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BEREC Preliminary report in view of a common position on monitoring mobile coverage

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Content

1 Introduction

In the fulfilling of their duties, a number of National regulatory authorities (NRAs) are monitoring mobile coverage[1]. There are a number of reasons why mobile coverage monitoring is necessary, for example:

- To **provide independent and reliable information** on the state of mobile coverage in their respective countries. Such information is often made available by the NRAs to consumers, respective national governments and the European Commission. Besides, by communicating mobile coverage and publishing maps or data at regular intervals, NRAs inform consumers about the coverage of their MNO, give an overview of national networks development and consequently contribute to more competition and investment. Publishing comparable metrics or maps increases transparency and helps consumers to make informed decisions before subscribing to a MNO and thus promotes competition.
- To **ensure mobile network operators (MNOs) meet their coverage obligations**. NRAs monitor the mobile coverage so as to assess if the operators comply with the conditions and obligations set out in the licences. This can help increasing spectrum efficiency through greater geographic and population coverage with positive impact on the reduction of the digital divide.

This document contains the outcome from a first BEREC assessment addressing how mobile coverage measurement and publication are achieved by some European NRAs. This assessment focuses on the objective of some NRAs to provide independent and reliable information. It does not intend to change the way NRAs monitor mobile coverage to ensure mobile network operators (MNOs) meet their coverage obligations set out in the licences/right of use (RoU) of the mobile operators (second point above).

The document draws on first exchanges of experiences between NRAs and from information provided by NRAs in response to a questionnaire from the Institute for Management of Innovation and Technology (IMIT).

The document gives the high-level characteristics that are essential to the provisioning of mobile coverage information to consumers, policy makers and industry. More specifically, the document covers the following aspects:

1. Define a common vocabulary for mobile coverage;
2. Describe the main characteristics of mobile coverage measurement and reporting, and some of the key standards used in this space;
3. Highlight the main mobile services that are monitored by NRAs;
4. Describe some of the key features of maps used by NRAs to report on mobile coverage; and
5. Serve as a first step forwards future BEREC work.

[1] This document is focused on the experience of NRAs which are monitoring mobile coverage and does not cover the experience of other entities (public or private) which may perform similar activities.

1.1 Key findings

This document highlights the following points:

1) Variation in measurement metrics and methods: there are different ways of estimating and presenting mobile coverage. BEREC has noted that NRAs and the European Commission use different methods, all of which have the common aim of providing reliable mobile coverage information in the form of figures and maps

2) These variations are due to the fact that there are different ways to measure MNOs mobile coverage. For example, theoretical modelling may be used to give coverage estimates. Similarly, actual RF measurements on the ground may also be used. Each technique has its own merits and shortcomings. In any case, all techniques invariably require statistical analysis in some form or shape.

3) The different ways to measure MNOs mobile coverage can be explained by the fact that Member States have imposed different coverage obligations to resolve the specific coverage issues they deal with. Different coverage obligations may require different measurement metrics and measurement methods to best assess MNO's compliance with those obligations.

4) BEREC also notes here that variations in measurement metrics and methodologies across Europe can lead to the following:

    a. Difficulty in comparability of coverage of different European Member States: Those differences in the methodology can make it difficult to compare mobile coverage.

    b. Inconsistency across different Member States from the point of view of an individual MNO,

    c. Inconsistency across different Member States from the point of view of providers of innovative digital services for vertical use cases across Europe, for example, connected and automated transport system and 5G applications.

This document has also highlighted two key areas which are essential in the process of measuring and reporting on mobile coverage. The following gives a list of the two areas and highlights the areas of where some commonality already exists, areas where effort into achieving commonality is being undertaken and areas where effort could be directed in the future.

Performance metrics

- **RF aspects**: this relates to the received signal power and similar technical metrics. Whilst there is some consensus on the metrics across different mobile technologies, there is probably a need for further work in this area to explore the range of metrics NRAs use and the measurement methodologies.

- **Quality of Service (QoS):** this document focuses on two services namely, voice and Internet access service (IAS). With regards to voice telephony, generally use the same metrics with perhaps variation in the measurement methodologies. For IAS, this is related to IP layer three metrics and possibly higher layers as well. A great deal of effort is being undertaking to achieve higher levels of harmonisations for Internet metrics and methodologies under the BEREC Net Neutrality Expert Working Group[2].

- **Quality of Experience (QoE):** Some NRAs use QoE for information reporting.
- **Time availability:** this study has highlighted variations in the practices of some of the NRAs. For example, some NRAs specify time availability whilst others do not. Furthermore, there is no common figure for time availably amongst NRAs who do specify time availability.

Presentation of coverage

In this document, BEREC found that many NRAs employ maps as a useful tool for conveying mobile coverage to a wide audience and provide with a greater level of transparency. Indeed, some NRAs consider maps as an essential tool to promote competition amongst operators. BEREC found the following high-level set of quality indicators for coverage maps:

- Accuracy,
- Transparency,
- Level of detail,
- Level of granularity and
- Accessibility for a wider audience.

1.2 Recommendations

To highlight existing commonalities and make maps easier to interpret and compare, NRAs could make their best effort to indicate the characteristics of the mobile coverage and consider including, as much as possible, the following indicators:

- Type of service
- User location
- User equipment
- Performance indicator
- Service availability on a covered area

BEREC thinks that the following steps could also increase clarity should NRAs publish coverage maps:

- NRAs could seek to improve the comparability between MNOs at mapping level – this would improve matters at least at the national level;
- The maps should be with sufficient levels of details and accuracy. In particular, NRAs may want to consider publishing multi-layer maps, for example with layers indicating different levels of coverage, such as “limited”, “good” and “very good”.
- In order to compare the maps of the different countries in Europe, it could be useful to determine a “minimum granularity” that shows a minimum of geographical precision.

[2] BEREC Net Neutrality Regulatory Assessment Methodology published in October 2017.

Further development on monitoring mobile coverage ought to be undertaken to establish in detail the range of current NRA practices from which commonalities can be drawn. This goal is best served by the following programme of activities:

1. Conduct a detailed survey of the practices of NRAs which covers mobile measurements, data processing, mapping, etc., in the context of their national circumstances, taking into account for example geographic factors, legacy and coverage obligations. This would help by bringing into one document detailed expertise drawn from the practices of the NRAs in this area.
2. With the outcome of the survey, specify the metrics and methodologies, and design a recommendation for Best Practices which would contribute to a more consistent approach while preserving the ability to take into account particular national circumstances where necessary.
3. Draw commonalities from the outcome of the survey.
4. Further explore linkage with the European Commission's broadband mapping initiative.

2 Characteristics of mobile coverage

This section reviews the essential elements needed to measure and present mobile coverage information in the regulatory domain. It also provides a high-level description of the techniques used by NRAs for coverage estimation and presentation.

In mobile communications, mobile applications, as the means to deliver digital services, often need to communicate with two or more end points in order to fulfil their tasks, and the role of a mobile network is to furnish the supply of connectivity and QoS to enable the workings of such applications.

In principle, mobile coverage is an expression of the extent to which mobile connectivity in support of mobile applications can be enabled, as a percentage of a given geographic area (national, indoor, outdoor, road, etc.) or population.

In general, mobile networks deliver the following types of services, namely:

- Vertically-integrated SMS and MMS;
- Vertically-integrated voice telephony (including VoLTE);
- Vertically-integrated specialised services; and
- Internet access service.

Usually, NRAs monitor the mobile coverage for voice telephony and IAS, and hence this document mainly focuses on these two main types of services. It is noted that some NRAs are also monitoring coverage for Internet of Things services provided by mobile networks, those services being usually delivered through IAS or vertically-integrated specialized services.

