BoR (17) 256

RSPG18-001

BEREC and RSPG joint report on Facilitating mobile connectivity in "challenge areas"

December, 2017

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Introduction

Many countries face difficulties meeting the increasing demand from users and local authorities for a mobile connectivity available in rural areas and in constrained areas such as indoor locations, subways, tunnels, hot spots, etc.

The main forthcoming objective of Europe 2020 is to become smart, sustainable and inclusive. European strategy seeks to ensure that by 2020 all Europeans should have access to much higher Internet speeds of above 30 Mbit/s and at least 50% or more of European households subscribe to internet access above 100 Mbit/s.

The Radio Spectrum Policy Group (RSPG) has previously considered coverage issues in a report and more recently in a workshop[1]. The technical and policy solutions to coverage challenges have continued to evolve and their implementation raises issues within both BEREC and RSPG competencies.

This joint BEREC-RSPG report aims at compiling some initiatives to facilitate terrestrial mobile connectivity in what could be described as ‘challenge areas’, where mobile connectivity is limited or non-existent.

In this report, the following challenge areas have been identified:

- Indoor;
- In transportation means;
- In non-profitable areas, such as white areas[2];
- In other areas such as protected areas, “grey” areas, low quality of service areas.

This list of “challenge areas” does not intend to be exhaustive. It reflects some difficulties encountered in Europe regarding mobile connectivity and reported by national regulatory authorities (NRAs) and spectrum managers.

This report describes the difficulties encountered in the identified challenge areas and will focus on the solutions and observed practices that have been implemented in EU member states to tackle the obstacles to mobile connectivity. Amongst other topics, this report addresses digital planning obligations or public/private initiatives, white area coverage, rural area coverage, constrained areas, indoor and transportation.

For each identified challenge area, the report focuses on technical solutions implemented or considered by EU member states. It also gathers regulatory or any legal measures that have been adopted in this regard. Forward-looking solutions are also studied, in the light of what is taking place in different markets.

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[1] See Report RSPG11-393 on improving broadband coverage: rspg-spectrum.eu/wp-content/uploads/2013/05/rspg11_393_report_imp_broad_cov.pdf and also RSPG workshop on coverage held on 8th November 2016.

[2] Areas in which there is no mobile broadband infrastructure and it is unlikely to be developed in the near future.

This Report can be used by policy makers as a knowledge base for methods of enhancing mobile connectivity in challenge areas.

Finally, at the end of this Report, examples of limitation or drawbacks to some described solutions are discussed but the Report does not describe the limitations of each solution. Policy-makers and NRAs will need to consider any limitations when proposing these as solutions to connectivity problems.

1. Indoor coverage

Today, consumers require more and more reliability from their mobile services. In 2013, the communications regulator in the UK, Ofcom, showed in a survey that the ability to make and receive calls was even more important than cost[3]. In particular, indoor coverage is becoming an increasingly important component of mobile service needs: indoor at work, as well as indoor at home, has become an essential issue that mobile network operators cannot ignore. In this section, BEREC and RSPG first give a description of mobile indoor coverage issues, then focus on studies and measurements performed in Europe to have a better understanding of indoor mobile coverage and, finally concentrate on dedicated indoor solutions in EU member states to improve indoor coverage.

1.1. Indoor coverage issues

Ensuring reliable indoor coverage in buildings is a challenge facing any mobile network operator or infrastructure provider. There is a significant difference when comparing outdoor and indoor coverage, for instance:

- in **the UK**, in premises voice coverage was 89% in 2016, compared with 97% coverage outside the premises, while in premises data coverage was 80%, as opposed to 93 % outside premises[4];
- in **the Netherlands**: in 2016, KPN's 4G mobile coverage was 98.4% outside the building whereas it was 96% indoors; Tele2's 4G mobile outdoor coverage was 76.3%, compared with 67% inside the buildings[5].
- In **Sweden** (October 2016), 4G mobile networks (allowing 10 Mbit/s data) covered approximately 69%[6] of areas outside buildings (excluding the 450 MHz band) compared with 44%[7] inside the buildings. Similarly, voice coverage[8] was 85% outside and 71% inside buildings.

[3] https://www.ofcom.org.uk/__data/assets/pdf_file/0018/62415/usage.pdf
[4] https://www.ofcom.org.uk/__data/assets/pdf_file/0035/95876/CN-Report-2016.pdf (Note that these coverage figures are based on an assumed average penetration loss of 10 dB to a good quality outdoor signal. This is then taken to provide a reasonable level of indoor coverage in a good amount of building floor space).
[5] www.4gdekking.nl
[6] Contains a margin for the body's impact on the antenna properties and attenuation of radio signals, such as when the terminal is held in the hand, to the head or near the body.
[7] Contains a +8 dB margin compared with the outdoor coverage

These differences reflect the service degradation experienced by users located inside the buildings, since the signals pass through materials on their way into a building, and can have to cross one or several walls.

This signal degradation is highly complex to predict due to the variability of the propagation environments and the unforeseeable nature of the signal loss. Indeed, the signal loss depends on the building form, on the building materials and on the receiver terminal characteristics.

For instance, modern buildings, that are designed to minimise heat loss by using certain types of insulation, often tend to increase the signal loss. Older buildings, particularly in rural areas with thick stone walls, can also represent a significant challenge.

Those characteristics have a large impact on signal strength and signal quality indoor.

