted by the previous administration so it was targeted for elimination. The FCC's decision also claimed the right to stop state and local governments from adopting their own net neutrality rules (FCC, 2017b). However, as of this writing, 22 of the 50 American states have sued the FCC saying it overstepped its authority (Rogers, 2018).

With the end of certification requirements for QoS compliance, it is not clear if the FCC will continue checking the accuracy of advertised claims for often misrepresented parameters like download speeds. The FCC's own survival is uncertain (Fung, 2016).

Canada (Canadian Radio-Television & Telecommunications Commission, CRTC)

With the US eliminating most QoS compliance obligations, the contrast with Canada could hardly be stronger. Canada has strict and extensive QoS obligations for electronic communication networks. Telecom Decision CRTC-97-16 governs these obligations, requiring operators to report their service failings on a monthly basis. The public thus has regular access to a large amount of fresh information on network outages and service interruptions, issues of major public concern due to the frequency of severe weather in Canada. In addition, federally regulated telephone companies must submit quarterly reports to CRTC on the service levels attained relative to 16 QoS indicators. If a standard is not met, the companies are required to report why and provide a remedy. Compliance with national QoS standards is enforced with fines, warnings, citations and notices of violation, all posted publicly online. In cases of repeated and severe noncompliance, violators may be subject to individual compliance programmes imposed by the CRTC.

While Europe focuses on QoS for end users, Canada focuses on QoS for firms competing with the remnants of Bell Canada and their ongoing need for access to Bell Canada's infrastructure, now owned by a number of local exchange operators. Decision CRTC 2005-20 (2005) finalized a plan for QoS rebates if the local operators fail to achieve minimum acceptable levels for any of 14 QoS indicators. The size of the rebate depends on the number of indicators missed. The decision also establishes terms and conditions for the reporting and auditing of QoS measurements. A public consultation was launched in 2017 on whether this framework needs modification as CRTC recently gained new powers to regulate the wholesale market for telephony and wants to relax what it now recognizes as coercive regulations based on QoS. (CRTC, 2017) The results of the consultation have not yet been published.

Japan (Ministry of Internal Affairs and Communications, MIC)

Japan's telecommunication laws recognize the need to maintain QoS but do not specify target levels. Those were left to the MIC. MIC's Telecommunications Bureau chooses the standards and monitors performance. But the OECD noted (2013) that MIC did not require network operators to publish information about QoS, nor did the Ministry itself publish such information. Nor does a government-sponsored website enable users to test the speed of their broadband connections.

Because ISPs did not have to report about QoS, and indeed, MIC directed them to tell customers that service quality cannot be guaranteed because the Internet is a "best effort" medium, Jitsuzumi (2011) says the Japanese public is poorly informed about ISP service offerings. In spite of that, Japan's retail Internet market is said to be vigorously competitive because of MIC's strict regulation of access to the infrastructure of the incumbent NTT.

MIC responded to the lack of public information about ISP services not by requiring measurement and disclosure but by proposing that ISPs negotiate a private agreement on rules for traffic management and then make the agreement's rules public:

> Responding to this call from MIC, ISPs and network operators organised a committee in September 2007 and presented the "Guideline for Packet Shaping" in May 2008 that set a voluntary standard regarding the shaping of packets and the disclosure of related information to subscribers… (Jitsuzumi, 2011)

Among other things, the Guideline endorsed the throttling of heavy data users. As Jitsuzumi notes, "neither the Japanese broadband sector nor the Japanese government have been very successful" in promoting the concept or practice of network neutrality.

By 2013, MIC had formed a Study Group on the Ideal State of Internet Service Quality Measurements, to review the suitability and fairness of the QoS information provided voluntarily by individual networks, to see if it was sufficient for consumers' needs. (MIC, 2013) But the Fukushima nuclear disaster and tsunami in 2011 totally eclipsed the debate about traffic management and net neutrality. Attention shifted instead to the problems of network resilience and sustaining communications during crises. Since 2007, MIC's Fire and Disaster Management Agency has been developing the nationwide "J-ALERT" early warning system, which automatically activates broadcasting stations and crisis response networks to distribute information about severe weather, tsunamis, earthquakes, ballistic missile launches from North Korea and other urgent threats. MIC reinforced network reliability and resilience standards in 2016 (MIC, 2016). MIC's policy on consumer protection changed as well, with the previous laissez-faire approach being replaced by a new law promoting inclusion: "barrier free" access to communication services and media suitable for "people with physical and mental challenges". The prioritization of emergency response communications and handicapped access divert attention from net neutrality.

Republic of Korea (Korea Communications Commission and related bodies)

Created in 2008, KCC is a converged regulator responsible for broadcasting and telecommunications. Article 56 of Korea's Telecommunications Business Act of 2011 gave them the right to order network operators "to furnish data necessary for evaluation of quality" and to request quality improvements. KCC can also attach conditions to licences to improve QoS. QoS measurements are put online at KCC's WiseUser portal.[41] SmartChoice[42] is KCC's website for comparing the performance of different network technologies deployed in Korea with each other and with what is available elsewhere in the world. It also offers tutorials on evaluating QoS and an archive of older indicator measurements. Finally, a "download speed-check" and other tests (VoIP voice quality, webpage loading time, traceroute, etc.) can be found at http://speed.nia.or.kr, a website operated by the National Information Society Agency (NIA).

KCC and the Ministry of Science and ICT (which defines broad policy goals) are quite pro-market. But unlike regulators in other technologically advanced countries, they seem more concerned with the quality of broadcasting than with Internet access. Almost as surprising is their focus on the control of "harmful content" and promoting locally produced programs. These are seen as crucial quality issues, rather than the enforcement of technical standards. However, Korea is preparing to introduce Ultra-High-Definition (UHD) TV

[41] http://www.wiseuser.go.kr.

[42] https://www.smartchoice.or.kr/.

broadcasting, which involves a transition to new technical standards, so they cannot ignore that aspect of their work.

Regarding the Internet, KCC's approach to QoS is similarly content oriented, as they scour Korean-language websites at home and abroad for abusive remarks and personal data that may have been posted illegally. This requires keyword lists and searches for credit card, passport, driver's licence and health insurance numbers, followed by warnings, suspensions and takedowns. In 2016 they increased the number of websites they regularly monitor from 2.8 million to 3.4 million.

A large part of Korea's earnings from exports comes from telecommunication equipment. In fact, they dominate certain market sectors globally (DTV receivers and smartphones, for example). As a result, two semi-official industrial organizations have great influence outside the country. The Electronics and Telecommunications Research Institute (ETRI) does basic research with the aim of securing patents and formulating "core technologies" for the future. Their 5G Giga Service Research Laboratory is largely responsible for the project described in the next paragraph. The Telecommunications Technology Association (TTA), on the other hand, aims to set ICT industry standards and provides testing, certification and compliance evaluation services. It collaborates with standards organizations around the world including the ITU, ETSI and 3GPP (where it is an Organisational Partner).

Korea plans to introduce the world's first commercial 5G network at the Winter Olympics in Pyeongchang in 2018. Base station deployment started in September 2017 and a public trial service is expected to begin in February 2018. This early deployment is intended to help fill gaps in the ITU's QoS standards development work, contributing:

- End-to-end measurement rules for bridging fixed and mobile networks;
- QoS indicators for direct mode (terminal-to-terminal) links that bypass base stations;
- Parameters relevant to the management of links between operatorless devices (the Internet of Things);
- Insights into the impact of network slicing and virtualization on QoS; and
- Estimates of tolerable levels of jitter and packet loss for new use cases like virtual reality, remote control of driverless vehicles, etc.

The hope is that these will feed into ITU-T Study Group 12's agenda.

3.4.8 Summary of Findings from Outside Europe

Some of the differences among EU MS in the measurement and reporting of QoS indicators for telecom networks are substantial. But when compared to other parts of the world, the differences shrink. The US has largely abandoned QoS reporting obligations while Canada is reviewing its strict regime. In Asia, on the other hand, eliminating harmful content and promoting local broadcasts are South Korea's QoS priorities while Japan wants its networks to be able to survive disasters. If anything can be learned from these comparisons it is that Europe's choices are like different items on a menu while beyond Europe there are different menus.

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3.5 Task 5: Common Standards for Network Performance

3.5.1 Objectives

In this section key elements of a common standard for measuring network quality and performance are discussed. This task requires answering two questions:

- How does Europe progress from the indicators that regulators have already put in place to the indicators needed to regulate and support the more advanced networks envisioned for the period after 2020?
- What actions need to be taken – and what obstacles overcome – to make this progression acceptable to all stakeholders?

Starting from the current situation regarding QoS and QoE (described under the rubric of Task 4), possibilities for an acceptable common set of indicators meeting Europe's needs can be identified in several ways.

3.5.2 Distilling Existing Indicators

Our inventory found at least 858 QoS indicators that regulators in the EU Member States want regularly measured. When these are compiled as a single consolidated list, grouped by parameter and theme, it is clear that many indicators can be reduced to a smaller set of shared topics. Table 3.18 summarizes the topics addressed by the QoS/QoE indicators now mandated by the EU's telecom regulators.

Table 3.18 Topics addressed by the EU's currently mandated QoS/QoE indicators

Category	Parameters
I. Network service availability	
A. Activation	1. Time interval between request for and start of service a. Is a new physical installation required or not 2. Number & type of service complaints during 1st month
B. Number portability	1. Proportion of cases with procedural problems 2. Rate of service interruptions 3. Transfer time
C. Service interruptions (faults)	1. Frequency of occurrence 2. Time to respond to fault reports 3. Time to recover/remove fault condition/repair/restore
D. Network congestion	1. Busy hour traffic measurement a. Day of week, hour of day 2. Call blocking rate 3. Call interruption rate
E. Emergency (112) services	1. Time to answer calls 2. Caller location identified or not 3. Call abandonment rate 4. Handicapped access a. Suitable medium (video calling, SMS, phone-writer, etc.) b. Waiting time for response
F. Network reliability	1. Mean time between failures 2. Mean time to repair 3. Scheduled maintenance/downtime 4. Resilience a. Backup power b. Alternative routing
G. Specific to mobile networks	1. Coverage 2. Signal strength
II. Log-in and set-up	
A. Voice	1. Call set-up time a. On-net / off-net, domestic / international

	2. Call set-up success/failure a. On-net / off-net, domestic / international 3. Time needed to interconnect networks for call relay
B. Data	1. Login time / time to register / time to obtain IP address 2. Login failure / success rate
III. Session	
A. Voice	1. Call failure rate, completion rate 2. Transmission delay 3. Speech transmission quality 4. Call interruption rate 5. Connection restoration time
B. SMS / MMS	1. Message delivery time 2. Completion failure rate 3. Lost messages
C. Internet	1. DNS lookup (delay, success rate) 2. TCP and UDP port access / blocking 3. Nominal throughput, upload / download a. Maximum / minimum / average data throughput 4. Latency a. Jitter 5. Packet loss rate 6. Traffic shaping 7. Browsing a. Navigation time b. Web page loading time c. Web page loading failure rate d. Site blocking rate 8. Email a. Time to log in b. Session failure rate c. Lost message rate 9. File transfer a. Port blocking b. Throughput / upload / download c. Transfer success / failure rate 10. Streaming a. Rate of stream inaccessibility b. Access time (for first video frame to arrive) c. Flow rate d. Freeze occurrences e. Skip occurrences f. Cutoff rate 11. Video calls a. Setup time b. Failure / success rate c. Audio / video quality d. Interruption / breakoff rate 12. VoIP a. Call failure / success rate b. Setup time c. Speech transmission quality d. Interruption / breakoff rate
IV. Customer care services	
A. Help desk	1. Response time 2. Rate of unanswered calls
B. Inquiries	1. Response time 2. Rate of unanswered calls
C. Directory assistance	1. Response time 2. Rate of unanswered calls
D. Complaints	1. Billing problems a. Frequency b. Time to Resolve 2. Prepaid account problems a. Frequency b. Time to resolve

Source: Authors’ inventory of regulations published by NRAs, 2017.