2.1 User location

One of the characteristics of mobile networks is to provide services to consumers in different locations such as in rural areas, in urban areas, in road vehicles, on trains, etc. It follows that the users can be located in an indoor or outdoor environment, can be static, in slow or high movement. User locations may be categorised in the following ways:

- **Indoor:** this means inside buildings or places in which there is typically an extra shielding of the radio signal compared to the outdoor usage. Depending of the indoor location of the user the received radio signal varies. The extra shielding attenuation is highly dependent of several factors such as the type of materials, walls, height, etc. Indoor mobile communications represent the majority of user cases.
- **Outdoor** (static or slow movement): this means outside buildings or places where typically there is not an extra shielding of the radio signal compared to the indoor usage. Depending on the outdoor location of the user the received radio signal varies.
- **In transport** (car or train, in slow or high movement): this means inside an automotive vehicle[3] or a railway vehicle[4] in which there is typically an extra shielding of the radio signal compared to the outdoor usage. Depending on the 'in transport' location/velocity of the user, the received radio signal varies.

[3] Any vehicle as defined by Council Directive 70/156/EEC.
[4] As defined by Regulation (EC) No 91/2003 of the European Parliament and of the Council.

Indoor and in transport situations render the evaluation of the mobile coverage more challenging because coverage in such locations depends on a number of factors such as the type of building materials, vehicle / train construction, location within building, vehicle and train, etc.

Therefore, many NRAs set higher requirements for outdoor conditions to make sure that mobile signal is available indoor as well. The indoor coverage is then evaluated in reference to the outdoor coverage immediately available outside a given building. For example, some NRAs set a predetermined attenuation (x dB) between the signal outside and inside buildings. However, a fixed attenuation cannot be accurate for all buildings, especially for example, for energy efficient buildings which attenuate radio signals more than conventional buildings.

BEREC and RSPG are also working on a joint report dedicated to mobile connectivity in challenged areas including indoor and in transport environments.

2.2 User equipment

There are many different devices used for accessing mobile services which can influence the mobile coverage of the serving MNO. Mobile phones, smartphones, tablets and wearables such as smartwatches or smart glasses are personal user equipment (handsets) which can influence the connectivity by the way they are handled.

Furthermore, there are a range of factors[5] that can affect handset sensitivity[6] performance, including but not limited to:

- *The consumer use scenario:* whether mobile handsets are used in the hand away from the body, with an earpiece or close to the head can affect antenna performance and hence handset sensitivity performance;
- *Antenna design:* whether an internal or external antenna is used and its size can affect the gain of the handset antenna and hence handset sensitivity performance;
- *Handset design:* different handset materials can have different absorption effects on mobile signals and hence affect handset sensitivity performance;
- *RF receiver design:* noise and nonlinearity introduced by the handset receiver circuitry can affect handset sensitivity performance;
- *The number of frequency bands supported:* as more frequency bands are added the handset antenna and receiver design becomes more complex, which can make it more difficult to achieve good sensitivity performance.

In fixed wireless access, a modem often with an external antenna is used to access mobile services in a static location. Here, coverage can be influenced by the outdoor directive antennas or indoor receiving boxes depending on factors such as the type of antenna used in the receiving boxes or on the height of outdoor antennas.

When the user equipment, such as handset performance, is part of the mobile coverage definition, the NRA may wish to specify this characteristic.

[5] Source: Mobile Handset Testing (November 2015); https://www.ofcom.org.uk/research-and-data/technology/telecoms/mobile-handset-testing

[6] The sensitivity of a handset is understood to be the smallest amount of external power delivered to the handset antenna such that the handset can maintain reliable communication. Source: Mobile Handset Testing (November 2015); https://www.ofcom.org.uk/research-and-data/technology/telecoms/mobile-handset-testing.

2.3 Performance indicators

In general, geographic coverage is declared available in areas where a user can connect to their mobile network, set up and maintain a call for a minimum period of time, reach a specific data rate in data transmission or similar types of criteria for successful service access. For practical reasons, NRAs use one or several key parameters to consider whether there is mobile coverage. Each NRA uses a different set of parameters and different thresholds. These parameters could be grouped in three sets of performance indicators:

1. RF signal levels / Technical criteria
2. Quality of service
3. Quality of experience

2.3.1 RF signal levels / Technical criteria

Technical criteria to define whether a specific location is covered or not consider received radio signal level and its quality.

Radio signal characteristics depending on the technology in use were examined, for the downlink, in details in corresponding ECC Reports (ECC Report 118, ECC Report 103 and ECC Report 256, respectively):

- For GSM (2G) technology, RxLev (Received Signal Level) and RxQual (Received Signal Quality) are representative of the received level and the quality of the call. During the call, RxLev corresponds to the power level received by the mobile on the transmission channel.
- For UMTS (3G) technology, coverage area is based on a value of RSCP (Received Signal Code Power), collected RF energy after the correlation / descrambling process, or Ec/Io (signal to noise ratio).
- For LTE (4G) technology, RSRP (Reference Signal Received Power) is the linear average of the received power of the downlink reference signals contained in one radio frame at the UE receiver input terminal. In order to detect the presence of an LTE network and log on in a given location, a specific minimum signal level has to be available.

In principle, different technologies, different bands and possibly different operators may require different RF threshold.

2.3.2 Quality of Service (QoS)

The radio signal level and quality does not guaranty that a mobile user can effectively access and use the service. Therefore, some NRAs are considering whether a location is covered using criteria that are more related to the quality of service that is provided at that location.

QoS is defined by ITU-T Recommendation E.800 as the "*totality of characteristics of a telecommunications service that bear on its ability to satisfy stated and implied needs of the user of the service*" in which "service" is a set of functions offered to a user by an organization.

QoS covers the whole end-to-end view of a telecommunications service and can be subdivided in separate parts that all have an influence on the resulting QoS. The degree of QoS depends on the collective effect of all sub-parts. This is illustrated in Figure 1 which is based on the ITU-T Recommendation and which explains the difference among network performance, QoS and Quality of Experience, discussed in the next section.

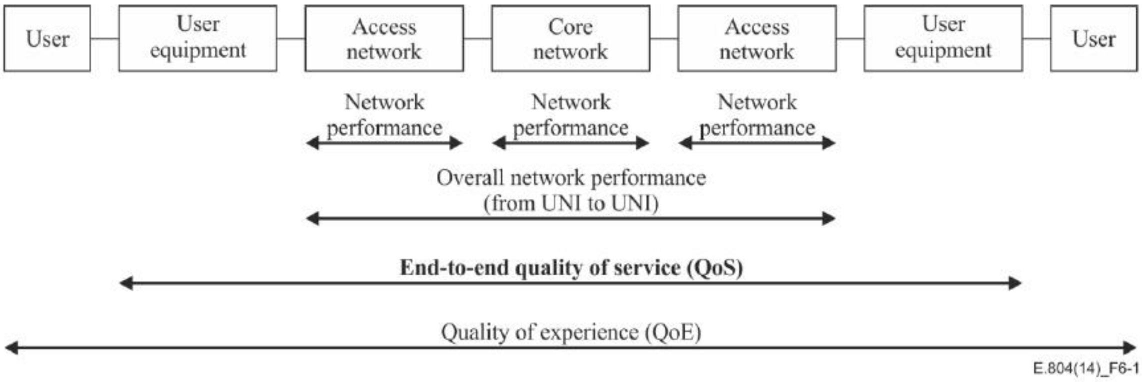


Figure 1 – *End to end QoS*

As set out in the above figure, in general QoS is considered to be an end-to-end service. However, since the QoS consists of the collective effect of numerous single performances, any QoS analysis will have to deal also with sub-parts, e.g., network and terminal performance that can be analysed separately and independently from another. Besides pure network performance, other factors may influence quality of service. For example, the performance of terminal equipment can impact strongly on the QoS, depending on how it has been implemented or due to aging, software incompatibility, or specific configuration issues, which has already been described in details in Section 2.2 in this document.

There are a lot of standards and concepts dealing with QoS that are focusing on specific details and aspects of QoS. The main objective for QoS evaluation is to identify degradation of service resulting either from congestion or from operators' practices (e.g. priority given to selected traffic streams over others).[7]

There are some QoS parameters for voice service and IAS that can be used to define mobile coverage, and in addition to these, NRAs may specify additional QoS parameters to be measured in order to assess the quality of the mobile network. When measuring QoS parameters, NRAs may specify 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. Each NRA defines its own set of minimum requirements for QoS parameters.