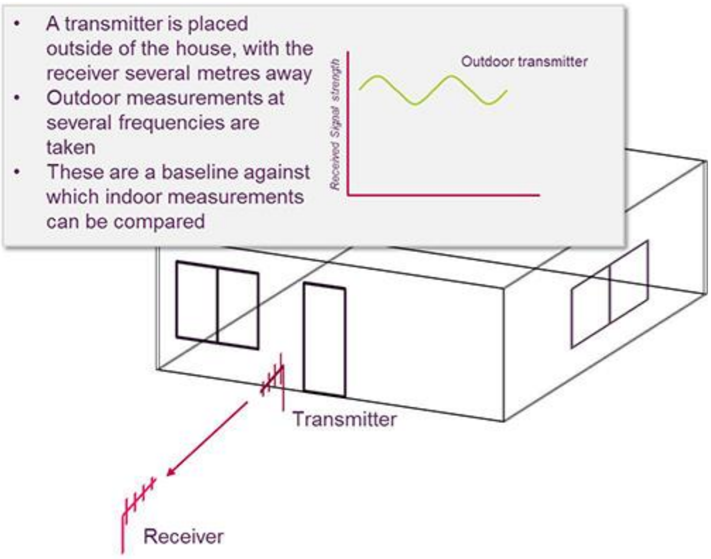

Figure 1 – Measuring the effects of construction materials on indoor coverage

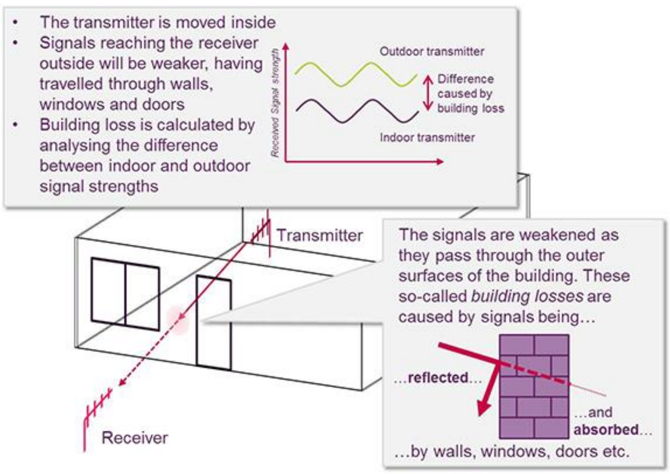

Figure 2 – Measuring the effects of construction materials on indoor coverage[9]

[8] 2G and 3G mobile networks
[9] Source: Ofcom, https://www.ofcom.org.uk/research-and-data/technology/general/building-materials

However, despite the technical difficulties in providing satisfactory indoor mobile coverage, consumers expect to have instant access to the mobile network regardless of whether they are indoor or outdoor. The challenge is to deliver fast and seamless connectivity to indoor users. Some studies have suggested that around 80% of all mobile usage traffic is indoor[10]. Data consumption in indoor environments is predicted to increase to above 90% in the next few years[11]. Although indoor coverage, quality of service (QoS) and quality of experience (QoE) differ from case to case, it becomes more and more appropriate to evaluate and manage indoor mobile coverage in order to facilitate mobile connectivity inside the buildings.

The new EU framework for energy efficient buildings[12] may have inadvertently contributed to indoor coverage problems. Modern energy efficient buildings or windows may attenuate radio signals up to 40 dB, when conventional building attenuation is 15 – 20 dB. Coverage problems are discovered in both new and renovated buildings. The problem occurs especially in new energy efficient houses or apartment buildings and older concrete apartment buildings, when new metal foiled energy efficient windows are installed.

Solving connectivity problems caused by construction technology with radio technical solutions is not always efficient or even possible. Enabling indoor coverage from outdoor base stations should also be in the interest of the construction industry. Mobile telephony and mobile connectivity is expected in homes and offices. In countries like Finland, where the wired telephone network is widely dismantled, mobile phone coverage is also a matter of safety.

Whilst indoor coverage remains a challenge in Europe, some countries have already taken measures to address mobile coverage inside of buildings.

1.2. Studies and measurements to have a better understanding of indoor mobile coverage

The enormous variability of building forms and materials might inspire a certain pessimism as to the possibility of providing any quantitative guidance on building loss. The situation is not, however, as bleak as it may appear and methods are arising little by little in some EU member states to set up standards defining indoor mobile coverage.

For example, in **the UK**, Ofcom has led studies, measures and calculations comparing indoor and outdoor signal levels in order to find an average of “building entry loss” that can result in a better prediction of mobile coverage inside the buildings.

The UK NRA continues to review its approach to establishing the likely signal loss experienced indoors. At present, despite large variations in losses in different buildings, Ofcom estimates between 10 and 18 dB of loss can represent reasonable average values

[10] In North America. Source : https://www.cisco.com/c/dam/en/us/solutions/collateral/service-provider/small-cell-solutions/smallcells-infographic.pdf

[11] Source: Ofcom, https://www.ofcom.org.uk/__data/assets/pdf_file/0015/63006/final_report.pdf (2013)

[12] On 30 November 2016 the Commission proposed an update to the Energy Efficiency Directive 2012/27/EU including a new 30% energy efficiency target for 2030, and measures to update the Directive to make sure the new target is met.

for frequencies between 800 to 2600 MHz and for the vast majority of existing UK housing stock. From a regulatory perspective, a coverage obligation is in place on a single UK operator to provide a signal capable of supporting an at least 2 Mbit/s mobile service inside at least 98% of UK Households by the end of 2017.

In **Romania**, ANCOM decided to place indoor coverage obligations on all licenses: a 95% probability of indoor reception is required. To verify the compliance with this requirement, ANCOM leads outdoor field measurements and then adds a correction factor to the results in order to obtain the indoor signal. Regarding the indoor coverage, the correction factor relating to the indoor propagation attenuation is stipulated in the licenses as follows:

- 6 dB for radio signals in the frequency ranges 800 MHz and 900 MHz, and 8 dB for radio signals in the frequency ranges 1800 MHz and 2600 MHz for coverage in rural areas and coverage on national and European roads, as well as on highways;
- 12 dB for radio signals in the frequency ranges 800 MHz and 900 MHz, and 16 dB for radio signals in the frequency ranges 1800 MHz and 2600 MHz for mobile coverage in urban areas.

In **Austria**, the coverage obligation of the Multiband-Auction 2013 includes also indoor coverage requirements (for data services in the 800 MHz band for dedicated communities) with an extra attenuation of 20 dB considering building loss.[13]

In **France**, there is no indoor requirement placed on licenses; however in order to reflect users' experience (concerning voice and SMS services) Arcep has defined a correction factor to the outdoor strength field measurements[14]. Mobile operators have to publish mobile coverage maps with several levels of coverage:

- "Satisfying coverage": a certain strength field level is measured. It corresponds to the case where mobile coverage is generally available outside of buildings;
- "Good coverage": a correction factor of -10 dB has been applied in order to reflect the locations where the coverage is available most of the time outside of buildings and sometimes inside of the buildings;
- "Very good coverage": a correction factor of -20 dB has been applied in order to reflect the locations where the coverage is available outside of buildings and most of the time inside of the buildings.

In **Sweden** there are no particular indoor requirements in the licenses. However, the operators have an agreement with the NRA how to present their coverage on their coverage maps. The signal is measured or predicted outdoors and a margin of 16 dB penetration loss applied. Very good coverage is defined as an area where one probably can both make phone calls and use mobile broadband outside and inside. Indoor coverage depends on the walls, windows and doors and where in the building one is.