A problem with this table is that, because it combines indicators from all the Member States, it is more comprehensive than the selection of indicators found in any one state. The average number of QoS indicators per country is about 30 but some states implement just 8-10, so the above list would be unacceptable to some as a starting point simply because it is too long.

So we might come at the problem from the opposite direction, by identifying the indicators chosen by the countries that mandate the fewest indicators. That should produce a bare-minimum set to which additions could be made according to local needs and preferences. However, when this is done, it turns out that the minimum set consists entirely of indicators for the handling of 112 emergency calls plus a few specific coverage and broadband speed obligations for cellular licensees.

Another approach is to identify the indicators that are most widely mandated. That set already enjoys wide support, so perhaps support could be widened without too much additional effort. Section 3.4.6 introduced such a list, which is repeated below:

- Time needed to activate a communication service at a fixed location
- The frequency of faults reported per subscriber line
- Average time to troubleshoot, repair and eliminate faults
- Average response time for calls to customer services
- The proportion of mobile phone calls dropped or interrupted prior to normal completion
- Frequency of complaints about inaccurate billing
- Data transfer rate in the download direction

This would be a good starting point for discussion but it may not cover enough areas of concern to regulators and the public. A third possibility is to lengthen the list of most commonly mandated indicators, stopping at 26, which is the median number of indicators that Member States measure. The result of this exercise is shown in Table 3.19.

Table 3.19 A common set of network performance indicators for Europe (limited to 26)

Category	Indicators
Internet	Data transfer speed (maximum, minimum, typical); Web page loading time; Latency; Jitter; Packet loss rate
Voice	Call set-up time; Unsuccessful call rate; Speech transmission quality; Response time for calls to the operator, customer service and directory assistance
Mobile	Network availability; Probability of successful connection in an area covered by the network; Dropped call ratio
Customer service	Time between request for service and start of service; Fault frequency; Time to troubleshoot & eliminate faults; Frequency of complaints about billing
Emergency calls	Total number of 112 calls per year; 112 calls as a percentage of total emergency calls; Percentage of false calls; Average time to answer; Percentage of calls answered within 10 seconds; Call abandon rate; Average time needed for operator to receive the caller’s location

Source: Regulations published by NRAs.

The list in this table may be the most practical starting point for the development of a common European standard for measuring network performance, based on current practices. Clearly the list is neither large enough to contain all the indicators of interest, nor is it sufficient to guide the development of future networks. But a common set of indicators does not preclude the adoption of additional indicators by individual States or by the region as a whole.

Table 3.19 and the list that precedes it are preliminary compromises, attempts at synthesizing lists likely to be acceptable to most Member States. However, no study by outside consultants can substitute for the process of building consensus among those responsible for implementing a regional policy on quality indicators and the measurement of their parameters. We believe it is inappropriate for us, at this stage, to suggest there is only one "best" list.

But note that the EECC entered this debate by proposing its own regional list of QoS parameters, in Annex IX:

For undertakings providing access to a public communications network:

- Supply time for initial connection
- Fault rate per access line
- Fault repair time

For number-based interpersonal communications services:

- Call set up time*
- Bill correctness complaints
- Voice connection quality
- Dropped call ratio
- Unsuccessful call ratio*
- Failure probability
- Call signalling delays

For Internet access services:

- Latency
- Jitter
- Packet loss

* "Member States may decide not to require up-to-date information concerning the performance for these two parameters to be kept if evidence is available to show that performance in these two areas is satisfactory".

Maps Linking Coverage and QoS

Table 3.20 suggests network performance indicators and measurement methods that might be added to the website of the EU's Broadband Mapping Project (SMART 2014/0016).[43] Thus far, the mapping project team has been building and refining the software for their platform, acquiring data to map broadband speeds and coverage throughout the region, and working to overcome dissimilarities among the data sets that were expected to be comparable. For the long term their aim is to go beyond speed and coverage mapping to visualize the geographic distribution of other QoS/QoE data as well. So the Commission requested our recommendations for data sets that the project might develop during their next phase (2018-2020). Our suggestions are summarized in Table 3.20.

[43] https://www.broadbandmapping.eu/.

Table 3.20 Network performance indicators for Broadbandmapping.eu

Metric	Measurement method
Indoor signal strength (outdoor signal strength in areas without buildings)	1) Periodic testing by NRAs at sample points 2) Apps for crowd-sourced measurements
Service availability	1) NRA testing of signal strength over the course of a week 2) Crowd-sourced weekly log 3) MNO reports on MTBF and MTTR
Voice quality	Implement ETSI standards, e.g. ES 202 765-2 V1.1.3 (2010-03) (STQ) with updates
Packet loss	NRA testing at indoor sampling using ETSI standards such as 202-057 (STQ)
Download speed	1) Test downloads by NRA at peak traffic hour 2) crowd-sourced weekly log
Latency	1) Test downloads by NRA at peak traffic hour 2) crowd-sourced weekly log

3.5.3 Are the EU's existing QoS indicators necessary and sufficient?

As Task 4 found, and the EECC confirms, Europe's current inventory of mandated QoS indicators needs modernization. It is skewed toward voice telephony and includes variables whose relevance is already questionable. More importantly, it does not recognize certain themes as part of the QoS agenda that we believe will be of growing importance in the years ahead. In some cases, further development of the relevant standards may be needed before the following claim their rightful place among the parameters subject to regular measurement and reporting requirements:

Resilience/reliability: As noted in Section 3.4.5, Bulgaria, Finland and Sweden have benchmarks for network resilience aimed at reducing the possibility of service disruption caused by bad weather or the loss of mains power. While reliability appears on our comprehensive list of QoS indicators, it does not appear on the lists of widely mandated indicators because most European countries do not have minimum reliability requirements for public networks. International standards exist on this topic (e.g. ITU-T Rec. Y.2614, IEC 60605-6:2007, ENISA, 2011, etc.). Even though risk factors vary geographically (earthquakes may be the main problem in one place, dry season fires in another), relying entirely on national decisions in this field may no longer be sufficient. Uniform minimum standards for continuity of service throughout Europe will be needed as society's dependence on network services grows with the DSM. As the draft EECC notes in Recital 13, "While in the past the focus was mainly on growing bandwidth available overall and to each individual user, other parameters like latency, availability and reliability are becoming increasingly important" (European Commission, 2016).

Energy efficiency and pollution reduction: Telecommunications can reduce greenhouse gas emissions from travel and industry, but the telecom industry's own "carbon footprint" steadily grows. In addition, discarded electronic devices and batteries are a growing source of pollution globally. Equipment standards should take complete product "life cycles" into account.

Network security: Use of new advanced networks will depend on the trust their users put in them for consumer transactions and increasingly all business operations. One major gap in network and systems security is particularly relevant to the next generation of FMC based networks – the move toward software definition of network operation with virtualization of its switching and routing elements. That enables operation of multiple separated services on the same infrastructure. Thus, a densified network may be re-used in many different topologies with multiple performance criteria for multiple types of services. However, the single point of failure introduced into this (the hypervisor) is compounded by the move to multi-tenancy hosting centres, if cloud-based operations are employed. The results might be unauthorized access to medical implants and industrial control systems – recognized as dangers in the proliferation of IoT networks, demonstrating the risks of living in an always-connected world.[44] But the rapporteur of ETSI's Cyber Security Technical Committee, notes there is a need "to converge this mass of standards toward useful, interoperable sets" (Rutkowski, 2017).

Privacy/identity protection: The recent theft of millions of credit histories and other sensitive personal data from an increasing number of commercial organizations (e.g. Equifax) is further proof of the vulnerability of information stored online. Even casual web browsing is being tracked to build profiles while rules enforcing "the right to be forgotten" remain incomplete. The EU's General Data Protection Regulation, due to come into force in 2018, will have great impact but it is time for privacy and identity protection to be recognized as essential parts of network QoS. ETSI TR 103 304 V1.1.1 (2016-07): "CYBER; Personally Identifiable Information (PII) Protection in mobile and cloud services"[45] is a good start.

Health and safety: The biological effects of radio frequency energy are still poorly understood even after a century of widespread human exposure. Unfortunately, ignorance offers no protection, particularly as we move to higher frequency bands where the energy content of signals is greater and molecular resonance effects become significant.[46] Our lack of insight into which exposure situations are safe or risky must end if we want always-on microwave and millimetre-wave radiators to permeate our homes and public spaces. Until we have better answers from research, these standards (among others) provide some basis for regulating exposures:

- Directive 2013/35/EU: on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields)[47]
- Recommendation ITU-T K.52: Guidance on complying with limits for human exposure to electromagnetic fields
- IEEE C95.1–2005: Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.

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[44] Articles 40 and 41 of the draft EECC address these issues but mainly in terms of incident reporting and speed of response.

[45] http://www.etsi.org/deliver/etsi_tr/103300_103399/103304/01.01.01_60/tr_103304v010101p.pdf.

[46] "…although the forces involved are tiny, resonant effects allow THz waves to unzip double-stranded DNA, creating bubbles in the double strand that could significantly interfere with processes such as gene expression and DNA replication… Ordinary resonant effects are not powerful enough to do this kind of damage but nonlinear resonances can. With terahertz scanners already appearing in airports and hospitals, the question that now urgently needs answering is what level of exposure is safe." (MIT Technology Review, 2009).

[47] See also "Guide for Implementing Directive 2013/35/EU on Electromagnetic Fields" (2016), https://www.entsoe.eu/Documents/SDC%20documents/entsoe_EMF_report_web.pdf.

In the future, other gaps in QoS indicators may need filling

Location indicators: All EU Member States check the accuracy of emergency number 112 caller location data from mobile phones, and several future 5G use cases discussed as part of Task 2 require very high locational precision (cooperative ITS and medical tele-presence, for example). The EU's Broadband Mapping project, meanwhile, confirms the importance of common standards for geographic data and shows the need for greater consistency throughout the region. There are also privacy concerns associated with location tracking and disclosure. Since the 2005 release of ISO 19133 (the Geographic Information-Location Based Service-Tracking and Navigation Standard), the number of organizations focussing on these issues has grown rapidly. Including location indicators and standards for their accuracy as QoS parameters for mobile networks in general, not just for calls to emergency services will become necessary in the future.[48]

Efficient sharing and use of spectrum: Commission Communication COM(2012) 478: "Promoting the shared use of radio spectrum resources in the internal market" was a milestone but it has not been fully absorbed yet into ETSI and CEPT's work. Intensification of spectrum use in the next few years will require more – and more efficient and creative – band sharing, as well as more intensive exploitation of bandwidth. Standards for improved sharing and more efficient use of spectrum might be referenced by NRAs in the setting of licence conditions or as norms in license exempt bands.[49]

Levels of new interference sources for dense networks at specific locations: For instance, Wireless power transfer (WPT) will be discussed at WRC-19 under Agenda Item 9.1.6. WPT has recently been identified as a potential new source of interference to radio communications, particularly if the charging of moving vehicles by road-embedded sources develops along with road-side transceiver systems. Hopefully, some policy guidance from WRC-19 may be forthcoming.