The standard ETSI TS 102 250-2 V2.2.1 defines QoS parameters and their computation based on the field measurements. BEREC notices that out of these parameters, some of them are being used by the NRAs to define mobile coverage for voice service and IAS, and some are being measured only as an indicator of the quality of service in the mobile network.

2.3.2.1 Voice service

Voice service related KPIs (Key Performance Indicators) that are used by some of the NRAs to define mobile coverage are:

- Call Success Rate [%],

[7] (Source: A framework for Quality of Service in the scope of Net Neutrality, Dec 2011)

- Call Block Rate [%],
- Dropped Call Rate [%],
- Speech Quality [MOS], according to ITU-T P.862 and ITU-T P.863.

Call Success and Dropped Call are defined with respects to a given call duration which differ from one NRA to another.

Thresholds to be met by the mobile operators for some of the KPIs above, as minimum criteria to have mobile coverage are defined by each NRA, and may vary from one NRA to another.

Additional KPIs which are measured by some NRAs to assess quality of the network may include:

- Call Setup Time [s],
- Handover Success Rate [%].

2.3.2.2 Internet access service (IAS)

While most of the NRAs define voice service related KPIs, only few of them define IAS related KPIs to evaluate mobile coverage. The only IAS related KPI that is used by the NRAs to define mobile coverage is data rate [kbit/s].

Minimum downlink data rate to be met is usually defined by the NRA, but minimum uplink data rate to be met could also be defined. Data rate KPI could be defined for different services (file download and upload or web browsing). It is important to highlight that NRAs treat data rate parameter differently: as a possible maximum theoretical data rate for one user in the outdoor environment, as a data rate measured outdoor outside of peak hour time, as a minimum data rate to be achieved by the user, etc. Thresholds to be met, as minimum criteria to have mobile coverage, also differ among NRAs.

Additional KPIs to be measured by NRAs to assess quality of the network may include:

- Data Transfer Cut-off Rate [%],
- IP Service Access Failure Rate [%],
- IP Service Access Time [s],
- Session Failure Rate [%],
- Session Time [s] and
- Ping Round Trip Time [ms].

It should be stressed here that BEREC has developed a regulatory assessment methodology[8] in order to provide guidance to NRAs with the implementation of the net neutrality provisions of the Regulation 2015/2020[9]:

[8] BEREC Net Neutrality Regulatory Assessment Methodology published in October 2017.

[9] Regulation (EU) 2015/2020 of the European Parliament and of the Council of 25 November 2015 laying down measures concerning open internet access and amending Directive 2002/22/EC on universal service and users' rights relating to electronic communications networks and services and Regulation (EU) No 531/2012 on roaming on public mobile communications networks within the Union,

http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2120&from=EN

- This work constitutes the basis upon which NRAs will converge as time evolves. It builds upon previous BEREC guidance on IAS QoS monitoring and best practices common to both fixed and mobile.
- It specifies a harmonised quality of service measurement metrics (KPIs) as well as their respective measurement methodology, all of which is targeted to maximising measurement accuracy and to enable the comparison of measurement results between different member states. The speed measurement is based on multiple parallel HTTP connections. This document also defines measurement metrics for delay, delay variation and packet loss measurements. It also describes the most important factors that should be taken into account when assessing measurement results and gives guidance on information collection.

2.3.3 Quality of Experience

The overall acceptability of a service, as subjectively perceived by the end user, is expressed in terms of Quality of Experience (QoE). QoE as defined by ITU-T E.804 includes the complete end-to-end system effects (client, terminal, network, services infrastructure, etc.) and may be influenced by user expectations and context.

QoE parameters are being used by some NRAs only for measuring and verifying the quality of experience by the end user from a mobile network and for service information reporting only[10].

QoE is measured subjectively by the end user and may differ from one user to the other. However, it is often estimated using objective measurements through complex algorithms describing a statistical (experience) based relationship between subjective and objective measurements. There are various techniques to measure QoE.

For voice services, the listening quality of speech can be objectively measured by methods for assessing end-to-end speech quality of telephone networks and speech codecs, as perceived by the user. These methods are described in ITU-T Recommendations P.862 (PESQ, Perceptual Evaluation of Speech Quality) and P.863 (POLQA, Perceptual Objective Listening Quality Assessment).

For Internet services, measuring QoE is mainly related to the streaming video services as perceived by the end user. Objective algorithmic model for measuring the visual quality of IP-based video services is described in the ITU-T J.343.1 recommendation.

QoE is often used to stress the subjective nature of quality assessments in telecommunications and its focus on the user's perspective of the overall value of the service provided. BEREC notices that overall user satisfaction of voice and internet services provided to the end users is usually measured by using practical measurement techniques, including Drive Testing, Walk Testing and Crowdsourcing, explained in more details in Appendix – C of this document.

2.4 Service time availability within a covered area

All the characteristics described above give a picture of mobile coverage and capacity at a specific moment and at a specific place. However, even in an effectively covered area, the services (voice or date) are not available at 100% attempts. This is due to the fluctuation of

[10] https://www.ofcom.org.uk/__data/assets/pdf_file/0017/68201/smartphone_cities.pdf

radio conditions (weather, peak hour, etc.) and occasional break-downs. In this respect, providing the service time availability can complete the notion of mobile coverage.

Generally, the service time availability is defined as a percentage: it refers to the availability of a given service (voice / data) during a specific timeline. Sometimes, it might be described as a number of minutes/hours during which the service is (or is not) available on a reference period. Furthermore, the reference period can be narrowed to specific moments of the day (busy hours for instance) with an impact on the service time availability.

Some NRAs specify the minimum service time availability that needs to be reached in order for a specific location to be considered as covered. BEREC notices that some NRAs put such requirements in their licences/RoU:

- In France: coverage availability outdoor at least 95% of the time.
- In Portugal: 99.977% network availability (GSM), 99.990% network availability (UMTS).
- In Romania: network unavailability less than 35 min during a 6 month period.
- In Greece: annual service availability for 900 MHz and 1800 MHz bands, greater than 99.5%, not less than 95% for continuous period of 48h.
- In Ireland and Romania: Mobile operators have the obligation to keep the network logs.

Besides, BEREC estimates that service time availability might have an impact on the end-user, since they can feel the effect of bad or good service availability. Thus, it seems an important criterion that, if available, should be taken into account when monitoring mobile coverage.

However, though the service time availability seems to be an important detail, it remains difficult to measure precisely such a criterion as it is almost impossible to do continuous measuring on a massive number of places throughout the year. Some NRAs rely on their operators' logs (in Ireland and Romania: Mobile operators have the obligation to keep the network logs), other NRAs consider the service time availability as the percentage of allowed unsuccessful measurements when verifying an area declared as “covered" by an operator.

3 Presentation of mobile coverage

This section describes how information on mobile coverage is usually provided.

NRAs provide such information to public and private entities (policy makers, the European commission, other public departments, media, operators, retailers, etc.) and consumers. An emerging audience for coverage information are industrial players interested in machine-to-machine coverage. This is the case, for instance, of car manufacturers that are developing connected cars.

There are two ways to express information on mobile coverage:

- with “macro” information expressed as % of a given geography or of a given population (metrics).
- with the availability of a mobile service in a specific location or area (usually through a map).

3.1 Macro information on mobile coverage represented through metrics

Mobile coverage obligations differ from one country to another, depending on the distribution of population over the country, the size of rural and hard-to-reach areas and national policies in general. The mobile network coverage in a country can be expressed as a percentage of coverage relating to the population, geographical area or both. BEREC notices that the majority of NRAs define population coverage obligations, which can ensure good coverage of highly populated areas such as cities and towns (which are often home to the majority of the population in a country). On the other hand, NRAs that define geographical coverage obligations at a relatively high level encourage mobile connectivity in rural areas and islands. Besides these two metrics, commonly NRAs define must cover areas in order to ensure mobile coverage in areas with low population density or hard-to reach areas, railways or roads, or other areas that are of specific interest.