[13] Source: RTR, https://www.rtr.at/en/tk/multibandauktion_AU/27890_2013-03-26_F1_11_Tender_Document_Multiband_Auction_2013.pdf
[14] Source: Arcep, https://www.arcep.fr/uploads/tx_gsavis/16-1678.pdf

1.3. Deployment of dedicated indoor solutions to address indoor coverage

A number of measures are underway to facilitate mobile indoor connectivity in several EU member states. These measures consist of promoting the deployment of dedicated indoor solutions including Wi-Fi, repeaters, femtocells and Distributed Antenna Systems (DAS).

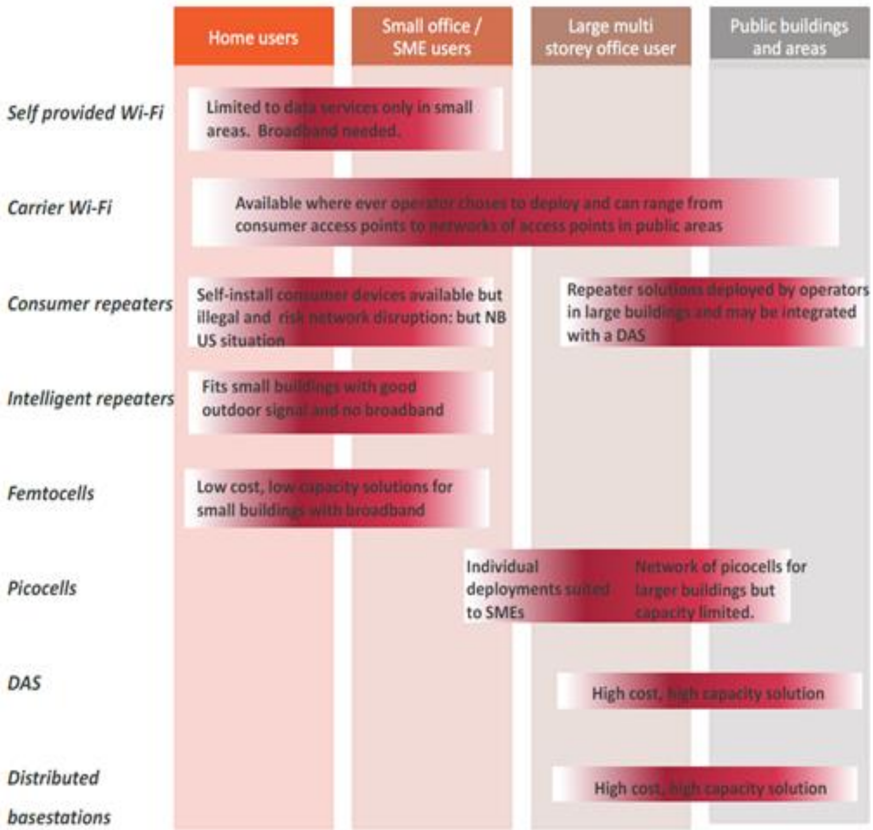

Figure 3 - Summary of dedicated in-building solutions[15]

1.3.1. Wi-Fi

For many years, Wi-Fi has been deployed in homes and businesses: users buy their own Wi-Fi access point and install it themselves. This type of Wi-Fi has been used to provide data services; these past few years, it is more and more promoted to receive calls and SMS to the mobile phone number.

For instance, in 2015, the **Swiss** mobile operator, Swisscom, claimed to be the first European operator to effectively combine voice-over-LTE and Wi-Fi calling to overcome weak mobile signals in heavily insulated buildings.

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[15] Source : Ofcom, https://www.ofcom.org.uk/__data/assets/pdf_file/0015/63006/final_report.pdf

Furthermore, a solution for indoor coverage in **The Netherlands** is being rolled out by MNO's with Voice over Wi-Fi (Vo-Wi-Fi). This is a good solution especially for highly insulated new builds, which are often connected via fixed broadband.

In **the UK**, as well as in France, all MNO's have also implemented Wi-Fi calling on their networks, although these implementations are at different stages of development and in some cases fully available only on a limited number of devices.

In **Ireland**, the operator Eir in Ireland has launched Wi-FI calling[16].

1.3.2. Repeaters

A repeater is a mobile signal amplification device which requires a signal from MNO's basestation/NodeB/eNodeB (also known as donor site) to work. Both the signals coming from the donor site towards the user equipment (downlink) as well as the signals coming from the user equipment to the donor site (uplink) are amplified. The link between donor site and the repeater could be via radio (off the air repeaters), fibre (fibre optic repeaters) or other types of dedicated network. To be able to select which signals and operators to amplify or not, the repeaters are normally equipped with different types of filters as for example channel-filters, band-filters and digital-filters. Repeaters are not only used for indoor coverage in buildings but also used to cover road tunnels, train tunnels and metros.

Repeaters do not add any capacity to the network. It should be noted that although indoor coverage can be significantly improved by installing an indoor off the air repeater, the signals from the donor site must be adequate for the repeater to work properly. Correct installation and good hardware are also important when working with repeaters to minimize the noise impact on the donor site.

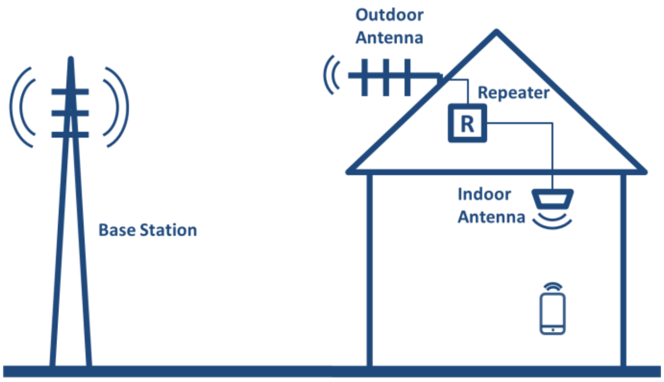

Figure 4 - off the air mobile repeater

In this way, in **the Netherlands**, three MNO's have a combined policy for providing indoor repeater systems which operate on their mutual frequencies. Large public space buildings, for example hospitals, represent a positive business case for installing and operating these systems.