Also, in Section 3.4.7, additional gaps in the QoS measurement toolkit for future converged networks were identified by the Korean Telecommunications Technology Association in their description of what they hope to learn from early deployment of 5G. We cite those again here to emphasize the incompleteness of the current set of standards. The gaps the Koreans noted and brought to the ITU's attention are:

- End-to-end measurement rules for bridging fixed and mobile networks;
- Defining QoS indicators for direct mode (terminal-to-terminal) links that bypass base stations;
- Identifying parameters relevant to the management of links between operatorless devices (the Internet of Things);
- The impact of network slicing and virtualization on QoS;

[48] Article 102 para. 5 of the draft EECC says, "Competent regulatory authorities shall lay down criteria for the accuracy and reliability of the caller location information provided" to emergency call-in centres.

[49] Sharing of facilities, infrastructures and radio frequencies is discussed often in the draft EECC, too often to summarize here, but a few statements state out as especially significant: "With growing spectrum demand and new varying applications and technologies which necessitate more flexible access and use of spectrum, Member States should promote the shared use of spectrum… Shared use of spectrum increasingly ensures its effective and efficient use… " (Recital 113) and: "exceptions [to service neutrality] should not result in certain services having exclusive use, but should rather grant them priority so that, in so far as possible, other services or technologies may coexist in the same band" (Recital 109).

- Establishing tolerable levels of jitter and packet loss for new use cases like virtual reality, remote control of driverless vehicles, etc.

3.5.4 Converging the existing EU standards

Tables 3.21 and 3.22 labelled the QoS indicators with brief descriptions meant to be understood by ordinary people. But for implementation, the descriptions might have to be translated into a small set of related measurements. For example, "the time between request for service and the start of service" is relatively clear in meaning, but in practice it would probably be measured separately for fixed voice, mobile voice, fixed broadband and mobile broadband. Similarly, several different measurements of the same parameter might be needed to discover if the *distribution* of values is acceptable: the *average* time between a request and the start of service might be accompanied by measurement of the percentage of service requests not fulfilled within a certain time interval, or the number of times the start of service was re-scheduled.

Thus, in addition to differences in their choice of indicators, Member States often differ in the choice of benchmarks for the same indicator. Table 3.21 shows the different "time targets" set by regulators for restoring interrupted service 95% of the time.

Table 3.21 Member states often differ on benchmark values for the same parameter

Member State	Time targets for fixing faults (95% within time limit unless otherwise noted)	Member State	Time targets for fixing faults (95% within time limit unless otherwise noted)
Austria	24 hours for 90% of faults occurring on weekdays	Hungary	72 hours
		Ireland	4 working days
Belgium	40 hours	Italy	90 hours
Bulgaria	72 hours	Latvia	20 hours
Croatia	24 hours for 80% of faults	Lithuania	48 hours for 80%
Cyprus	72 hours	Slovakia	96 hours
Denmark	84 hours	Spain	48 hours

Source: NRAs' published regulations.

It is hard to know now how willing NRAs would be to modify their benchmarks if they had to agree on a common value. Very likely their willingness would differ from one parameter to another and one country to another. It might also depend on whether a target value was specified by an ETSI standard, or if different methods and values are specified by different standards. We learned from our inventory of indicators that there can be several ETSI standards for measuring the same variable, sometimes in different ways. So part of the problem of a surfeit of QoS indicators is actually a surfeit of standards.

Table 3.22 identifies the standards most frequently cited as the authority or basis for measurements of specific QoS indicators and the indicators they specify. The current version of each standard is cited here, although regulatory instruments often specify versions that have been superseded. Persisting use of older versions of standards is another part of the problem.

Table 3.22 Standards most often cited in EU NRA QoS measurement mandates

Standard reference number	Title	Indicators defined & measurement procedures described
ETSI EG 201 769-1 V1.1.1 (2000-04)	QoS parameter definitions and measurements; Part 1: Parameters for voice telephony service required under the ONP Voice Telephony Directive 98/10/EC	Supply time for initial connection; Fault rate per access line; Fault repair time; Unsuccessful call ratio; Call set up time; Response times for operator services; Response times for directory enquiry services; Proportion of card and coin operated public pay-telephones in working order; Bill correctness complaints
ETSI EG 202 009-2 V1.3.1 (2014-12)	Quality of telecom services; Part 2: User related parameters on a service specific basis	Audio broadcast – Audiostreaming; Directory enquiry services; E-mail; Fax; Internet services; Multimedia Message Service (MMS); Operator Services; Short Message Service (SMS); Telephony; Video broadcast – Video streaming; Voice mail; Voice messaging
ETSI EG 202 057-1 V2.1.1 (2013-01)	User related QoS parameter definitions and measurements; Part 1: General	Supply time for fixed network access; Supply time for Internet access; Proportion of problems with number portability procedures; Fault report rate per fixed access lines; Fault repair time for fixed access lines; Response time for operator services; Response time for directory enquiry services; Response time for admin/billing enquiries; Number of customer complaints per data collection period; Customer complaints resolution time; Bill correctness complaints; Prepaid account credit correctness complaints; Bill presentation quality; Customer relations; Professionalism of help line
ETSI EG 202 057-2 V1.3.2 (2011-04)	User related QoS parameter definitions and measurements; Part 2: Voice telephony, Group 3 fax, modem data services and SMS	Unsuccessful call ratio; Call set up time; Speech connection quality; Fax connection quality; Data rate of dial-up access to the Internet; Short Message Service (SMS) QoS parameters
ETSI EG 202 057-3 V1.1.1 (2005-04)	User related QoS parameter definitions and measurements; Part 3: QoS parameters specific to Public Land Mobile Networks (PLMN)	Unsuccessful call ratio for telephony; Dropped call ratio
ETSI EG 202 057-4 V1.1.1 (2005-10)	User related QoS parameter definitions and measurements; Part 4: Internet access	Login time; Data transmission speed achieved; Unsuccessful data transmission ratio; Successful log-in ratio; Delay (one way transmission time)
ETSI TR 101 578 V1.2.1 (2015-07)	QoS aspects of TCP-based video services like YouTube™	Video IP Service Access Failure Ratio; Video IP Service Access Time; Video Reproduction Start Failure Ratio; Video Reproduction Start Delay; Video Play Start Failure Ratio; Video Play Start Time; IP Service Access Failure Ratio; IP Service Access Time; Video Session Cut-off Ratio; Video Session Time; Impairment Free Video Session Ratio; Video Expected Size; Video Downloaded Size; Video Compression Ratio; Video Transfer Cut-off Ratio; Video Transfer Time; Video Mean User Data Rate; Video Playout Cut-off Ratio; Video Playout Cut-off Time; Video Expected Duration; Video Playout Duration; Video Freeze Occurrences; Accumulated Video Freezing Duration; Video Skip Occurrences; Accumulated Video Skips Duration; Video Maximum Freezing Duration; Video Freezing Impairment Ratio;

		Video Freezing Time Proportion; End-to-End Session Failure Ratio
ETSI TS 102 250-2 V2.2.1 (2011-04)	QoS aspects for popular services in mobile networks; Part 2: Definition of Quality of Service parameters and their computation	[Partial Selection:] Radio Network Unavailability; Network Selection and Registration Failure Ratio; Network Selection and Registration Time; Data Call Access Failure Ratio; Data Call Access Time; DNS Host Name Resolution Time; FTP Setup Time; FTP Session Failure Ratio; FTP Mean Data Rate; FTP Data Transfer Cut-off Ratio; Mobile Broadcast Network Non-Accessibility; Mobile Broadcast Interactivity Response time; Mobile Broadcast Session Cut Off Ratio; Mobile Broadcast Audio Quality; Mobile Broadcast Video Quality; Ping Round Trip Time; Push-to-Talk over Cellular (PoC) Voice Transmission Delay; Streaming Service Non-Accessibility; Streaming Video Quality; Streaming Audio/Video De-Synchronization; Mobile Telephony Service Non-Accessibility; Telephony Setup Time; Telephony Speech Quality; Telephony Cut-off Call Ratio; Video Telephony Service Access Time; Video Telephony Cut-off Call Ratio; Video Telephony speech quality; Video Telephony video quality; HTTP Service Non-Accessibility; HTTP Setup Time; HTTP Mean Data Rate; Web Radio Audio Quality; WLAN Association Failure Ratio; WLAN Association Time; E-mail Login Access Time; E-Mail {Download|Upload} Setup Time; MMS Send Failure Ratio; MMS Retrieval Failure Ratio; MMS Notification Time; SMS Service Non-Accessibility; SMS Completion Failure Ratio; SMS End-to-End Delivery Time
ETSI TS 102 250-3 V2.2.1 (2011-04)	QoS aspects for popular services in mobile networks; Part 3: Typical procedures for Quality of Service measurement equipment	Speech telephony; Video telephony; Group Call; Store-and-forward services; FTP; HTTP: E-mail; Streaming video; Media download
ETSI TS 102 250-4 V1.3.1 (2009-03)	QoS aspects for popular services in GSM and 3G networks; Part 4: Requirements for Quality of Service measurement equipment	General requirement for data logging; Fixed QoS Test-equipment; Mobile QoS Test-equipment
ETSI TS 102 250-5 V2.4.2 (2015-09)	QoS aspects for popular services in mobile networks; Part 5: Definition of typical measurement profiles	Classification of measurement environments; Service profiles; Usage Profiles for Data Sessions
ITU-T Rec. G.107 (06/15)	The E-model: a computational model for use in transmission planning	"…transmission planning tool for assessing the combined effects of variations in several transmission parameters that affect the conversational quality of 3.1 kHz handset telephony"
ITU-T Rec. G.109 (09/99) – Amendment (01/07)	Definition of categories of speech transmission quality	"…defines five categories of end-to-end speech transmission quality for 3.1 kHz handset telephony"
ITU-T Rec. P.862 (02/01)	Perceptual evaluation of speech quality (PESQ): An objective method for end-to-end speech quality assessment of	

	narrow-band telephone networks and speech codecs	
ITU-T Rec. P.863 (09/14)	Perceptual objective listening quality assessment	
ITU-T Rec. Y.1540 (07/16)	Internet protocol data communication service - IP packet transfer and availability performance parameters	"Internet protocol aspects – Quality of service and network performance"
ITU-T Rec. Y.1541 (12/11)	Network performance objectives for IP-based services	"…defines classes of network quality of service (QoS) with objectives for Internet Protocol network performance parameters... These classes are intended to be the basis for agreements among network providers, and between end users and their network providers".

Sources: NRA documentation.