A set of metrics to be defined when providing ‘macro’ information about mobile coverage, includes but is not limited to:

- Geographical area considered: national territory, regions, districts, roads, railways etc.,
- Coverage extent: percentage of the population covered, percentage of the households and/or settlements covered, percentage of the area covered, number of kilometres covered.

The different ways in which mobile coverage is being measured by NRA makes comparison between different Member States complex if not impossible. For instance, the percentage of population covered in two different countries is not comparable if the underlying characteristics of the mobile coverage are not the same.

3.2 Mobile coverage on specific location represented through maps

Many NRAs employ mapping as a useful tool in order to encourage understanding of the scale and scope of mobile coverage; and provide a greater level of transparency and as one way to stimulate competition amongst operators.

In principle, coverage maps aim at informing consumers of the availability of mobile signal or service in a specific area or location that is relevant to them, e.g. places near where they live and work; commuter routes; areas of shopping; etc.

In addition, publishing maps increases users' awareness of the market: consumers can easily compare the availability of mobile networks and choose which operator offers the service best adapted to their own needs. This comparison between operators facilitates switching from an operator to another and thus promotes competition.

BEREC notes the following:

- NRAs have different requirements with regard to the publishing of maps. In some countries, there is no obligation to publish maps (i.e. the mobile networks operators decide to publish their mobile coverage or not at their own discretion).
- In some countries, operators have an obligation to publish mobile coverage maps. Some NRAs publish on their own website a link to the maps located on operators' websites.
- In some countries, NRAs publish their own maps.

BEREC believes that the sharing of practices and experiences regarding maps amongst NRAs would be welcomed by NRAs, as part of future work.

The following is an initial attempt to give examples of good practices for creating coverage maps. These practices aim at providing the viewer with maps that have a sufficient level of accuracy, transparency and accessibility by a large consumer audience.

3.2.1 Accuracy

As mobile coverage maps can be addressed to consumers, the information needs to be as close as possible to the user experience. As such, the underlying coverage definition (which is discussed in section 2 of this document) should be carefully chosen in order to reach that aim. Nevertheless, it is also possible to give a better representation of coverage by showing several layers of coverage in order to provide information on whether a specific place is well or poorly covered and by providing the maps with good geographical granularity.

3.2.1.1 Detailed information with several layers

One important criterion is the number of layers of quality that may be required to give relevant information about mobile coverage. The following maps provide an example of how coverage can be displayed.

- Maps showing whether the service is available or not: Covered / not covered (no additional layer, see example in Figure 2);

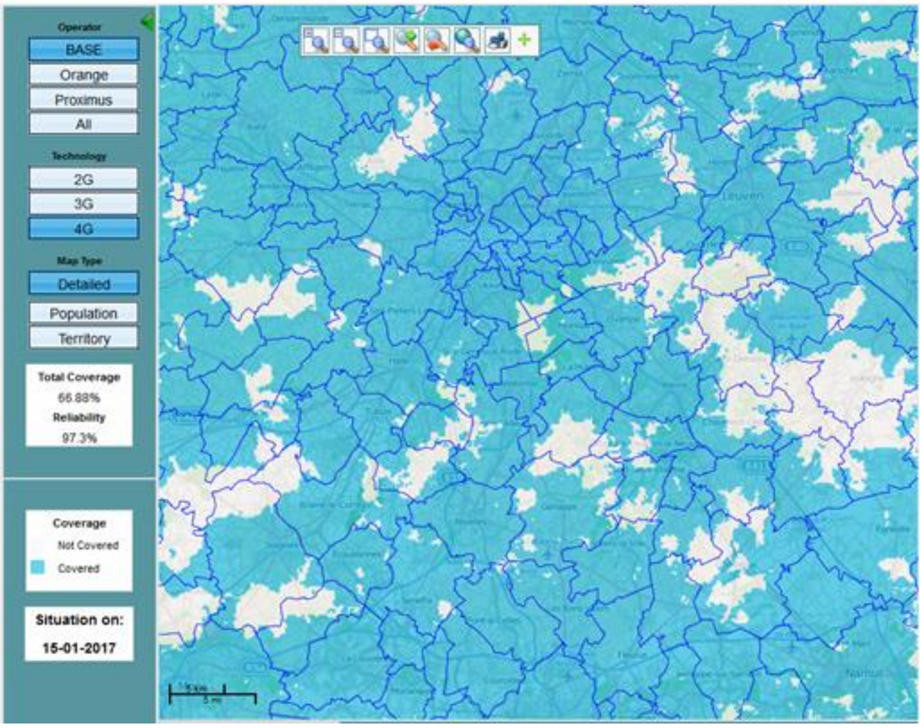


Figure 2 – *Base's 4G Mobile coverage map published by BIPT (Belgium)*

- Maps with more layers give the public a more precise understanding of the network coverage. Indeed, in an area with a supposedly good coverage, the customer experience is not always the same, depending on the distance between the mobile device and the base station. Thus, some NRAs and operators are publishing maps showing different layers or qualities of mobile service available: with this additional feature end-users can have a better overview of the *in situ* mobile coverage (see examples in Figure 3 and Figure 4 below)

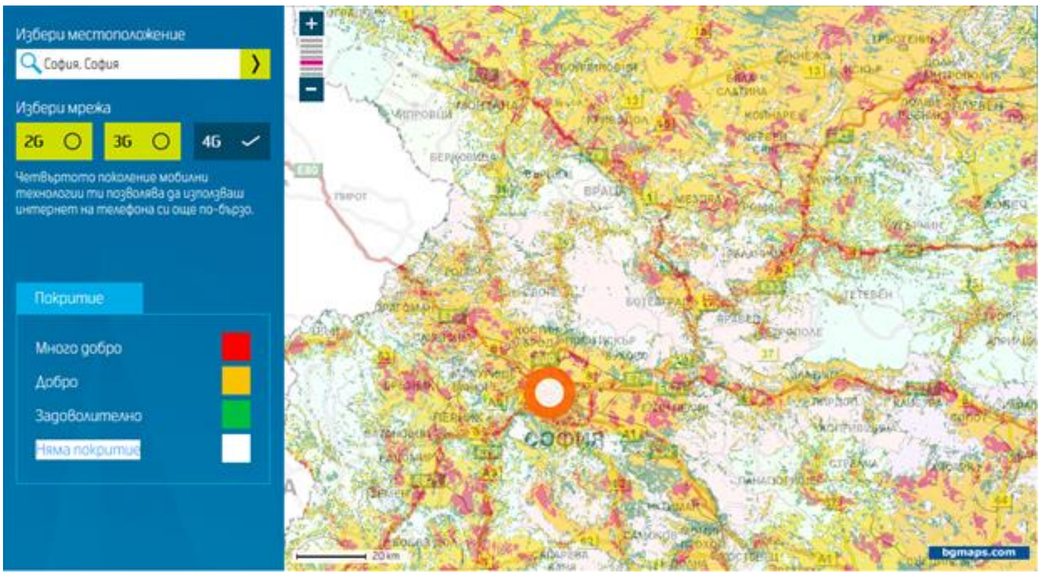


Figure 3 – map on Telenor's website (a Bulgarian mobile operator) with several layers of coverage: No coverage, correct coverage, good coverage and very good coverage are detailed