[16] https://www.eir.ie/wificalling/

Another typical example is the use of repeaters in **Malta**. Indeed, Malta's thick walls offer challenges to operators in providing adequate mobile services inside the buildings. This situation leads, in many circumstances, to a loss of coverage and QoS. Thus, when the "donor" mobile signal level is adequate, indoor repeaters are often used to address this issue.

In **the UK**, the use of mobile phone repeaters is only authorised if it is supplied and operated under the control of a mobile network operator (under its Wireless Telegraphy license); thereby, the use of self-installed repeaters is unlawful. At the beginning of 2017, Ofcom has set out proposals in a public consultation on measures to develop a specification that would allow consumer installed repeaters to be placed on the market in the UK on a license exempt basis. The consultation sets out a specification that may allow such devices to be deployed without significant risk of network interference. In particular, Ofcom suggest that in order for the repeater to work in a safe way, it would need to be able to determine the reduction in signal power on the path from the base station (the coupling loss) and automatically to adjust its gain, so that it would only amplify the signal sufficiently to provide an acceptable service, while not unduly raising the noise within the mobile network or blocking (overloading) the base station's receiver. Ofcom also suggests that, as different networks base stations may be in different proximity to the device, it should be limited to only communicating with one mobile phone network at a time.[17]

1.3.3. Smallcells and Femtocells

A femtocell is a low-power access point, providing wireless voice and broadband services to customers in homes and in small office/home office. This small box, similar to a Wi-Fi access point but using frequency bands that are licenced to the operators, accesses the operator's network via the user's broadband connection and then transmits mobile signals to the mobile devices of users in the home. In a word, a femtocell is like a localised mobile network in the home/office.

In the case of big office buildings (or sometimes outdoor), the same kind of access is provided by smallcells installed by operators.

[17] For more details, see: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/100277/Mobile-phone-repeaters.pdf.

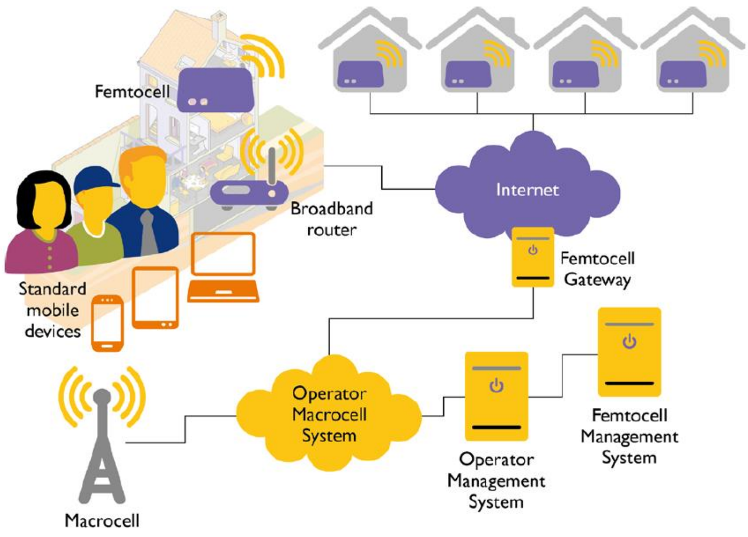

Figure 5 - Typical Femtocell Deployment Scenario[18]

In **the UK**, all MNOs can offer femtocells for customers with poor indoor reception, available at cost (and in some cases limited to the business user market). A multi-operator femtocell solution has been developed commercially by a company (aimed at small-medium businesses). This solution requires a contractual relationship with participating mobile operators to resource a direct feed from the networks.

1.3.4. Distributed Antenna Systems

Distributed Antenna Systems (DAS) are an infrastructure of cables and antennas installed within a building to distribute mobile signals. A DAS allows the connection of a wide range of wireless devices, such as cell phones, tablets and public safety radio, without interfering with each other.

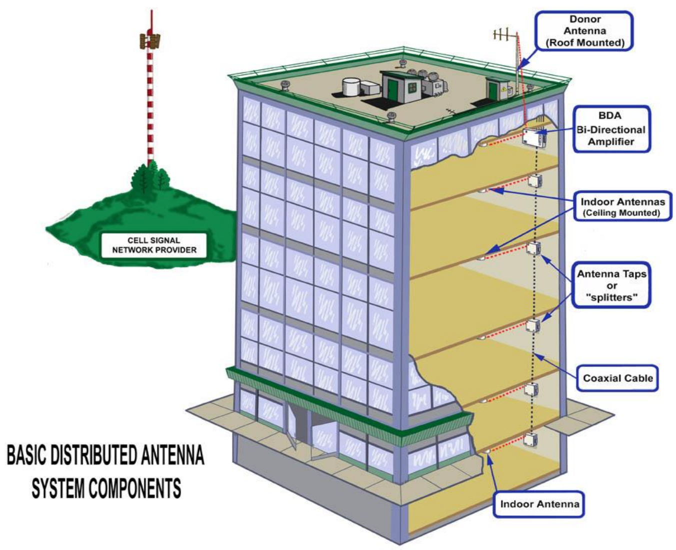

Figure 6 - DAS system components[19]

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[18] Source: Small Cell Forum http://www.smallcellforum.org/

DAS are mainly deployed in public environments. Indeed, many areas are equipped with antenna networks such as airports, sports complexes, shopping malls, congress centres and transport stations. In **France**, Hub One tested the compatibility of DAS with 4G at Charles de Gaulle Airport (Terminals 2E and 2F). Experimentation has shown the coexistence of LTE and TETRA services on the same network of antennas. In **the UK**, DAS is deployed in a number of large scale, high footfall indoor environments including at the Canary Wharf shopping centre, Gatwick Airport and the recently completed 'Shard' office space.

1.3.5. Construction regulation

In **Finland** the Government has suggested that indoor coverage of mobile networks would be considered in the regulation of construction of buildings and their energy efficiency. It is essential that connectivity is considered in the planning phase of a residential area, a building or renovation. It should also be evaluated how indoor coverage of mobile networks could be considered in the EU-regulations for energy efficiency of buildings. Indoor connectivity is also necessary for enabling e.g. smart buildings and IoT-systems for energy efficiency.

The 4G licenses in Finland include obligations for reasonable indoor coverage. Still, changes are required on the construction side, as the costs for providing indoor connectivity in energy efficient buildings with up to 40 dB building penetration loss cannot be carried by the MNOs.