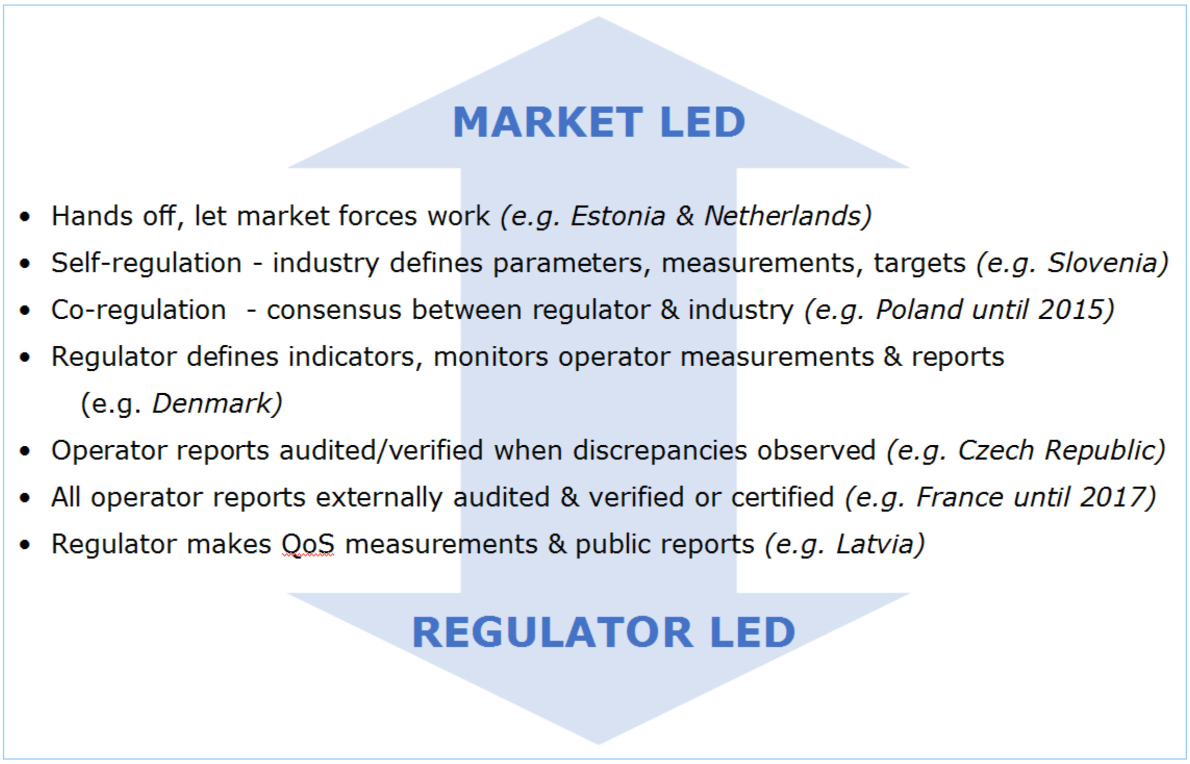
3.5.5 Toward a Common Set of NP/QoS/QoE Indicators

Since virtually all EU Member States rely on ETSI standards and definitions, the differences among them in implementing QoS measurement obligations is more than a little surprising. To some extent this may be due to differences in language, as discussed in Section 3.4.6. That may seem farfetched, but we found instances where language differences were large enough that we could not be sure if we were dealing with the same or different indicators.

Therefore, a small but practical suggestion for moving toward a common European set of indicators is to have ETSI adopt a consistent numbering system for the indicators they define and ask the Member States to keep the number with the indicator's definition when translating it into the local language. That would remove any doubt about whether two indicators are the same or different. ETSI already numbers their standards documents, but one document might contain dozens of different indicators (ETSI TS 102 250-2, for example). Some Member States respond to the need for a finer-grain, language independent reference system by citing the section or paragraph number containing the indicator's definition. This can work but only if used consistently.

Our inventory of Europe's NP/QoS/QoE indicators revealed substantial diversity among the Member States. A simple measure of this diversity is the number of QoS indicators that must be regularly measured and reported - it varies from 7 to 74. That variance reflects more than a language difference. It might be described as a difference in philosophy, or attitude, with some countries apparently believing that regulators should lead the economy's evolution while others believe the market should lead (see Figure 3.22).

Figure 3.22 Differences in attitude toward market regulation



These different perspectives or economic attitudes may be the biggest obstacle to converging on a common approach to measuring network performance and user experience. It is unlikely that any particular set of proposed indicators could erase the differences, although negotiations might narrow them in practice, particularly regarding the details of measurement methods, benchmark values and reporting cycles.

3.5.6 A European Expert Group on a Common Set of QoS Indicators

Given the large number indicator/parameter measurement options, a regional discussion moving toward a consensus decision about which indicators to adopt as a common core set seems appropriate. We envision a Europe-wide work group, like BEREC's "Net Neutrality Expert Working Group" (or COCOM's "Expert Group on Emergency Access") taking "ownership" of the task. They would meet regularly – and/or use online file exchanges – to sort through the list of options and gradually identify the ones with the most support and clearest value. The process should be open to everyone interested. Specific methods of measurement would be proposed that Member States would be "encouraged" to implement (like COCOM's 112 KPIs). If something stronger than "encouragement" is needed, the short list of indicators and measurement methods could be the subject of an EU Regulation. The current diversity in implementing measurements of QoS is directly attributable to subsidiarity, resulting from the use of Directives to foster the use of QoS indicators. Directives do not impose commonality on the form or method of implementation. This is compatible with the very brief sketch of the process in EECC Article 97 and is discussed in more depth under the rubric of Task 6.

3.5.7 Summary

It is necessary to modernize and rationalize the Member States' choices of NP/QoS/QoE parameters and indicators and move toward greater commonality in purpose and methods of measurement. Despite the current diversity, we believe a process of convergence can succeed, though it may not be quick. Consensus needs time to develop and just as importantly, standards are still emerging in thematic areas of great relevance, like network resilience and reliability, privacy and identity protection, spectrum sharing and efficient use of bandwidth and power. ETSI and BEREC will be central to the process, supplying institutional legitimacy, focus and expertise.

Task 5 Bibliography

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3.6 Task 6: Key Quality Indicators for Monitoring Network Performance and Reliability

3.6.1 The Need for Coherent Quality Indicators in the DSM

In this task, the aim is to examine the way forward following analysis of the current status of quality of service, coverage and expected future network developments. In the Digital Single Market (DSM), social and economic dependency on network access will be a dominant theme in everyday life. Large capital expenditure is forecast to underpin the DSM, in ubiquitous high speed broadband fixed and mobile networks. Increased take-up of networking as a pillar of the European economy will depend on its reliability, security and respect for privacy. So, effective standards in these areas are called for, to be well monitored and enforced. That effort is justified by the fundamental economic and social dependency on networking operation that is expected.

There is therefore a need for NRAs to have suitable indicators, which match the vital significance of service and network availability for always and everywhere, by observing the quality perceived by the end user. End users will also need such indicators to identify the best suppliers to meet their needs in the EU's highly competitive communications market.

In consequence, an analysis of the developments required and the organization of the implementation needed to achieve this are briefly laid out. This includes the form of the indicators needed in terms of level, subject and composition, as well as the framework for their implementation.

3.6.2 Migrating to Quality in Telecommunications

Following our analysis, we propose a policy framework with 12 specific elements to introduce quality indicators for NRAs and other stakeholders, including the user community and service providers. The overall aim is to ensure the operating excellence of EU communications networks, both mobile and fixed, with converged forms, through management of the quality measurements and their monitoring. These measures will be required for a reliable, suitably performing and trusted set of services to underpin the DSM for Europe's citizens. The approach taken here is that the goal for NRAs, and also administrations and the end-users, is to support rapid understanding and comparisons of the actual quality of communications through accurate and up-to-date simple indicators, where possible with real time measurements.

All network QoS activities should not just be aimed at today's needs but also take into account the future. Indicators will converge for fixed and mobile towards web and Internet working with a packet based infrastructure. Much of that will be IP-based (but perhaps not for all IoT networks, which could be quite different) and increasingly so, if IPTV expands further, especially for streaming and non-linear viewing. Thus, IP traffic will reach across access networks, core and backbone networks, including the transit networks for long distance and international working. Two main classes of service can be envisaged for the future:

- QoS-enabled, i.e. managed quality services - generally from the EU operators (which are guaranteed but only within fairly variable limits today, particularly for mobile)

- OTT (Over-The-Top) services, which today are provided in a best-effort mode, without end-to-end QoS, often based on network neutrality principles. In the future, they could possibly become managed services with guaranteed QoS.[50]

Note that QoS is today moving from its initial definitions for circuit switched networks, to prevent service degradation by SMP operators and targeted to traditional telecommunication networks (i.e. PSTN/ISDN/GSM and broadcast networks) to today's QoS for IP networks and services (e.g. for NGN and LTE/LTE-A, with Wi-Fi and soon 5G).

According to the ITU (2015b) there are four possible elements in a regulator's approach to QoS:

- Obtaining enough accurate information on the level of QoS actually implemented in a network and enough to identify any problem areas. This is essential, since without appropriate information the actions required cannot be taken.
- Pursuing constructive interaction with the operator to encourage and foster improvement.
- Imposing enforcement regulations for performance, e.g. required minimum levels with fines and/or compensation for end-users, if required.
- Publishing information on QoS performance to inform customers on quality levels and most importantly, to enable service comparisons for an efficient, competitive market.

The measures necessary for NRAs to assure quality are now considered in further detail, especially on what constitutes quality for end users, based on multiple measures, as well as for NRAs, operators, service developers and equipment and software suppliers. The concept of a compound indicator made up of multiple QoS indicators for multiple networks is considered. This anticipates tomorrow's converged networks, especially for 5G where complex heterogeneous networks may be linked together in dynamic configurations.

The 12 elements in the proposed policy framework are:

1. Redefining the main indicators of network quality
2. Indicators should enable comparisons of services and equipment and also the possibility of replacement of best effort Internet service with guaranteed QoS
3. A meticulous selection process will be needed to assemble the new quality indicators
4. For networks of mobile converged with fixed, compound sets of standards are needed – so KPIs become KQIs
5. Measurement criteria incorporated in KQIs should include those critical parameters for a modern networked society, selected by an expert group
6. NRAs should have their own facilities for monitoring quality
7. KQIs may need to be enforced in the future by a detailed (i.e. bottom-up) approach
8. A roadmap is needed for a phased introduction of more advanced indicators, KQIs
9. Measurement methods for quality parameters and benchmark values for parameters linked to KQIs
10. A public database of KQI measurements by operator and location is needed, EU-wide

[50] The ITU SG-12 group on quality standards has a current work item on OTT: G.ACP: Guidelines regarding the minimum QoS and QoE threshold to be fulfilled during the use of alternative calling procedures ("OTT"). The addition of delivery guarantees for virtual circuits has been the subject of development for some time, e.g. Pujolle (2000).

11. Extension of the NRA remit for the 5G world – KQIs for vertical applications
12. Implementation at an administrative level – through EU Regulation for introduction and for compliance enforcement

1. Redefining the main indicators of network quality

In examining network quality in terms of future optimal indicators it is useful to recall the definitions used currently defining on the measures of quality, following the ITU-T E.800 series:[51]

- NP – the performance of a network in terms of several core parameters
- QoS – The network end-to-end quality that covers only the networks involved up to the user network interface (UNI)
- QoE - the extended quality as perceived by the end user, i.e. beyond that assessed by the operator - which is *limited to networks managed by that operator*, not other networks (although interconnection agreements between operators include QoS specifications for relevant parameters and the accepted in-service levels, (ITU, 2015b)

There are algorithms and models already defined for QoS and QoE, e.g. in ITU-REC - G.1011 (07/16) resulting from field trials and statistical studies relating QoE to QoS. Generally, the QoS and QoE results have been found to be:

- Quite service specific
- Technology specific – and so are determined by the network technology and corresponding services for QoS and QoE algorithms.