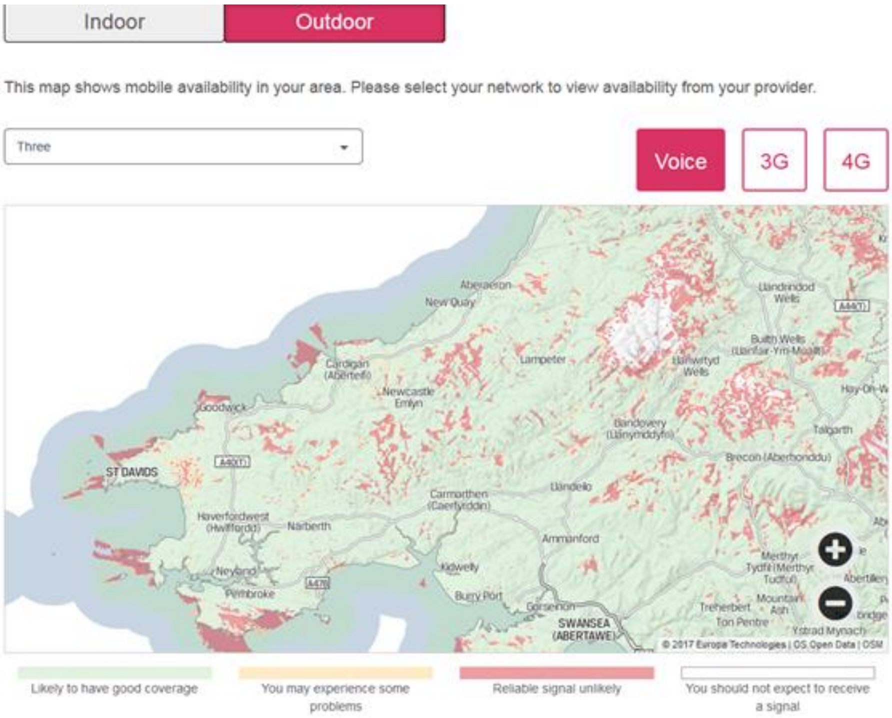


Figure 4 – ***map on OFCOM's website (United Kingdom) with several layers of coverage***

3.2.1.2 Maps with a sufficient granularity

The granularity of a map is the size of the smallest polygon (usually a square also called pixel) on which the displayed mobile coverage is assumed to be the same. Hence, the granularity gives the precision of the map: the smaller the granularity, the more precise is the map.

Those NRAs that publish maps pay close attention to their granularity: the mobile coverage should be displayed with the best granularity possible so as to give the most precise information to the end-users. Indeed, part of a "pixel" that is across the border of a mobile coverage will show an incorrect information (either showing coverage on the part of the pixel that is not covered or showing lack of coverage on the part of the pixel that is covered). With sufficient granularity, this difficulty is alleviated. Currently, a granularity of 100 m x 100 m or finer could be considered as a good practice.

In addition, it is important to distinguish two factors: one is the resolution of the map used to perform the estimated mobile coverage calculations and the other is the map used for displaying the estimated mobile coverage. As an example of the importance of these factors, if a map with a resolution of 1 km x 1 km is used to perform the coverage calculations it does not make sense to publish the coverage calculations in a map with higher resolution (e.g. as 200 m x 200 m). So, the resolution of the map to publish should have, at best, the resolution of the map used in the calculations or lower resolution, what can be useful in some circumstances (e.g. to consult the full country mobile coverage).

When publishing a mobile coverage map, NRAs and mobile operators are invited to mention its granularity.

Additionally, especially for the benefits of mapping experts, as the calculation of the coverage maps is invariably closely related to very specific and detailed issues (map grids, terrain layers, propagation fine tuning optimization, etc.) the ownership/source of these calculations would have to be made clear. In the same context, when coverage maps are calculated and provided by the mobile operators it could be informative for the users if it were to be made clear whether the data provided was verified by NRA (and possibly how it was verified). This matter is highly relevant given that different mobile operators can use, as an example, different propagation models which could lead to different results (e.g. more or less favourable in terms of propagation/coverage provided). Either way, the used parameters in the propagation models should be comparable or at least described (even if the coverage maps are calculated by NRAs).

3.2.2 Transparency

The information provided in a map should be explained so that the consumer may have a better understanding of precisely what the map shows. It makes sense to include the following information:

- The service and/or the technology represented; and
- A legend describing clearly the layers used by the map.

3.2.2.1 Service and/or technology

BEREC notices that there are different types of maps that aim at giving different indications to the end-users.

Indeed, maps may represent the mobile coverage by technologies (2G / 3G / 4G), as it is presented above or by services (Voice, data services (see section 2)). For instance, Arcep, the French NRA, gives the choice between coverage maps either for voice and SMS or for mobile internet services.

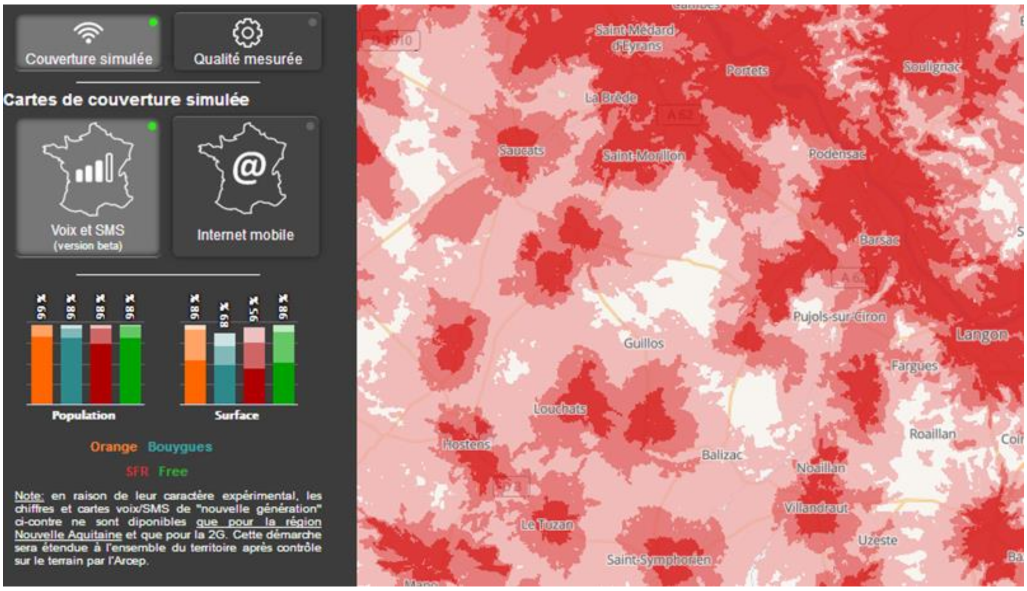


Figure 5 – ***Different services can be represented (Voice&SMS / Mobile Internet) by Arcep (France) (here the Voice&SMS is shown)***

3.2.2.2 Legends

When focusing on the previous maps, it appears that there are different ways to represent the layers. Indeed, the legend of coverage maps is either a choice of different colours or a gradation of a same tone (See Figure 6).

Figure 6 – Different ways to present a map's legend: Arcep (France), BIPT (Belgium) and Telenor (a *Bulgarian mobile operator)*

This descriptive part of a map is very important for the user to be able to read and understand correctly the map. For instance, the map's legend of the French regulator (Arcep) shows three layers of coverage and for all of these layers (see Figure 6), Arcep explains what they mean:

- limited coverage means: "Most of the time, you may give a phone call and exchange SMS outside of the buildings, but probably not indoors";
- good coverage means: "Most of the time, you may give a phone call and exchange SMS outside of the buildings and sometimes indoors";
- very good coverage means: "You may phone and exchange SMS outdoors and most of the time inside of the buildings".

3.2.2.3 Accessibility by the wider audience

The websites of NRAs or similar authorities are an easy way to provide mapping to its consumers and citizens. Indeed, some NRAs already publish official maps on their own website[11] or on a dedicated website[12].

If all the maps of all operators in a given member state are presented on the same website, consumers can then look up the geographical mobile coverage of different operators (see Figure 7). This makes it easier to compare different operator offerings and help consumers make a better informed choice of service provider.