1.3.6. Private GSM/LTE networks

In 2008, the **Netherlands** created the possibility for operating private GSM networks in the 1800 MHz: low power use can be made of the 2x5 MHz, which is license-free available in the DECT guard band (1780-1785/1875-1880 MHz). Specialised companies (other than MNO's), but also one MNO, made a positive business case from providing such services. The number of pGSM networks is over 500. The healthcare sector is the largest user because of high indoor use requirements. A combined pGSM/DAS system offer its users high reliability, availability, better radio coverage, and the option of customizations for their mission/business critical processes.

Sweden has a license exempt in the above mentioned frequency band too. The frequencies can be used for GSM, UMTS, LTE and WiMax. Both MNOs and other may use it for indoor coverage.

2. Ensuring mobile connectivity in road and rail transport

For many reasons, mobile networks operators may encounter difficulties in accessing infrastructures like roads, railways, tunnels or subways. This leads to a lack of mobile connectivity for consumers who are travelling. For instance, coverage of road and rail routes

[19] Source : http://www.cc-n.com/solutions/distributedantennasystems

in the UK remains lower than coverage across the wider landmass, with 62% voice coverage of major roads (excluding Motorways) and 45% data coverage reported in 2016[20].

In this section, BEREC and RSPG study the nature of the difficulties and constraints that mobile operators have to face in order to bring mobile coverage in transportation means. They then focus on the measures that have already been taken in Europe to enhance mobile connectivity along transportation routes.

2.1. Difficulties and constraints whilst travelling

BEREC and RSPG believe that there are three key factors which contribute to a lower coverage in vehicles and trains.

First of all, according to Ofcom measurements, the signal loss experienced for reception inside a car or train means that the signal outside must be on average around 10 dB higher than would otherwise be necessary for a good quality of experience. The construction materials used in some newer trains contribute to the poor coverage. In particular, the train windows are sometimes coated in a metallic film or mesh. While this has the desired effect of helping to regulate the temperature within the train, the coating also weakens or blocks mobile signals from passing through. These losses can vary from vehicle to vehicle and train to train. Besides, and particularly in the case of rail, the deep cuttings and tunnels can often constitute an obstacle to deliver a proper signal to these places using the existing macro network. This challenge is related to indoor coverage (see above 1.1)

Another difficulty in along transport routes is due to the practical coordination needed to deploy the mobile infrastructure in these locations, especially in tunnels. Because several players are involved in the infrastructure deployment, operators have to face safety issues and they must take into account journey disruption issues. These factors can mean that access to land is difficult to obtain in the first place, and subsequent deployments are more complex. Added to this, interference concerns with the railway’s own communications infrastructure may be at play and sometimes mobile operators encounter contractual problems in obtaining access.

Lastly, as the user is moving, sometimes very fast, from one location to another, mobile connectivity can be affected by handover issues.

2.2. Solutions to facilitate mobile connectivity in transportation means

To address the challenge of mobile connectivity in transit, several EU member states have already implemented some solutions.

Network sharing constitutes one common suitable response to improve mobile connectivity on the move:

[20] Source : Ofcom, The above figures include offsets for in vehicle signal attenuation

- In **Austria**, mobile operators concluded infrastructure sharing agreements for special areas such as tunnels, underground and railways (mainly under participation or control of the facility owner).

- In **Spain**, Másmovil and Orange concluded a deal in 2016 to share transport capacity to reach the sites (backhaul links).

- Use of DAS systems in tunnels.

- Repeaters or Wi-Fi in trains.

There are also EU member states that place *coverage licence obligations on operators*. For instance in **France**, the LTE licences require that mobile operators offer coverage on main roads and for rail networks (see below Table 1)

Coverage obligations of transportation lines (% of kilometers)	17 January 2022	17 January 2027	8 December 2030
Main roads (approximately 50 000 km)		100% (800 MHz)	100% (700 MHz)
Regional rail network: national coverage (approx. 23 000 km of lines)	60% (700 MHz)	80% (700 MHz)	90% (700 MHz)
Regional rail network: coverage in each region		60% (700 MHz)	80% (700 MHz)

Table 1 - Mobile coverage obligations along main roads and railways in France for 4G

Furthermore, the *State involvement* and close negotiations between stakeholders have shown some success.

For instance, in **the Netherlands**, the administration has a flanking policy towards mobile coverage in tunnels and subways. Since 2016, there are regular meetings between Ministries, tunnel owners (in most cases the State) and MNO's. It was found that MNO's recognise the importance of mobile coverage and are willing to invest to install the necessary systems. The underlying principle is that the tunnel owners facilitate the possibility for mobile coverage infrastructure and that MNO's are responsible for the financing of technical facilities and maintenance. In 2017 the administration is working on producing an inventory list of the existing tunnels that lack mobile coverage. Once the inventory list is completed, all involved parties will continue the dialogue in order to find solutions for mobile coverage in tunnels.

The UK is another example where the State has taken a role in facilitating mobile connectivity while in transit. The UK Government has a committed to make it a requirement that future train franchises provide free on board Wi-Fi to passengers and Ofcom is working with the Department for Transport and Industry to consider the different approaches that can be taken, including the deployment of further trackside infrastructure, and delivery through the existing network infrastructure.

Finally, even if mobile operators cannot offer a steady and high quality of service in all means of transport, BEREC and RSPG consider it important to *keep consumers aware* of the performance of their mobile services through *transparent and localised information*. In this respect, some EU national regulators provide reliable information to the public:

- In **the UK**, Ofcom is currently undertaking programmes of research to define as precisely as possible the average signal loss experienced in different kinds of cars and trains in order to give appropriate information to consumers on the in-vehicle performance of the macro-network in areas that they travel around.
- Each year, in **France**, Arcep conduct quality of services (voice, SMS and data) measurement campaigns and publish reports in order to compare MNOs and to inform French customers. The results of the 2017 campaign are available on a dedicated website[21] and all the measurements are available on open data[22].