These constraints limit their use across many (converged) networks.

To meet the goals of end-user satisfaction, rather than of operator compliance with quality targets for offered services at the network extremities, key indicators will need to move up from being internal, network oriented for the service provider to being external, i.e. user oriented end to end, as user to user (which include M2M for machines for IoT networking), to support future society's network dependence (as considered in ITU-T REC - Y.1541, Network QoS Objectives, for IP Based Services). For QoE measurement, the service termination point (STP) may be within the user's premises, as shown Figure 3.23.[52]

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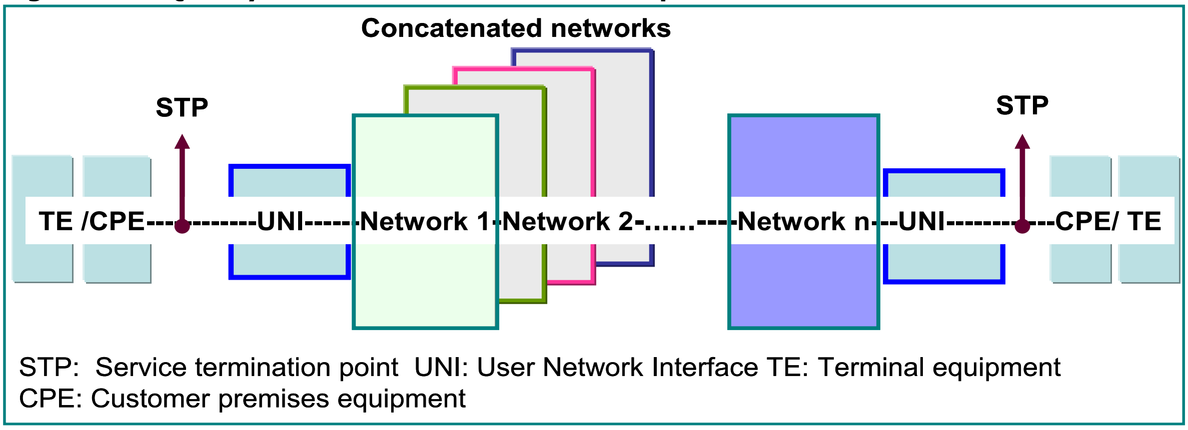
[51] Both ETSI and the ITU have relevant definitions such as the series ITU E800-899 – Quality of Communication Services: Concepts, Models, Objectives and Dependability Planning; with recent additions for example E.802 Framework and Methodologies for the Determination and Application of QoS parameters; E.804, Quality of service aspects for popular services in mobile networks.

[52] That includes connection to the customer CPE for the customer's network, i.e. to the end-user or at least up to the user's network interface (UNI) that connects the CPE to the network. Although the service provider determines the performance of the service, the user's premises network will have an impact on the QoE observed, an effect which may be determined from differential measurements, comparing measurements across the premises network infrastructure.

Figure 3.23 Quality for the end user across multiple networks



Source: ITU Rec Y1541.

For closer assessment of user satisfaction, the network indicators based on technical performance may need to move towards QoE for a future dependent networked society, even though they may be summed from the basic parameters for NP and QoS. That will include multiple network impacts, for example IP packet delay variations (IPDV) across multiple networks. 'Experience' for the IoT, for M2M, still relies on monitoring the crucial parameters.

For QoS – the differences between QoS *perceived* by the end user and QoS that is *required* by the end user define the quality of experience, QoE, under the ETSI and ITU-T QoS model, largely from ITU Study Group-12. Also, when examining QoE versus QoS, satisfactory QoE varies by application, for example, acceptable email quality will not be the same as a two-way HD video for telesurgery or business teleconferencing in terms of acceptable ranges of the dependent parameters. The differences among QoE, NP and QoS are summarized in Table 3.23.

Table 3.23 QIs have different targets, attributes, parameters and measurements

Indicator type	Quality of Experience (QoE)	Quality of Service (QoS)	Network Performance (NP)
Target user group	User oriented		Service provider oriented
Attributes used to measure quality	User perception/ behaviour attributes	Service attributes	Network connection attributes
Focus of measurement parameters	Focus on user experience	Focus on observed effects during service use	Focus on network design, operations, maintenance
Measurement points	Measure overall user perception of quality of use	Measure quality between service access points	Measure between network elements end to end

Sources: Authors, based on Janevski, 2015.

QoE also includes qualitative terms that refer to the user satisfaction from the service offered as well as the user attraction of the service. Such definitions are given in ITU-T Recommendation G.1000 (2001), which offers a general QoS framework and specifies seven QoS criteria for networks:

- Speed (for all services and functions)
- Accuracy (e.g. speech quality, call success ratio, etc.)
- Availability (e.g. coverage, service availability, etc.)
- Reliability (e.g. dropped calls ratio, number of billing complaints, etc.)
- Security (e.g. identity theft, financial fraud prevention)

- Simplicity (e.g. ease of use of services, ease of service activation)
- Flexibility (e.g. interfacing to other operators, networks, gateways, etc.).

It is also important for NRAs, to monitor quality at the level of the customer interface with the operator, for the customer care services function. Using the above variables, these may include:

- Speed (e.g. for download/upload, advertised and contracted for vs actually experienced)
- Accuracy (e.g. bill correctness)
- Availability (e.g. call centre waiting time for customer care, complaint handling rate, etc.)
- Reliability (e.g. number of billing complaints, customer service satisfaction rate, etc.)
- Security (e.g. protection levels of customer details, blocking stolen mobile handset rate)
- Simplicity (e.g. ease of contract termination and number portability; software updates)
- Flexibility (e.g. ease of change in contract, choice of billing methods: online billing etc.)

But the latter are contractual, operational parameters, rather than physical performance.

2. *Indicators should enable comparisons of services and equipment and also replacement of best effort Internet service with guaranteed QoS*

All the above indicators can be used to compare connectivity quality, service quality and operator customer care quality. Note also that such indicators should all move from being circuit switched (PSTN) to being IP-based packet switching. Measurements should be localized and pinpoint specific user conditions as far as possible, e.g. indoors as well as outdoors, rural as well as urban, time of day and day in week, with trend indicators over time.

The QoS framework however has a major challenge that until now has not been suitably addressed, as administrations have perhaps found it too complex. However, with the advent of the DSM, a culmination of the forces of stronger network dependencies may compel a policy revision, as the future network infrastructures would need critical QoS-enabled Internet support for mobile and also for fixed broadband over NGN. That might progressively displace traditional best-effort Internet conditions that lack QoS enforcement, due to the operational framework being inherited from previous IETF guidelines. If so, the scope of QoS might be to cover two possible areas where QoS parameters apply. Both will need regulation on the QoS levels required:

- QoS regulation between operators and end-users.
- QoS regulation between EU operators via national or international interconnections

Note that interconnected networks pose especially difficult problems. For instance, QoS end to end may have to work across different implementations of levels of packet control and levels of supervision because diverse implementations of networks have been put into operation. There will also be different types of provisioning (e.g. IntServ, DiffServ, MPLS-TE and OTA over-provisioning for mobile).

A major issue here is that although the Internet is usually described as a "best effort" system, unable to guarantee service quality, this misrepresents the underlying situation.

IP packet headers have always had 'type of service' and 'precedence' markers, although the routers and packet switches relaying the packets may often have ignored those bits. So other network layers came into wide use – for Ethernet, for instance, and other solutions created by the IEEE because the need has long been recognized for good traffic management to maximize network performance. The EU has funded many projects in this field and BEREC has recognized the need to integrate QoS with net neutrality. A widely shared goal among those working on such topics is to have QoS guarantees built in to the infrastructure so changes in Internet governance are not needed.[53]

3. A meticulous selection process will be needed to assemble the new quality indicators from the various component QoS/QoE indicators

The concept of a composite or compound or 'higher level' indicator made up of multiple QoS indicators is a potential approach for better comprehension of overall quality in a complex multi-network environment, introduced for NGNs (ITU,2017). It is being actively studied by SDOs as networking quality has already become intensely detailed at the sensing level and in the future will be more so. More practical quality indicators that can be more easily assimilated would combine multiple networking parameters, pragmatically and this has begun to be explored in the international standards fora[54]. The concept implies producing a combined or compound indicator that offers a measure of overall quality. Such a summation should also have advantages of simplicity of comprehension, not just for regulators comparing the status of a network clearly, but for the public when quality measures are published. Multiple measures would be combined for a 'composite parameter' that integrate several parameters. Examples may be:

- Reliability parameters: MTBF, MTTR
- Availability: temporal availability (% of uptime) x geographic availability (in terms of coverage)
- QoE for audio: measured level of perceived voice quality
- QoE for video: measured level of perceived video and image quality.

There could also be further simplifications in the above, for instance, by combining availability with reliability. That would form a more comprehensive assessment of reliability. One of the undecided options for such indicators is whether its components should be weighted to emphasize a particular component more, e.g. for the reliability indicator, MTBF might be positively weighted, to emphasize frequency of failure.

As already used across the MS[55], quality indicators may consist of several QoS parameters amalgamated for better insights into the overall quality of communications. There are significant inter-relationship between different QoS parameters and some QoS parameters

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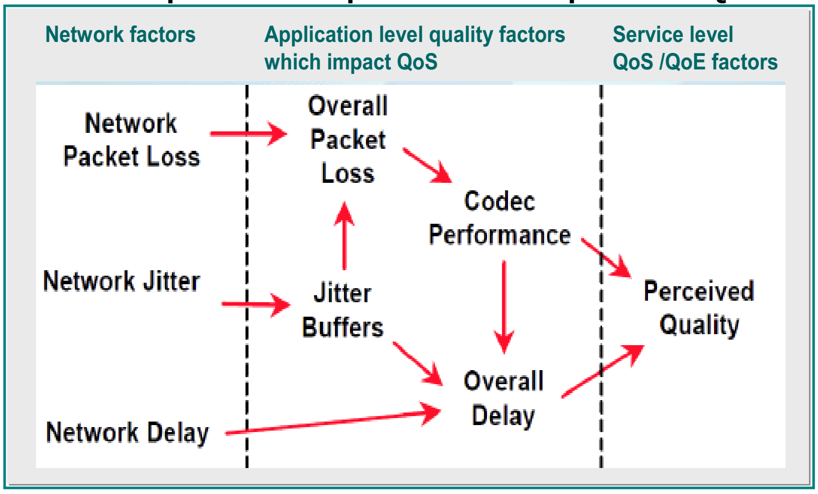
[53] Examples here include Project NETQOS: Policy-based Management of Heterogeneous Networks for Guaranteed QoS (FP6 funded project, 2006-2009) - http://cordis.europa.eu/pub/fp7/ict/docs/fire/projects-netqos_en.pdf; IETF, "RFC 7222: Quality of Service Option for Proxy Mobile IPv6" (May 2014), https://tools.ietf.org/html/rfc7222; and ITU-T Recommendation Y.2617 (06/2016), "Next Generation Networks – Packet-based Networks: Quality of service guaranteed mechanisms and performance model for public packet telecommunication data networks", https://www.itu.int/rec/T-REC-Y.2617-201606-I/en.