[11] For instance: the Belgian Regulator, BIPT www.ibpt.be/en/consumers/telephone/quality-of-service/coverage-maps-mobile-networks
[12] For instance : the French Regulator, Arcep: www.monreseaumobile.fr/R, and the British Regulator, Ofcom: checker.ofcom.org.uk/mobile-coverage

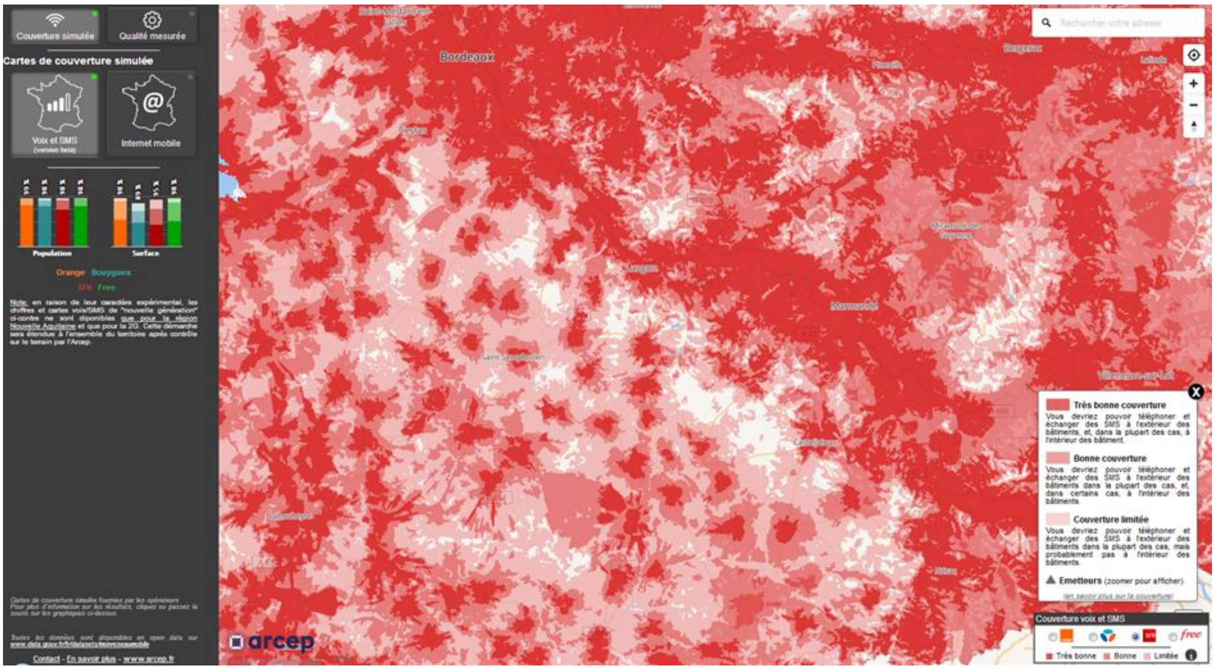


Figure 7 – 4 *layer map presented on ARCEP's dedicated website www.monreseaumobile.fr (France)*

In some countries, consumers can view the number of operators offering voice or data services in a specific location. For instance, BIPT publishes an aggregated map on which the consumers can see how many networks are present on a given spot (Figure 8).

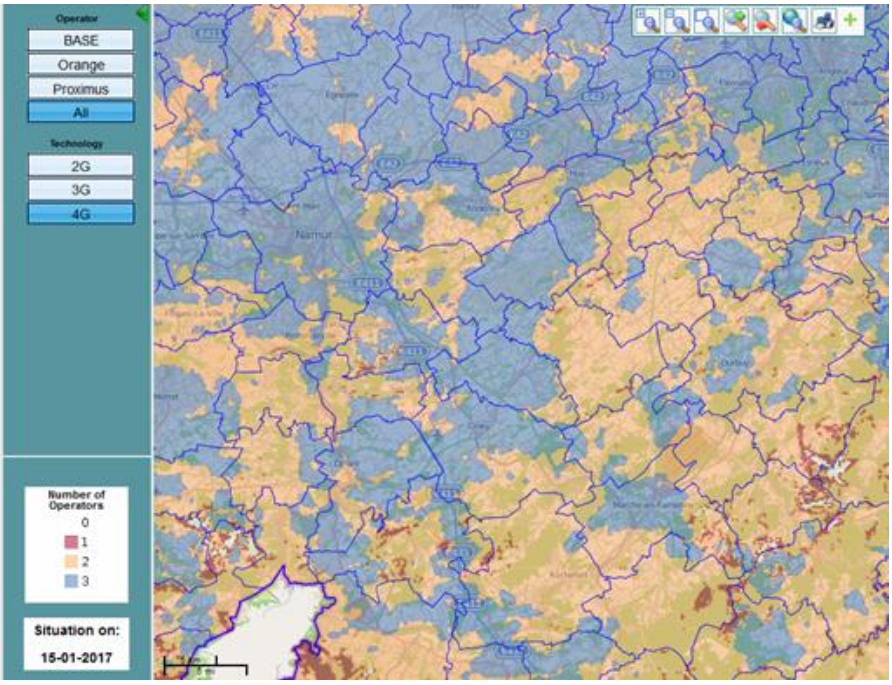


Figure 8 – Aggregated ***map published by BIPT***

Increasing the accessibility of maps and websites (including contacts and help options) providing such maps to a wider consumer audience is also achieved by considering the following:

- Consumers with visual and/or hearing impairments; and
- Variations in different languages and/or local dialects.

4 Appendices

Appendix – A: Characteristics in option

1. Frequency bands

European Communications Office (ECO) Report 03[13] on the licensing of mobile bands in Europe presents the most recent information available to the ECO on the licensing of the harmonized frequency bands in CEPT countries.

The harmonized frequency bands in ECC framework and in European countries are illustrated in the following Table.

Band	Size (MHz)	ECC framework (main deliverables)	EC decision
700 MHz (694-790 MHz)	2x30 + 20 (option 0 to 4 blocks of 5 MHz) (SDL)	ECC/DEC/(15)01	(EU) 2016/687
800 MHz (**790-862 MHz**)	2x30	ECC/DEC/(09)03	2010/267/EU
900 MHz (**880-915 MHz / 925-960 MHz**)	2x35	ECC/DEC/(06)13	2009/766/EC 2011/251/EU
1452-1492 MHz	40 (SDL)	ECC/DEC/(13)03	(EU) 2015/750
1.8 GHz (**1710-1785 MHz / 1805-1880 MHz**)	2x75	ECC/DEC/(06)13	2009/766/EC 2011/251/EU
2 GHz (1920-1980 MHz / 2110-2170 MHz)	2x60	ECC/DEC/(06)01	2012/688/EU
2.6 GHz (2500-2690 MHz)	2x70+50	ECC/DEC/(05)05	2008/477/EC
3.4-3.8 GHz	400	ECC/DEC/(11)06	2008/411/EC 2014/276/EU
	Total : 1210 MHz		

Table 1 - Harmonized frequency bands in ECC framework

Moreover, the current ECO Report 03 also contains licensing information on the bands 1900-1920 MHz and 2010-2025 MHz which are no longer part of the CEPT regulatory framework for MFCN (Mobile/Fixed Communications Networks) - these bands have been deleted in the amended ECC Decision(06)01 and have not been harmonized for mobile networks under an implementing decision of the European Commission.

2. Technology

Mobile networks, in their digital form, started with the implementation of GSM (Global System for Mobile communications) networks in 1991, then in the beginning of 2000 UMTS (R99) networks started to be implemented and in 2008 and 2010, the standards for LTE (Long Term Evolution) and LTE-A (Long Term Evolution-Advanced) were finalized, respectively. The first implementation of LTE commercial networks began approximately in 2010 in Europe.

[13] Available on EFIS at www.efis.dk. EFIS is the tool to fulfill EC Decision 2007/344/EC on the harmonised availability of information regarding spectrum use in Europe and the ECC Decision ECC/DEC/(01)03 on EFIS.