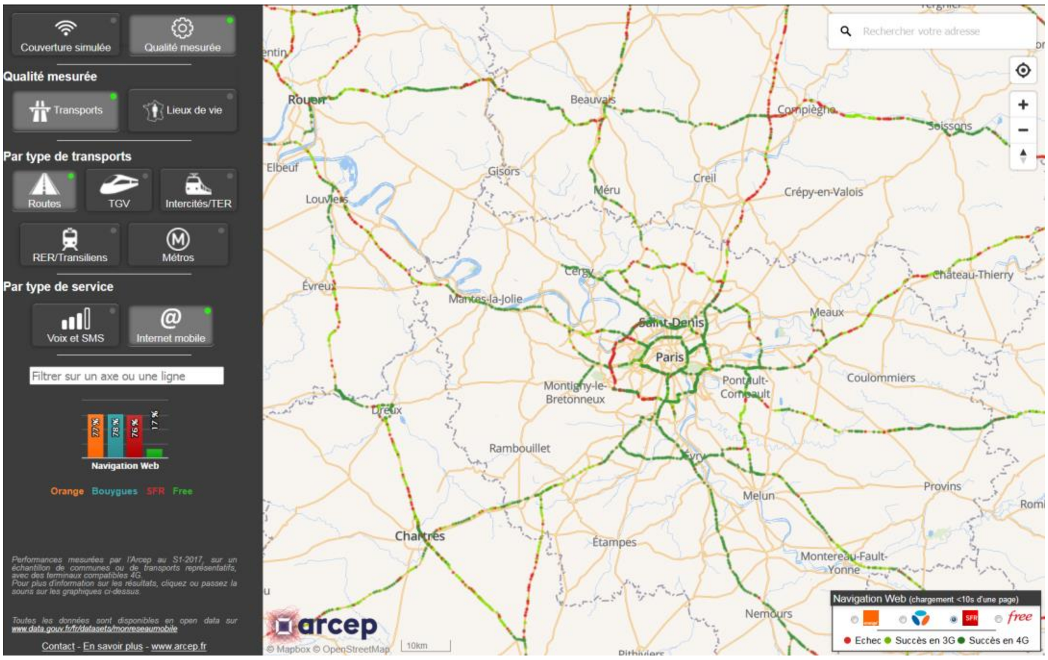

Figure 7 – Arcep informs mobile users of the MNOs' QoS and coverage performances, www.monreseaumobile.fr

3. Extending coverage within non-profitable areas

Non-profitable areas represent another challenge for mobile coverage in EU member states, since they are locations where mobile network operators have an expensive roll-out with little potential income. Generally, these areas are remote rural areas where there often is a significant lack of mobile broadband coverage.

In this section, BEREC and RSPG give an overview of the issues raised in non-profitable areas and then will focus on the measures that have already been taken in Europe to address this challenge.

[21] www.monreseaumobile.fr
[22] www.data.gouv.fr/fr/datasets/monreseaumobile/

3.1. Non-profitable area issues

BEREC and RSPG identified two main key factors contributing to this phenomenon:

- *Cost* of installing and maintaining sites in rural areas, especially with the likelihood of sometimes significantly higher costs for backhaul (noting that for remote sites satellite backhaul can play a role in reducing these costs), trackway access, power, rents and in some instances the tower itself. Compared to urban areas, the cost is also increased in case of difficult terrain such as mountains and forests, with a higher proportion of obstacles and natural clutter, meaning a greater density of sites can be needed to cover an area appropriately (when setting aside capacity considerations);

- *Reduced economic benefit* to the operators in terms of traffic on the mast and users in the coverage area;

3.2. Dedicated solutions to address non profitable areas

A number of measures have been taken in several EU member states in order to take steps towards meeting this challenge.

3.2.1. Placing coverage license obligations on operators

A common approach to promote wider wireless broadband service coverage consists of introducing specific obligations in spectrum licences. The 2012 RSPG /BEREC Report on "Economic and Social Value of Spectrum"[23] showed that coverage obligations should be carefully defined and should take into account the benefits for consumers as well as the ability to measure the compliance: If the requirement is poorly specified, then operators can easily comply with the obligation without bringing the users an appropriate service. Actual implementation of coverage obligations usually addresses the key objectives for mobile broadband coverage, in particular with respect to mobile coverage in non-profitable areas. In several cases competent authorities imposed asymmetric coverage obligations (e.g. dedicated coverage lot for one of the MNOs) in order to avoid replication of infrastructure in non-profitable areas.

In this section, BEREC and RSPG give a non-exhaustive list of coverage obligations set in the EU in order to facilitate mobile connectivity, even in remote areas.

The **Austrian** Regulatory Authority Telecom-Control-Commission (TKK) has defined different obligations in each band. Most of them are formulated in terms of percentages of population. One requirement of the coverage obligation in the 800 MHz band dealt with communities that had a poor broadband coverage prior to the auction procedure. TKK identified 541 villages, most of them with less than 20% indoor coverage and less than 50% outdoor coverage. As a result of the auction the coverage obligation forces one operator

[23] http://berec.europa.eu/eng/document_register/subject_matter/berec/reports/61-joint-berecrspg-report-on-exploring-the-economic-and-social-value-of-radio-spectrum-for-certain-electronic-communications-services-with-respect-to-the-frequency-assignment-procedures

(which bought a special coverage lot) to cover 360 and the other operator to cover 180 of those communities with broadband services with a minimum data rate of 2 Mbit/s (DL) and 0.5 Mbit/s (UL) (at least 50% indoor and at least 90% outdoor). It is expected that a vast majority of those villages will be covered as a result of the fulfillment of the coverage obligation.[24] In preparation for the award of 700 MHz spectrum RTR is currently conducting a study on the cost of covering certain areas like roads, non-populated areas and deep indoor.

In **France**, coverage obligations are mainly formulated as a percentage of the population of an area to be covered by deadline dates. Added to this, an "area of high priority (an area with a low density of population) has been defined by the French regulator (Arcep) for LTE deployment; this area represents 63 % of the territory and 18 % of the population. The operators have an obligation to cover a certain percentage (population) of this area (40 % by January 2017 and 90 % by January 2022). As a result some parts of rural areas now have 4G at the same time as urban areas. A "normal" rollout would have taken longer to bring 4G coverage to these areas without these obligations. Some similar obligation has been developed for GSM and UMTS. Arcep publishes and regularly updates an online observatory to follow these obligations: http://www.arcep.fr/zones-peu-denses

In **Malta**, the operators were required to provide services on a nationwide basis: 99% of the outdoor Maltese territory has to be covered with mobile services. This type of requirement is intended to ensure that electronic communications services are provided within the entire national territory, irrespective whether the area is densely populated or rural.