[54] There are several relevant standards, principally from the ITU, ITU-T REC-Y.1545: Roadmap for the Quality of Service of Interconnected Networks That Use the Internet Protocol. Also ITU-T REC-Y.1546 Hand-over performance among multiple access networks.

[55] This integration of parameters is already fairly common in the EU, as noted in the previous analysis of the existing QOS situation across the EU MS, for instance Italy and Hungary integrate many parameters into a single composite indicator.

specifying network factors may be applied to application factors. QoS parameters have inter-relationship such as those shown in Figure 3.24.

Figure 3.24 Network performance parameters and perceived QoE



Source: Authors, based on Janevski, 2015.

Similarly, some quality parameters for applications, such as those for multimedia, may also be applied to service level QoS parameters which may lead on to QoE measurements.

4. For future converged networks, compound sets of standards are needed

Following choice of the elemental parameters and target levels to be integrated, choosing how they are combined is the next concern. An EU-wide consensus-building effort for composite indicator standardization may be needed. It would involve the relevant SDOs, led by the NRAs, to form an expert group with other stakeholders, along the lines of the COCOM or BEREC expert working groups (ECC, 2017). The form of combination will be equally as challenging as the choice of component parameters, because there are many approaches to combining elements into a higher order indicator, including:

- Simple aggregation by summation as linear addition
- Proportional, i.e. multiplication products using proportions of the maximum expected value of parameters (e.g. temporal availability as a percentage, multiplied by one of the choices for geographic coverage, as a percentage, for the reliability parameter example above)
- Weighted – a weighting factor multiplies each parameter according to its perceived impact
- A layered model with different levels of significance of parameters, in layers with weighting by layer and perhaps within layers
- Multiple cross correlations – more complicated but more accurate, as many parameters have a non-linear effect on the overall quality indicator. For instance, a signal level at its low end of the range (so it is just viable) and at the very high end may not have a linear relationship with the perceived quality indicator, so this would be adjusted for (Moroney, 1951).

Currently the ITU under its network quality initiative in SG-12 (Question 12) is considering a form for a whole statistical framework for qualifying and quantifying quality differences from the QoE perspectives of users. This framework[56] will be needed by NRAs, operators and the equipment/software suppliers. But the statistical approach to multi-criteria QoE/QoS is still in evolution in the SDOs, for example for its weighting factors, and whether they can be fixed or should be left open, as any fixed standardization of weights could be quickly outdated.

Consequently, at this point it may be useful to add the term key quality indicator, KQI (as also suggested in the RSPG Second Opinion on 5G Networks), which is defined as a multiple or compound set of QoS standards with QoE parameters and associated measurement methods with benchmark values, possibly using weighting. We such as indicator, we emphasize the difference between performance (the extremes of functioning of some machine, e.g. speed, latency) and actual quality (in terms of excellence and superiority for the end–users, especially for consistency and reliability - and hence guaranteed performance).

This anticipates future converged networks, particularly 5G, where complex heterogeneous networks may be interconnected in sequence in a dynamic manner i.e. it can change with each session or call. A compound KQI indicator should combine the KPIs used today for a single network – either mobile or fixed – while also integrating several lower level parameters into a higher order indicator. Moreover, future networks (as explained in Task 5) may have to take on new quality parameters of a socio-economic nature – e.g. security and privacy, for both converged networks end to end, e.g. mobile into fixed long distance into fixed local loop over xDSL or a cable TV access network with CPE (ITU, 2013) which might include Wi-Fi, as much as single networks, mobile or fixed wireline.

The jurisdiction for KQIs would be for the whole EU rather than national and thus would be aimed more towards Regional quality indicators. This approach is already used by COCOM, the body that rules on emergency telephone numbers, which has adopted regional KPIs for the emergency call number 112. It has also been continually reviewing its parameter list for these KPIs to refine them and has been surveying Member States in order to enforce 112 calling implementation since 2008.

Much of the standards effort in the SDOs (particularly the ITU and ETSI) are also aimed at the customer interface with the operator. The objectives are to set standards for customer care, in terms of mean time to respond to network faults, errors in billing and service activation, and so on, as well the overall rate of curing customer issues, for instance those logged by trouble ticketing in call centres. Here, again, QoE becomes a more significant quality measure than QoS. Note that customer service quality is critical for service provider survival, as much as for customer satisfaction. However, it is unlikely that a move to KQIs can be achieved in a single step – a phased approach is more likely to succeed for this more complex indicator, to gain acceptance, then to build its infrastructure and secure EU-wide take-up.

5. Measurement criteria incorporated in KQIs should include those critical parameters for a modern networked society, using an expert group

For the use of NRAs, a large number of potential candidates exist for parameters, specified largely by the main SDOs – the ITU, ETSI, IETF, etc. (see Task 5). But for a policy level

[56] The ITU have proposed a statistical framework (under consideration and not yet public) "A Proposed Statistical Framework for QoE Centric Benchmarking Scoring and Ranking", 20 December 2016, to be based on ITU-T Recommendations P.1401 and E.804.

choice, a higher level of description is needed. At this overview level, key technical network parameters for KQI would include measurements at:

- Channel level, e.g. the physical signal quality, for single and multiple interconnected networks (e.g. as in the ITU Y series of recommendations from SG-12)
- Session and call level, e.g. successful rate of access to services/calls and rate of dropped sessions/calls, also measured as a call retention level or failed attempts rate
- Multimedia application level, e.g. video quality, voice quality (as in ITU-T P.800-899 series and in ETSI standards for mobile voice and video quality).

The parameters above have multiple sub-components of quality, each being a more detailed parameter. For example, signal quality, can be measured by the received power level, as that has direct impacts on communications quality, confirmed through measurements of more detailed performance parameters. For instance, signal quality may be assessed from:

- IP packet error ratio (IPER) UNI to UNI across n networks
- IP packet loss ratio (IPLR) UNI to UNI across n networks
- Average IP quality performance over the day in terms of speeds, BER, delay and IPLR
- Delay and delay variation (i.e. standard deviation) across n networks over the day

For consistency and end-to-end levels of quality, generic classes of quality assessment would cover multiple types of networks, each with their own QoS target levels. These types of networks might range from long distance NGN networks to mobile networks of all kinds, as well as home networks[57] forming a chain of interconnected networks[58]. Today's quality parameters should start by including:

- Reliability and availability
- QoS (user perspective) – and user complaints could be collected to compare quality.
- Network performance (operator internal perspective)

Additionally, for society's increasing dependence on networks for the DSM, extra parameters will be needed. These are at the level of what might be termed socio-economic external factors, and are becoming critical. They are:

- Security
- Privacy
- Health and safety (especially with millimetric bands for 5G)
- Accessibility for all
- Energy efficiency

To be more exact as to their precise scope, each may be expanded into greater detail. For example, reliability might be integrated with availability. But each of those can also be broken down into several QoS parameters and network performance parameters to provide a more exhaustive analysis. These component parameters and their standards

[57] As analysed in, for instance, ITU Rec Y.1565, Home Network Performance Parameters.

[58] Consideration of multiple network QoS parameters in aggregated forms are already progressing, e.g. ITU-T Y.1566, Quality of service mapping and interconnection between Ethernet, Internet protocol and multiprotocol label switching networks, from SG-12.

may not be static, but instead, likely to evolve with development of new technologies and their respective standards.

For EU-wide acceptance these indicators would need to be agreed at EU and Regional level, as well as internationally, eventually. While the role of this study is to give the main quality indicators, the component parameters of each are most likely to evolve with time. Hence all component parameters, measurement methods, benchmark values and standards would need to be agreed at EU and Regional level (and perhaps internationally). For instance, in the future, reliability as a main indicator might be expanded to include further parameters of resilience such as:

- Autonomy measures for loss of primary power (i.e. duration of backup power systems which today may be minutes for many mobile base stations) to equate to the constant power provided over traditional copper wireline local loops, powered from the exchange.
- Diverse routing measures – e.g. presence of alternative back-up signal paths with diverse routing for wireline and radio networks using adaptive, self-optimising SON strategies.

Suggestions for key quality indicators and their parameters are shown in Table 3.24, with the output expected from the indicator in terms of the attribute measured by the KQI.

Table 3.24 Suggested parameters for each prospective KQI

KQI	Metrics Parameters	Measurement Method
Reliability	• Availability – temporal and geographic coverage for a given signal level; • Effective coverage i.e. signal strength at local loop extremity; • Resilience	• Compound measurements of service interruptions/availability, MTBF, MTTR, time/location variations of signal level, signal quality, media and session quality. • Monitor signal level over time for MTBF, MTTR by NRA and /or end-users (App) • Indoor monitoring for effects of attenuation by rain/foliage/ ferro-concrete/wall insulation; • Examine resilience measures in place - (power backup, diverse routing etc.)
Channel quality and signal quality	• Signal Strength (indoors/ outdoors) and variations; • Packet loss rate, jitter, latency and latency variance, acceptance rate of false packets • Data transport: Bit rate (D/L- U/L speed) i.e. effective bandwidth; Volume/capacity, number of parallel user sessions.	• Indoor and outdoor monitoring as for reliability availability • Minimum received signal strength relative to that level the regulator determines is needed for service availability. For LTE, measure RSRP. For latency and jitter, measure RTT
Session quality	• Internet Access success rate; WWW access and performance • Set–up delay; blocking probability • Call success rate for voice calls • Access retention rate for IAS and voice calls.	• Test for access with all metrics parameters: 1) NRA testing on remote indoor sites 2) App for crowdsourced measures
Media quality	• Voice quality perceived (ETSI/ITU, etc. definitions) • Video quality perceived (ETSI/ITU, etc. definitions)	• Measure quality using ETSI and ITU methods: ETSI TR 101 578 V1.1.1 (2013-12): QoS Aspects of TCP-Based Video; ETSI ES 202 765-4 V1.2.1 (2014-05): QoS and network performance metrics and measurement methods; Part 4: Indicators for supervision of Multiplay
Privacy	• Digital privacy definitions (e.g. the "right to be forgotten" - GDPR) and for ownership of personal data • Privacy by default • Data control - by citizen of data collection and use	• Examine privacy measures implemented by service providers • Examine compliance to GDPR • Test for privacy by default • Test for data control by citizens and consent mechanisms