Mobile technologies evolution can also be seen through what is called generations “xG”:

- **1G (First Generation)** - Analogue mobile systems, based on FDMA (Frequency Division Multiple Access), without global roaming, used in 1980s;
- **2G (Second Generation)** - First digital mobile systems (e.g., GSM), based mainly on TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access), Circuit-Switched (CS) based, with global roaming, and with telephony and SMS as main services, started at the beginning of 1990s;
- **3G (Third Generation)** - First generation of mobile systems which included by default Packet Switched (PS) domain (for Internet access, and MMS) in parallel with CS (for voice and SMS), based on WCDMA –Wideband Code Division Multiple Access, started at beginning of 2000s;
- **4G (Fourth Generation)** - First generation mobile systems which is all-IP by default in access and core parts, based on OFDMA (Orthogonal Frequency Division Multiple Access), started at the beginning of 2010s.

Over the last 25 years, ITU has developed the IMT framework of standards — or International Mobile Telecommunication system — for mobile telephony and continues to lead international efforts involving governments and industry players to produce the next generation standards for global mobile communications.

International Mobile Telecommunications-Advanced (IMT-Advanced) systems are mobile systems that include the new capabilities of IMT that go beyond those of IMT-2000. Such systems provide access to a wide range of telecommunication services including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based.

IMT-Advanced systems support low to high mobility applications and a wide range of data rates in accordance with user and service demands in multiple user environments. IMT-Advanced also has capabilities for high quality multimedia applications within a wide range of services and platforms, providing a significant improvement in performance and quality of service.

Right now two technologies have been found to meet the IMT-Advanced criteria, namely, Wireless MAN-Advanced and LTE-Advanced.

Key features of IMT-Advanced:

- A high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;
- Compatibility of services within IMT and with fixed networks;
- Capability of interworking with other radio access systems;
- High quality mobile services;
- User equipment suitable for worldwide use;
- User-friendly applications, services and equipment;
- Worldwide roaming capability; and,

- Enhanced peak data rates to support advanced services and applications: 100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research.

IMT-2000 and IMT-Advanced families are illustrated in the following figure (Figure 9).

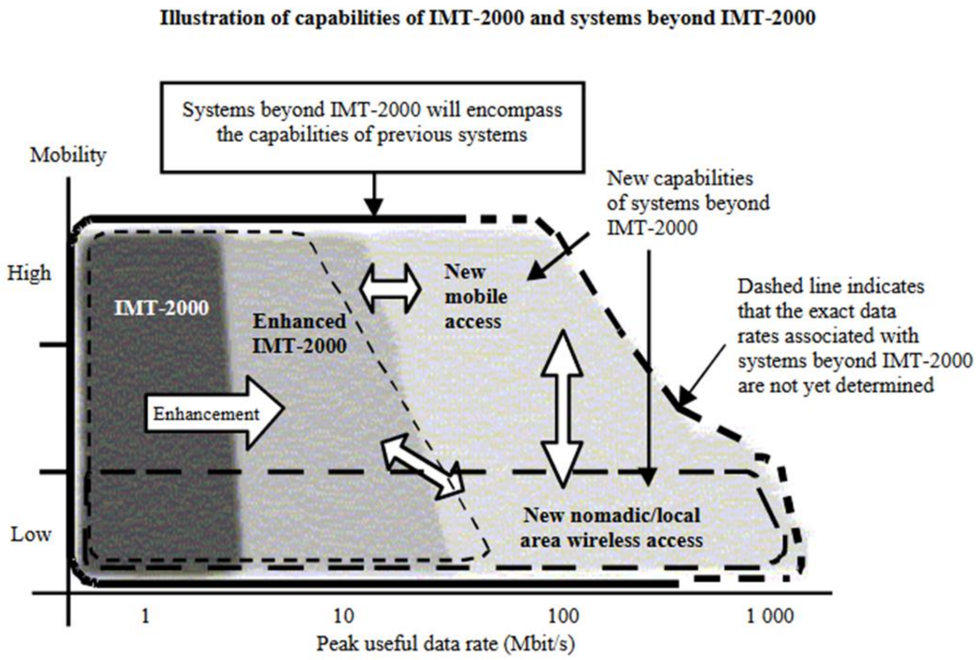


Figure 9 - Capabilities of IMT-2000 and systems beyond IMT-2000

IMT-2000, in use for over a decade since 2000, has been widely deployed and is commonly referred to as 3G.

The term “4G” remains undefined, but it is being applied by some operators to the forerunners of IMT-Advanced technologies — LTE, HSPA+, WiMax and to other evolved 3G technologies, which provide a substantial level of improvement in performance and capabilities with respect to the initial third generation systems now deployed.

In general the licenses/RoU are technology neutral in European Union countries but in practice specific technologies are implemented.

3. Source

Generally, the coverage is defined by the NRA (see section 2) and the maps or metrics that describe the extent of the coverage (see section 3) are provided by the operators that have the necessary tools to compute the information. Still, it can be useful that NRAs provide the source of the information (usually the operators) when they give an information on mobile coverage.

Appendix – B: Survey of NRA practices

Table to show how calculations and/or measurements are being used by different NRAs

Country (NRA)	Theoretical calculation	Drive Testing	Walk Testing	App-based (Panel)	App-based (Crowdsourcing)
Austria (RTR)	NO	NO	NO	RTR uses a mobile app to measure a sample of statistically significant locations in order to predict the coverage of mobile networks.	The RTR-NetTest informs users about the current service quality (including upload, download, ping, signal strength) of their Internet connection. In addition, a map view and statistics of previous tests can be accessed. (Source: https://www.netztest.at/en/) The NetTest data is not used to check the coverage obligations. Although, it is a good source to check the plausibility of the results.
France (ARCEP)	NO	YES At each obligation deadline, Arcep supervises drive-tests measurements in some randomly chosen areas: - Strength field measurements, - Voice-call attempts to check voice service coverage with 2G/3G, - Small DL to check data service coverage with 3G/4G	NO However some field measurements (walk tests) are done to measure mobile network's QoS	NO	ARCEP is interesting in app-based measurements and uses such data in order to "challenge" official measurements

Country (NRA)	**Theoretical calculation**	**Drive Testing**	**Walk Testing**	**App-based (Panel)**	**App-based (Crowdsourcing)**
Hungary (NMHH)	NO	YES Benchmark test for all mobile networks, all service providers - Coverage measurement 2G/3G/4G; - Data services test 3G/4G (File DL, File UL and ping).	NO	NO	YES, html5 and java based http://szelessav.net/hu/sebesseg_meres
Portugal (ANACOM)	YES.	YES.	NO	NO	YES. Please consult the following link http://www.netmede.pt/
Serbia (RATEL)	NO	YES Mobile drive testing benchmark for all mobile network operators once per year as of 2017 (drive test include more than 50% of the population to be covered, and all state highways and national roads of category one) - Radio parameters measurement - Voice service tested 2G/3G - Data services tested 2G/3G/4G (File DL, File UL, Static and Live Browsing, YouTube)	YES Regular walk testing measurements in randomly selected areas planned as of 2018	NO	YES RATEL NetTest application informs users about the service quality (including upload, download, ping, signal strength) of their fixed and mobile internet connection. In addition, a map view and statistics of all user tests can be accessed. Source: https://www.nettest.ratel.rs/en/

Country (NRA)	Theoretical calculation	Drive Testing	Walk Testing	App-based (Panel)	App-based (Crowdsourcing)
		Regular drive testing measurements in randomly selected areas planned as of 2018			
UK (OFCOM)	YES	YES	YES	YES	NO

Appendix – C: Practical measurement techniques

The practical techniques for measuring mobile coverage and mobile signal quality are diverse in their use and handling, but they often measure the same test parameters. The measurements have to be precise enough to evaluate the potential reduction in quality of service caused by the degraded network performance.

Test parameters generally include (but are not limited to):

- Download speed (from the measurement server to the user)
- Upload speed (from the user to the measurement server)
- Ping (latency)
- Packet loss
- Signal strength
- Connection transparency

Besides the theoretical modelling of mobile coverage, all measurement techniques can also be done by not-specialized teams, a panel of end-users or by crowdsourcing via a provided measurement app, although the measurement is sometimes carried out by specialists with testing equipment.