The Netherlands is in the process of considering a possible future legal coverage obligation. At this moment The Netherlands consisting of 388 communities. The local circumstances can vary between urban, suburban and communities with specific circumstances like (big) lakes, woods and nature reserves and parks. The Dutch administration is investigating a geographical coverage obligation of 98% per community in The Netherlands for the new licenses in the 700 MHz bands (the auction is foreseen in 2019). This coverage obligation would likely have the flexibility for the MNO to use other available spectrum rights and the obligation might apply in due time.

In **Portugal**, each mobile operator (in a total of 3 mobile operators) has the obligation to cover 160 parishes (with deadline dates), defined in the context of an auction in 2012, and these coverage obligations only can be met with the use of frequencies in the 800 MHz and 900 MHz bands (the operator should communicate if they intend to use the 900 MHz band), with speeds of 4 Mbit/s, 7.2 Mbit/s and 43.2 Mbit/s, that were defined based on the commercial offers subscribed by each operator. Additionally, further obligations (with deadline dates) were specified in another 588 parishes (196 parishes per operator), in the context of the renewal of the frequencies 1920-1980 MHz / 2110-2170 MHz in 2015/2016, where in each parish 75% of the population should be provided with a mobile broadband service that allows data transmission speed of 30 Mbit/s (maximum download speed) - this speed corresponds to the theoretical upper rate that is possible for a user in an external environment, including signalling/codification traffic – these coverage obligations can be met with all the frequencies for which rights of use were granted to the mobile operators.

[24] Source: https://www.rtr.at/en/tk/multibandauktion_ergebnis_20141223092801

Regarding the remote rural areas, in the spectrum auction conducted in 2012, the **Romanian** national regulator (ANCOM) imposed for each operator that acquired rights of use for the radio frequencies below 1 GHz (800 MHz and/or 900 MHz) the obligation to cover a certain number of the 676 localities unserved by broadband mobile communications networks, in direct proportion to the acquired spectrum resources. The deadline by which the operators were obliged to cover these localities was 5 April 2016. Starting from 6 April 2016, the Authority carried out a campaign to verify the degree of compliance of operators with their obligations to cover, by UMTS, IMT-enhanced (HSPA, HSPA+) or LTE technologies, or other equivalent technologies, the rural localities listed in the mobile communications network licences they had acquired. Following ANCOM's audit actions, three operators were found in breach of their obligation to cover 90 localities of those under their licenses.

In **Slovenia**, the population is exceptionally dispersed. In order to improve broadband coverage, the national regulator (Agency for communication networks and services of the Republic of Slovenia, AKOS) emphasised the need for coverage in so-called white areas in the spectrum auction conducted in 2014 for radio signals in the frequency ranges 800, 900, 1800, (2100) and 2600 MHz. The national regulator decided that, in addition to the general coverage obligations (75% of the population of the Republic of Slovenia), one operator[25] had to provide mobile broadband services at a bit rate of at least 10 Mbit/s downlink (outdoor) to at least 95% of the population of the Republic of Slovenia within 3 years. With this measure, AKOS aimed at providing suitable coverage of white spots in rural areas and appropriate regional distribution. AKOS also published a list of 300 locations – settlements or connected groups of settlements – which were either not covered or poorly covered by a fixed broadband network. Within the scope of the above requirements, the selected operator had the obligation (after 3 years) to provide at least 75% population coverage in each of the selected 225 settlements from the list.

In addition to this, the operator has to provide a suitable substitute service for fixed broadband access - fixed wireless broadband access (FWBA) – by installing appropriate internal or external customer-premises equipment (CPE) with a suitable antenna, providing a user experience bit rate of at least 10 Mbit/s downlink (and with guaranteed minimum bit rate of 2 Mbit/s downlink / 1 Mbit/s uplink) [26].

The AKOS's verification at the end of 3-year period (June 2017) shows that this obligation was successfully fulfilled. In addition to the required 225, another 18 locations from the list of 300 settlements or groups of settlements (so-called "white spots") were covered. AKOS notes that operator's network with base stations designed to cover the selected 225 locations covers over 40 thousand network connection points from the Collective Public Infrastructure Cadaster, where they do not have the possibility of adequate fixed broadband access.

Spain has been obliged to consider options for *refarming* 900 MHz and 1800 MHz frequency bands for new mobile technologies, since 2G networks approach the end of their natural life,.

[25] The auction resulted that operator with special coverage obligation is Si.mobil d.d., now A1 Slovenija d.d.)
[26] Chapter 2.2.4 Bit rate of the user experience in the document "Methodology for verifying the fulfilment of obligation" (http://www.akos-rs.si/files/APEK_eng/Radio/4G/Revised-Methodology-for-verifying-the-fulfilment-of-obligation-ENG-11.3.2016.pdf)

Coverage obligations were imposed at that time: Telefónica and Vodafone had to make a choice between two different commitments in population entities of less than 1,000 inhabitants, by 2013:

- investment obligations: Investment of 160 million euros and 80 million euros, for Vodafone and Telefónica respectively; or
- coverage obligations: delivering a signal coverage to 1 million inhabitants and half million inhabitants, for Vodafone and Telefónica respectively.

Both operators chose the “coverage obligations” option.

In 2011, in addition to the *refarming* bands, Orange (France Telecom at that time) was awarded a concession for the remaining paired 5 MHz block in the 900 MHz band. This operator committed to an investment of 433 million euros in population entities of less than 5,000 inhabitants, much higher than the 123 million investment indicated in initial specifications.

In the same year, the successful bidder Xfera (now Másmovil) agreed to make an investment of 300 million euros for three paired 5 MHz blocks in the 1800 MHz band. This amount represented five times the initial investment defined in the bid specifications.

With regards to 800 MHz and 2.6 GHz bands, specific obligations were defined for the successful bidders with paired 10 MHz in the 800 MHz band, Telefónica, Vodafone and Orange, which must have accomplished the following joint requirement by 2020: Cover at least 90% of the citizens in those population entities with less than 5000 inhabitants and a speed of 30 Mbit/s (this approximately implies reaching 98% of total country population).

In accordance with these coverage obligations, the Spanish Ministry of Energy, Tourism and the Digital Agenda (MINETAD) must define an 800 MHz Obligations Coverage Plan considering other bands or technologies. This plan will identify the population entities with no access to 30 Mbit/s, describing the corresponding coverage obligations and the technical definition for 30 Mbit/s. The MINETAD has launched a public consultation so that the awarded operators (Telefónica, Vodafone and Orange) and other interested organizations can make proposals to the 30 Mbit/s definition.