	• Active countermeasures: device protection; appropriate encryption; access control (e.g. passwords)	• ISO/IEC 27552: Personal information/Privacy Management System Requirements (under development). Regulation proposal on ENISA for certification* • KPI from METIS (2015), p. 17, Identity/location of communicator is not discoverable
Security	• Public, open EU-level standards in NIS are generally lacking today. A range of EU and international standards apply but there are gaps, especially for IoT security. Compliance to security standards is fragmented across the EU; • Certification of NIS services/products to provide EU level approval is lacking but national schemes exist. For future, use EU-wide certification metrics when available - as proposed in ENISA Regulation,17 Sep 2017, and certification under the 'Cybersecurity Act' (2017) as part of the EU Cybersecurity Certification Framework (2017)	• Assure certified countermeasures • Apply "security by design" (as required under GPDR) • Assure a security framework under ISO 27001 is in place • Test for known vulnerabilities and add countermeasures, especially for SDN/ NFV hypervisor for small cell networks and its slicing as single point of failure • Examine cloud SLAs & ensure compliance • Also ENISA (2009), Cloud Computing: Benefits, Risks and Recommendations for information security - http://www.enisa.europa.eu/act/rm/files/deliverables/cloud-computing-risk-assessment.
Inclusion and accessibility	• EU standards are lacking apart from Standardisation Mandate 376 but some MS have initiatives, perhaps under Universal Service Obligations with specific metrics; • Coverage obligations become critical for such groups; • Metrics are set by specific needs of each group; • Digital literacy campaigns form part of the needs and have their own metrics	• Measurement methods should be set by stakeholder groups for each disability • A key EU reference is the EDF (European Disability Forum)
Health and Safety – EMF, Millimetric RF	• General limits for manufacturers (IEC and EU) • Specific safety limits from medical authorities (e.g. SCENIHR, 2015): • Specific Absorption Rate (SAR) – defined as the RF power absorbed per unit of mass of an object, measured in watts per kilogram (W/kg) per gm of body mass.	▪ Defined procedures from EU medical safety authorities e.g. Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) Opinion on Potential health effects of exposure to electromagnetic fields (EMF), 2015 01 20; also IEEE Standard C95.1-2005 for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz
Energy efficiency and sustainability	• Power Consumption and pollution effects • Emission levels for GHG (ETSI, ITU, IEC, GSMA) • 3) Broadband network energy efficiency • Recycling and pollution assessment parameters	• Defined procedures from SDOs and EU ICT sustainability centres of expertise for power consumption & recycling, e.g.: 1) Clauses 6 and 7 ("Measurement of energy efficiency" and "Extrapolation for overall networks") in ETSI ES 203 228. See also Boldi, 2017, Chapter 8 ("Proposed metrics for 5G energy efficiency"); 2) ETSI TR 103 476 (Circular Economy in ICT). Directive 2012/19/EU gives rules and principles for the treatment of waste electronic equipment, as well as minimum targets for recycling and recovery by 2018. For mobile phones, see UL 110 (Standard for Sustainability for Mobile Phones, 2nd ed., 2017); IEEE 1680.1 "Standard for Environmental and Social Responsibility Assessment; ITU-T Recommendation L-1410 (2014), "Methodology for environmental life cycle assessments of ICT goods, networks and services; 3) See Clause 7.19 of 3GPP TR 38.913 V14.3.0 (2017-06) - http://www.3gpp.org/ftp/Specs/archive/38_ser

	ies/38.913/38913-e30.zip - last 2 scenarios (urban and rural) to be simulated for evaluation for range of traffic load levels. Also see ETSI Green Abstraction Layer, GAL : ES 2003- 237, (2014)

While the present study can examine the current state of quality control for networking and suggest systems of indicators, the final selection of parameters must be a far more detailed analysis that has industry agreement. The European expert group on quality indicators and their parameters mentioned in the previous step should be responsible for detailing and final selection of the indicators in the table with their definitions, parameters, standards and operating ranges. Members of such a group would be drawn from four main communities: NRAs, most probably co-ordinated by BEREC, the telecommunications equipment and software suppliers, communications operators and service providers of all kinds, the SDOs and also the user groups for business (e.g. INTUG) and European consumers' organizations (e.g. BEUC). Special interest groups (e.g. for accessibility, health and safety as well as sustainability) should be participants, both from government and NGOs. Following the views of the EU, BEREC could be the appropriate leading organizer, and the EU, via appropriate units from DG CONNECT would give support. Such a group could produce the common identifiers from the relevant standards by frequent regular meetings to decide on indicators. The scope of the group would be to cover all the concerns of the future networked society and economy for network quality through minimum acceptable levels, or benchmarks, for each parameter, then combined to form the relevant KQIs in agreed summation forms. Its organization, being at EU level, might be under the sponsorship of the Commission.

6. NRAs should have their own facilities for monitoring quality

In order to monitor network reality by verifying operators' delivery of quality, NRAs may need their own facilities for measuring quality in the future. Facilities with embedded instrumentation of networks might be set up for each NRA. Alternatively, there might be consideration of an EU level measurement platform, shared among all NRAs. That would also bring coherence and harmonization to parameters, measurement methods and data formats. [59]

Either approach would require additions to NRA budgets. Consequently, the cost to NRAs of the measurement process becomes a deciding factor in choices of parameters and methods. Here, funding for such a platform will be needed. One possibility could be central funding by the Commission of an initiative under a body such as BEREC, to seed the initiatives to ensure new networking quality levels in all MS for the next generation of small cell dense networks. BEREC's 2018 work programme includes a measurement tool that could be used (BEREC, 2017). Increasing dependence on networks, as envisaged for the future, signifies that network failure will be far more serious, justifying this expenditure. The need for monitoring is equally true for the socio-economic factors such as security, or health and safety, as for the performance parameters such as packet loss rate.

[59] There are already initiatives in this area. BEREC has proposed an EU-wide tool for net neutrality measurement for NRAs. There is also work from the IETF, examining agent-based network monitoring and management schemes for large scale measurement platform implementations (IETF 8193, 8194). In a parallel initiative, ETSI is considering a reference model for NFV management and orchestration ('MANO') across multiple networks and NFV use cases which could be used to manage data acquisition for such a platform (ETSI GR NFV 001 V1.2.1 (2017-5) May 2017, NFV Use Cases).

Monitoring approaches could be of several types but two principle forms stand out: first, embedded monitoring via network agents and, second, end-user measurements and reporting. To guarantee an accurate real time status of the network infrastructure, there should be multiple sources of measurement, which are independent of the service provider and wholesale operator and equipment vendors:

- Measurements directly by the NRA – internal, or third party under contract for field testing
- Network agents that can report network status to NRAs (following IETF RFC 8193/8194)
- End user apps with 24-hour polling and monitoring with reporting, which may be shared with MNOs or fixed line network operators. It will need large volume (possibly cloud-based) databases.

To provide an end to end picture, this would need quality reporting across networks, with aggregating monitoring tools that report network performance (NP) across the whole of the various different operator domains. To summarize across multiple networks, concatenation of reports, for the NRA would be needed. This should also include interconnection quality across multiple Member States for international EU calls. Data may come from actual calls or 'ping' type testing, monitored directly by the NRA, together with source data from the operator (MNO/FNO/ service provider). Thus, for comparison purposes, inputs from the providers should be offered, based on the service providers' measurements of QoS and wholesale operator measurements of NP.

7. KQIs may need to be enforced in the future by a detailed approach

Enforcement for KQIs, across all of the EU, promises to be a major challenge. To be effective, it may need to be at the level of analysis of its component parameters, for QoE and QoS i.e. bottom-up. Effective enforcement relies on reports at regular intervals (for instance monthly or quarterly) eventually in a later stage becoming real time, perhaps and publicly displayed, using inputs processed from multiple sources to compare results across service providers:

- NRA or NRA-employed third party specialist testers for all offerings
- End-users tracking using downloaded software tools

Enforcement may need the NRAs to give more guidance on testing methods for the industry players perhaps with more support and guidance than today and indicate and enforce the range acceptable for the parameters. In consequence, KQI necessities are:

- Budgets for both internal and external operations staff, equipment and ancillaries
- Analysis and presentation of measurements of QoE and QoS to form KQIs
- Training of NRA staff – and possibly of service provider staff
- Communications with service providers and operators

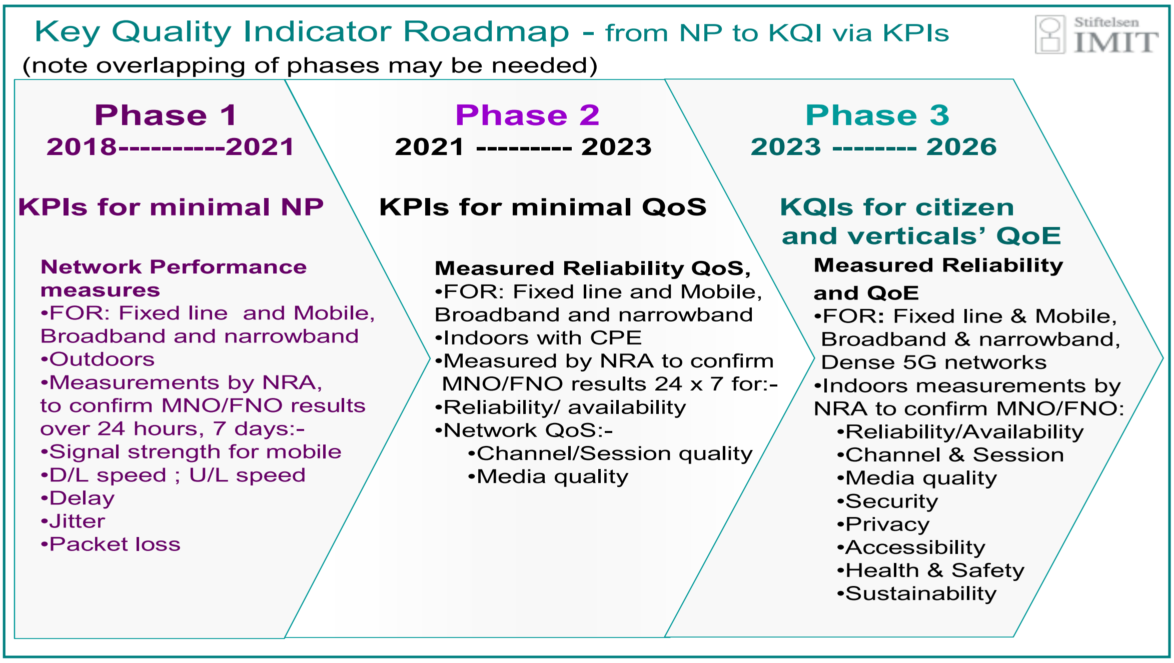
8. A roadmap is needed for phased introduction of more advanced indicators, KQIs

A roadmap for more advanced KQIs and its standardization process could be instituted for common KQI standards for the EU by a phased introduction of standards for communications that meet the quality levels for the DSM.

KQIs could be based on easy-to-measure QoE and QoS parameters. However, given the current state of the EU on existing QoS standards, as analysed in Task 4, a progressive phased approach with a roadmap is likely to be preferred. The progress we are considering especially for 5G networks, promised for such life-critical applications as connected cars and telemedicine in eHealth, implies high levels of reliability through new levels of network quality. That will take some time to be agreed, accepted and implemented across Europe. The standardization route required must have a synchronized timetable.

This is proposed in Figure 3.25 with a first phase of common network performance parameters and standards, i.e. terminating around 2021, approximately when some early 5G applications may have been released. A three-year phase 2 would finish in 2024, in which the extremities of network measurements are pushed to the user equipment interface. Finally, the user is included for QoE measurements, reached in three years by 2026, with a year of overlap for each phase.

Figure 3.25 Deploying future quality measures for the DSM in three phases



These phases may each need a basic network reference model for the parameters involved and their levels of aggregation. The model would describe the quality parameters involved and how they would be aggregated for the interconnected networks end to end, for a heterogeneous chain of networks – a model that may have to evolve with each phase.[60] That reference model would be agreed for all EU MS. It will need common understanding of measurement definitions (NP, QoS, QoE, KQI) across the different network types. To clarify responsibilities, obligations and targets, the reference model also may even need service level agreements (SLAs) for operators for KQIs, especially for 5G where safety of life depends on network reliability and quality. Such SLAs might be attached to spectrum or to operating licences.