1. Theoretical modelling

Theoretical modelling is based on mathematical and statistical calculations. To simulate coverage extents the following parameters could be needed:

- Digital Elevation Models (DEM) or Digital Surface Models (DSM)
- Location of base stations
- Antenna information (e.g. HCM-Agreement on data exchange; Source: http://www.hcm-agreement.eu/http/englisch/verwaltung/index_berliner_vereinbarung.htm
- Attenuation of signals for indoor coverage;
- Maps used in the calculations including the population maps;
- Propagation models;
- Indication of measurements done to calibrate the propagation models, if applicable;
- Sensitivity per service;
- SNIR per service;
- Coding rate per service;
- Modulation per service;
- Typical antennas used, including the radiation patterns;
- Link budgets.

The attenuation for indoor coverage may differ between older buildings, energy efficient buildings and moving vehicles, like cars or trains.

A simulation of coverage can be done applying different models. Some of these models are empirical models for calculating signal propagation; some are physical models. All these models were evaluated and calibrated by measurements.

The output of models are coverage maps which are either based on pixels or polygons and show which areas are covered by which base station as well as the quality of the signal in that area.

2. Coverage predictions

Coverage predictions are based on coverage maps of either the operators or the theoretical modelling software. Locations, routes or areas are selected as a statistically representative sample. These measurement locations are then tested by a team that uses mobile apps on handsets or measurement equipment to document the relevant parameters.

The results of these measurements are statistically extrapolated in order to predict the coverage extent. The calculated coverage extent can be shown on maps or in individual metrics.

3. Drive Testing

Drive tests are a coverage measurement technique, where users are in cars or on trains to monitor the mobile signal. Sometimes these tests are done as a crowdsourcing test, but usually professional test teams travel on predefined routes. Drive tests can also include spot checks at fixed locations.

At train tests various problems may occur, such as modern railway cars usually having metallized windows which result in mobile signals hardly getting inside the cars. Train operators work with repeaters or outdoor antennas to provide mobile signal or WIFI.

Drive Tests with cars are often used to measure mobile coverage on highways or in rural areas. Antennas on the outside of the car are equipped with an attenuator to compensate for the positive effects of the antenna on the roof of the car.

Drive tests not only measure mobile coverage but also the handover from one antenna to the other at various speeds.

4. Walk Testing

Walk tests, like drive tests, measure mobile coverage while moving around. One benefit of walk tests is that the movement is slower than at drive tests, so the handovers from one antenna to the next are tested at a different speed. Another benefit is that it can be used indoor or in car-free areas like pedestrian zones.

5. App-based

App-based measurements of mobile coverage can support all the mentioned techniques apart from theoretical modelling. Mobile Apps can be used for coverage predictions, when measuring coverage while driving or walking a predefined route as well as for panel-based measurements or crowdsourcing.

App-based tests may be executed by users as crowdsourcing applications, by a selected panel of statistically representative users or by a team of professionals to evaluate the network for regulators.

6. Panel based

Panel-based measurements are done by a number of selected end-users, ideally the same group of people over a period of time, who execute a provided coverage test. The test may be a mobile app on a smartphone, a desktop application or it may require special technical equipment, which is provided to the user.

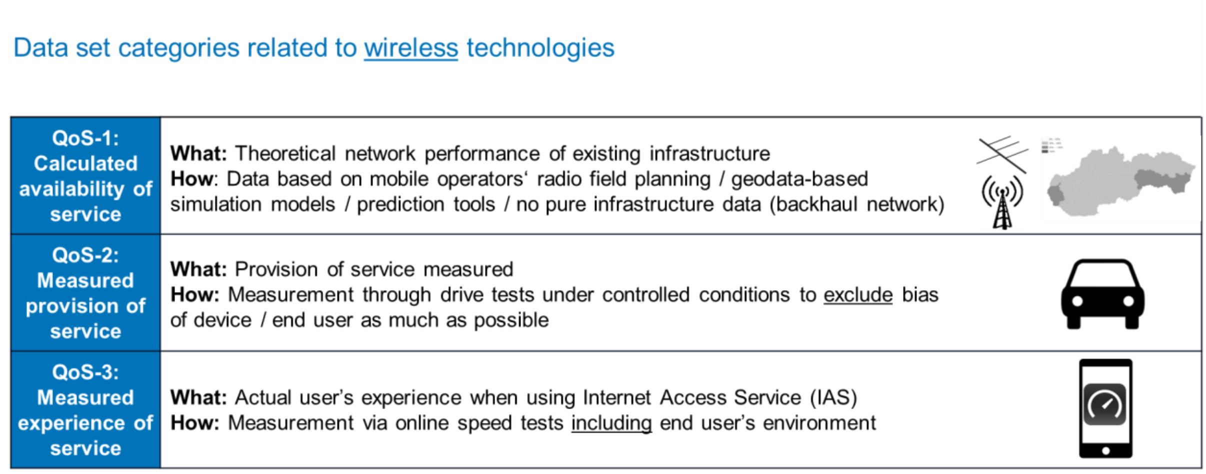
7. Crowdsourcing

Crowdsourcing applications are user oriented, intended for performing speed tests and measuring the quality of service for mobile internet connection. Usually, there is a map and visual representation (numerical and graphical) of the completed measurements with the options to filter results by test parameters, technologies, time periods and mobile operators. These applications include provision of measurement data according to the Net Neutrality and Open Data principle (all data can be published and made freely available to the general public for information, use, dissemination and other applications.)

When a test starts, the client (web browser or mobile application) establishes the connection with the measurement server, which is located at the Internet eXchange Point (IXP), as an independent point for all mobile network operators. This first connection is followed by tests where several parallel TCP connections are used to exchange small files and assess the current capacity and latency of the end user’s connection. The current signal strength is also measured, as well as connection transparency.

Crowdsourcing applications are desktop and mobile based and free of charge. However, during the tests, there is significant data consumption and in case of limited data volume end-users need to verify that data volume is not yet used up or their speed is not throttled due to the exceeded data volume of the selected bundle.

Appendix – D: Commission’s three layer QoS model



Data set categories related to wireless technologies

QoS-1: Calculated availability of service	**What:** Theoretical network performance of existing infrastructure **How**: Data based on mobile operators‘ radio field planning / geodata-based simulation models / prediction tools / no pure infrastructure data (backhaul network)
QoS-2: Measured provision of service	**What:** Provision of service measured **How:** Measurement through drive tests under controlled conditions to exclude bias of device / end user as much as possible
QoS-3: Measured experience of service	**What:** Actual user’s experience when using Internet Access Service (IAS) **How:** Measurement via online speed tests including end user’s environment

Figure 10 - Definition of the 3 layers of QoS defined for the European broadband mapping project

Appendix – E: Abbreviations

ANACOM	Autoridade Nacional de Comunicações (Portugal)
Arcep	Autorité de régulation des communications électroniques et des postes (France)
BEREC	Body of European Regulators for Electronic Communications

CEPT	European Conference of Postal and Telecommunications Administrations
DEM	Digital Elevation Model
DSM	Digital Surface Model
ECC	Electronic Communications Committee
ECO	European Communications Office
ETSI	European Telecommunications Standards Institute
IAS	Internet access service
IMIT	Institute for Management of Innovation and Technology
ITU	International Telecommunication Union
ITU-T	Telecommunication Standardization Sector
KPI	Key performance indicator
LTE-A	LTE advanced
MNO	Mobile network operator
NRA	National regulatory authority
Ofcom	Office of Communications (UK)
PESQ	Perceptual Evaluation of speech quality
QoE	Quality of experience
QoS	Quality of service
RATEL	Republic Agency for Electronic Communications and Postal Services (Serbia)
RF	Radio frequency
RoU	Right of uses
RSPG	Radio spectrum policy group
RTR	Regulatory Authority for Broadcasting and Telecommunications (Austria)
RxLev	Received signal level
RxQual	Received signal quality
SNIR	Signal to interference plus noise ratio
TCP	Transmission Control Protocol
VoLTE	Voice over LTE