Each phase will require reaching EU-wide consensus on the various options for:

- Network definitions,
- Measurement parameters
- Measurement methods,
- Ranges of acceptance, i.e. benchmarks for quality approval
- KQI assembly from QoE parameters

[60] Standards such as ITU-T Y.1566, those coming from ITU SG-12, and ETSI standards could be a starting point.

- QoE building blocks from QoS
- QoS building blocks from parameters

For the roadmap above, it is useful to have a simplified definition of a KQI with the indicators decomposed in more detail for each phase. This is given in Figure 3.26.

Figure 3.26 Breakdown of detailed quality metrics into a simpler set of KQIs

Breakdown of detailed quality metrics into a set of simpler KQIs

Stiftelsen IMIT

KQI	Metrics Parameters
Reliability	**MTBF, MTTR**, Physical Coverage, Availability/repeatability/ resilience/consistency, **Time variation in basic QoS metrics** (communications, session, media) during session, day, Week, year
Basic transport	**Signal strength**-Indoors & Outdoors at local loop extremity, rain/ foliage, via ferro concrete & insulation; network interconnection **Channel Capability –** Bandwidth, Bit rate (D/L-U/L), Volume capacity in parallel sessions, Latency
Communications Session	**Packet rate**, Packet loss rate, Delay, Jitter, False packets acceptance **Internet Access** and Web Performance **Voice & video Calls -** Success rate of set up, Drop rate/retention rate, Set–up Delay, Blocking rate
Media quality	**Audio quality for speech** - sound bandwidth, voice quality, noise level, distortion level, consistency **Full motion video quality** - channel bandwidth, picture and colour quality, resolution, luminescence, image distortion, pixellation /aliasing level
Accessibility with Health & Safety	**Accessibility** measures, as recommended by specialist organisations RF radiated signal limits (Centi / Millimetric)
Security & Privacy	Risk level ID Protection level
Energy Footprint	Energy Consumption, GHG level, recycling and pollution levels

Phase 1 KQIs

Phase 2

Phase 3

9. Measurement methods for quality parameters and benchmark values for parameters linked to KQIs

The measurement methods likely to be in use over the next decade will include refinements of today's methods for the evolving needs of future networks, especially 5G, in terms of types of test, frequency of testing, acceptable parameter ranges and new requirements that may emerge for specific technologies, especially in vertical applications for 5G infrastructures. There are basically three classes:

a) Passive methods:

Estimations using radio signal propagation theory with attenuation estimates for fixed and mobile transmissions to provide probabilities of indoor signal strength

b) Received signal monitoring with interactive session dialogue:

- Crowd sourcing for mobile by the end-user population
- Drive-by testing of signal strength (using monitoring equipment in cars)

c) Active methods:

- Network instrumentation for operators, to provide reporting data for operations and maintenance

- Network instrumentation for NRAs to verify operator reports. In contrast to single operators this could include concatenated network instrumentation for NRAs to cover the path of a session or call across multiple operators
- In-building measurements via mobile instruments (usually apps on handsets) for mobile signals
- Instrumentation for fixed line broadband.

The methods based on active monitoring measurements are likely to be preferred (i.e. category c primarily, with category b used just for confirmation as an independent second source).

10. A public database of KQI measurement by operator and location is needed

Following a phase of consultation with all stakeholders, results of the various measurement tests could become open data, placed in the public domain. The datasets could inform the public, relevant authorities and stakeholders (e.g. emergency services, energy companies) of the status of the various networks, in real time, for broadband and other networks. Private organizations with supplementary data sources such as SamKnows could also be incorporated, under specific conditions for support and checks on accuracy of data that would be paid for.

Such a data repository would stock the various reliability and performance measures, by service and network operator, geographically, including the overall availability of each service with coverage available and any major incidents. The overall database would enable citizens to better understand the quality being offered currently and for studies on quality trends and gaps to be carried out. The latter may be critical for 5G operations that will need a historical tracking of the evolution of reliability and performance over months or years. Development of 5G networks for vertical sector applications (e.g. connected cars, eHealth, Smart cities) could well benefit from constant surveillance and reporting of their quality, to detect any degradation in service levels. All could be given in real time. It should be made easily accessible by citizens and businesses to understand the state of their network quality.

However, creation of such a public, shared platform across Europe may possibly need seed funding from the EU.

11. Extension of the NRA remit for the 5G world: KQIs for vertical applications

Increasingly QOS/QoE will be a key support for the smooth functioning of the 5G world – principally from the viewpoint of those vertical sectors with a public offering, such as eHealth, ITS, smart city, smart grid energy, etc. These verticals could need specific KQIs for each industry (as briefly examined in Chapter 2) as acknowledged by the RSPG in its 2018 Second Opinion on 5G Networks (RSPG, 2018). Such KQIs may be more exacting in their demands, as well as less generic (i.e. far more specific) than is currently the case as these networks will become highly specialized. Certain 5G applications may also need more complex KQIs, e.g. connected cars demand reliability across multifaceted heterogeneous networks with consistent rapid response,[61] and telesurgery may need the ultimate in KQIs for reliability and time constants.

NRAs would have a role to play, possibly in conjunction with vertical industry bodies who can provide inputs on the critical performance factors necessary, and benchmarked values

[61] As indicated by the METIS-II EC project (2016) and also the project for DG Mobility and Transport (MOVE), AECOM, Performance Indicators for Intelligent Transport Systems (ITS), 2015.

for operational range limits. Industry stakeholders can provide feedback from the field on the actual observed functioning for the critical parameters.

This is a substantial undertaking for a single national NRA. Moreover, the equipment suppliers are likely to be international or perhaps Europe-wide, while user industries would possibly be organized at an EU level – for example the European Utilities Telecom Council (EUTC) for smart grids. It would thus be more effective that an initiative for each vertical sector should be implemented at a European level.[62] That would require a period of consultation for each sector to understand parameters, benchmarks, measurement methods and operational monitoring systems and factors such as security and privacy. The whole effort would need to be performed under an appropriate European operational framework as the consultation phase would then be followed by standards setting for the vertical industry, probably involving the appropriate SDOs (e.g. ETSI/3GPP, ITU, IEC, CEN/CENELEC, etc.) and a Reference Model to combine the standards and benchmarks into KQIs for the sector, with the monitoring scheme. Funding would possibly need to be at EU level, or in concert with the user industries. KQIs would be introduced as the 5G infrastructures are installed for each vertical application. This initiative implies that NRAs should also participate in the setting of KQIs for the vertical sectors, in concert with appropriate industry bodies and SDOs.

An entry of NRAs to vertical industry network regulation for 5G applications would probably need to be a phased process. It might be led, perhaps, by the regulators who are already multi-sector, such as the Energy Agency in Estonia, or the parent ministries that are often multi-sectoral - Italy's Ministry for Economic Development, the SESIAD Ministry in Spain, or Austria's Ministry for Transport, Innovation and Technology). With support from the relevant professional bodies, it might possibly occur in Phases 2 and 3 of the programme's route map outlined above, i.e. after 2021. Thus, an enforcement role may also be a key NRA requirement, using the Reference Model's measurements agreed with vertical industry professional bodies and the monitoring system required.

A closed segment of the KQI database might possibly be used to provide vertical sectors selected data from the KQI monitoring on an input to the design of future 5G networks and systems, based on actual quality and performance monitoring in near real time.

12. Implementation and enforcement via EU Regulation

The various measures explored above require a framework for the different actions if they are to be implemented within the timeframe suggested in the roadmap above, to build the Digital Single Market. The major barriers to this are closely connected - firstly the socio-political pressures for different national interpretations of the quality indicators, and secondly to the complexity of the field and its technical challenges. Consequently, implementation of the quality measures is likely to require some form of legal framework at EU level.

The move between the various phases of introduction of quality measures could be via the establishment of suitable EU Regulation. The aim would be to obtain a series of

[62] This is the recommendation of the RSPG's Second Opinion on 5G: Networks: "Industry will define such service performance and availability requirement and Member states will have to consider the consequences in terms of coverage obligation. In the case of cross-border services, it would be helpful if common service performance and availability requirements are used across EU." (RSPG, 2018, p. 17.)

synchronized common standards for quality indicators within the timeframe of each phase in the roadmap.

A Regulation rather than a Directive is more likely to ensure consistent compliance. An alternative might be an Implementing Decision via COCOM, if it can assure a common level of network quality in all its aspects outlined above, across all Member States. Without it, varied national interpretations would lead to a fragmented network infrastructure across Europe. It is for this reason that traditionally technical standards are agreed at internal Regional level, and global, as much as possible. Regulation would cover two main areas – the introduction of the quality indicators and the monitoring systems in hardware, software and operational procedures that would enable enforcement for the long term.

The choice of EU Regulation is justified by the need for synchronized take-up that ensures ubiquitous levels of quality across the Union. Any failures of quality in one MS would affect other connecting MS, especially on KQIs covering reliability as well as security and privacy. In consequence, such an initiative needs appropriate debate for progressive agreements among the stakeholders at the levels of the service providers as well as the regulatory (NRA and/or ministry) and EU levels.

Task 6 Bibliography

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4 Conclusions

Europe is at a turning point in its development of a new generation of networks for the Digital Single Market which may integrate existing fixed and mobile cellular networks with potentially far more advanced 5G networks, using smaller cells and much denser deployment and backhaul connectivity. The density of cells for 5G networks may demand prohibitively high expenditure. That could demand innovative and ingenious re-use of the existing fixed and cellular infrastructure to cuts costs – as the major cost item is backhaul.

We find that there is a closer coordination and commonality among the Member States at a technical and procedural level on the metrics for networking quality than is generally realized. Despite some major differences between MS in their network quality and performance parameters and measurement processes today, common solutions across the EU are possible for network quality. These could be used for harmonising definitions, metrics and measurements for coverage obligations as well. On the actual specifications of mobile broadband coverage obligations (e.g. % of population to be covered) and sanctions in case of non-fulfilment, there is less scope for a common EU approach; NRAs prefer to specify and control the implementation of coverage obligations.

Overall, this implies that implementation of future networks to underpin the DSM is quite practical, but only if a phased roadmap for the progressive rollout of new quality indicators can be agreed and followed. That can be delivered through working collectively with the NRAs to converge their approaches to network reliability, quality and performance in the larger sense of a more holistic view of quality. That should be approached from the user's viewpoint, built on quality of experience and of service. To implement all this, critical elements to build a future policy framework are proposed:

1. Redefining the main indicators of network quality.
2. Indicators should enable comparisons of services and equipment and also replacement of best effort Internet service with guaranteed QoS.
3. Flexibility is needed in applying quality measures, but the actual metrics, benchmark values and measurement methods need to be the same, consistent set across the EU MS.
4. For future converged networks, compound and composite standards are needed – so KPIs become KQIs.
5. Measurement criteria incorporated in KQIs should include those critical parameters for a modern networked society, chosen by an expert group.
6. NRAs should have their own facilities for monitoring quality.
7. KQIs may need to be enforced in the future by a detailed bottom-up approach
8. A roadmap for the phased introduction of more advanced indicators, KQIs, is needed.
9. Measurement methods for quality parameters and benchmark values for parameters linked to KQIs need to be agreed at European level.
10. A public database of KQI measurements organized by operator and location is needed, EU-wide.
11. NRA remits need to be extended for the 5G world: KQIs for vertical applications
12. At an administrative level, an EU Regulation would be appropriate for introducing new indicators and for compliance enforcement.

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