In **Sweden** one of the frequency blocks in the 800 MHz band was auctioned on condition that the licensee should cover certain identified uncovered permanent homes and business places with data communications at a cost of a least approximately 30 000 000 euros.

In 2013 and 2015, PTS was commissioned by the Ministry of Enterprise and Innovation to bring together telecom operators with local and regional representatives with the goal to promote the expansion of mobile networks, thereby further improving mobile coverage in Sweden. During several regional meetings in Sweden, operators and local and regional representatives discussed how to cooperate and to increase expansion and identify good examples of successful collaboration.

In 2016, PTS summarized the insufficient infrastructure conditions for 517 households in Vilhelmina municipality in the northern part of Sweden, followed by an invitation to interested parties to present technical solutions for these households. The purpose of the arrangement was to clarify if internet speeds of 30 Mbit/s could be achieved in a municipality where the infrastructure today is not considered to be sufficient and also to verify the assessment that Sweden can reach the EU Commission's target of 30 Mbit/s by 2020. As a result of this, a workshop was held in Lycksele municipality October 20th 2016 where 8 different technical solutions were presented.

In 2013, **the UK** Government established a fund of up to £150m for a Mobile Infrastructure Project to deploy masts into remote areas. 76 sites were deployed by the end of the programme in 2016. Additionally, all MNO's in the UK have a licence obligation to deliver a voice service across 90% (at a given signal strength) of the UK geography by the end of 2017. One operator also has a licence obligation to provide coverage (capable of supporting a 2 Mbit/s service, based on a lightly loaded cell) inside 98% of UK premises by the end of 2017.

3.2.2. Leading a concerted approach between involved stakeholders (public authorities, operators, local authorities)

If several countries impose coverage obligations directly in the mobile licenses, there is also sometimes a concerted approach between the involved stakeholders aiming at facilitating mobile coverage in non-profitable areas.

For instance, the **French** Government, the national Regulator and operators came to an agreement concerning the coverage of non-profitable areas. In 2003, a list of white areas was established; all operators, using network sharing (see below 0) and with public funding, had to cover with 2G technology (voice and SMS services) the centre of all villages on the list. This agreement was renewed in 2015, including an enlargement of the list and coverage with 3G technology. There are more than 3,800 villages in the program; more than 99% of them now have 2G and 3G coverage by all operators.

Thanks to a pragmatically concerted approach, **the Netherlands** offers in general a very high coverage. Indeed, in case of problems within a specific challenge area, local authorities assisted by the Radiocommunications Agency, together with the operator(s) explore the possibilities of improving coverage. In most cases this approach proved to be successful to solve coverage complaints.

In **the UK**, the Government decided to amend the law to make it easier for MNOs to deploy their networks. Government legislation has amended the Electronic Communication Code, which govern the terms on which land is acquired and accessed by the MNOs and Ofcom is consulting on a code of practice to supervise this[27]. In England and Scotland, planning law has also been amended to raise the threshold for the mast height which operators can

[27] https://www.ofcom.org.uk/__data/assets/pdf_file/0031/99148/ecc-consultation.pdf

deploy without having to seek formal planning permission.[28]. Scotland has also consulted on amending its planning law[29].

In **Malta**, the Government adopted a regulation to relax the regime for the installation of telecommunications infrastructures, such as mobile base station antennas. This regulation was adopted in 2007[30], and today, a full development planning permit is only required with respect to mobile phone antennas installed at certain locations, such as areas outside development zones and scheduled areas.

In **Austria**, the government published a "Masterplan for promoting broadband".[31] After the Multiband-Auction 2013, which raised 2 Billion Euros, the government announced to use 50% of the revenue (1 Billion Euros) for a public funding program for broadband in rural areas. Parts of the program are open to mobile operators (e.g. for connecting base stations via fibre or other backhaul investments).[32] The program, which is supposed to run between 2016 and 2020, is currently ongoing and several projects have already been funded.

In **Croatia**, another funding program "Program for Internet and broadband development" was carried out from 2012 to the end of 2015. It resulted in broadband access at a minimum speed 2 Mbit/s which should be increased to 30 Mbit/s in accordance with the objectives of the Digital Agenda. Target users include schools, health care institutions, public institutions and volunteer firefighters associations. Users were identified based on internal analysis, which culminated with identification of spots with no broadband access or spots with low quality data coverage, based on information collected from fixed and mobile operators. The Program was technology neutral regarding technical solutions, but in most cases resulted in an upgrade of mobile network coverage or capacity.

In **Spain**, the funding program "Programa Avanza Nuevas Infraestructuras de Telecomunicaciones (Plan Avanza)**"** was designed to bridge the digital divide as far as basic broadband was concerned and to build NGA facilities in areas where private investment alone is not sufficient. The continuation of the Aid Scheme, Extension of high speed broadband in Spain (PEBA-NGA), follows the same objective of bringing NGA broadband connectivity in areas where current networks are unable to satisfy the connectivity needs of citizens and businesses. The program has involved a total of 74 operators since 2013 mitigating deployment costs faced by operators and the creation of an environment favorable to infrastructure investments, including upgrading mobile network coverage and capacity.

PEBA-NGA is in line with the Europe 2020 Strategy and the Digital Agenda for Spain and has allowed MINETAD to move forward significantly on accomplishing their objectives. In fact, it has been evidenced by an increase from 3.3 million FTTH access installed in 2012 to 31 million in 2016.

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[28] see http://www.parliament.uk/business/publications/written-questions-answers-statements/written-statement/Commons/2016-03-17/HCWS631/

[29] https://consult.scotland.gov.uk/planning-performance/planning-controls-for-digital-communications/supporting_documents/Consultation%20on%20the%20relaxation%20of%20Planning%20Controls%20for%20Digital%20Communications%20Infrastructure.pdf

[30] http://www.justiceservices.gov.mt/DownloadDocument.aspx?app=lom&itemid=11557&l=1

[31] Source: https://www.bmvit.gv.at/service/publikationen/telekommunikation/downloads/breitbandoffensive.pdf

[32] Source: https://www.bmvit.gv.at/telekommunikation/breitband/foerderungen/

Regarding this matter, the MINETAD coordinates and collaborate with the Autonomous Communities in order to ensure the coherence and complementarity in the different Broadband Aid schemes and white areas.

In addition, Spanish General Telecommunications Law regulates the collaboration mechanisms between the MINETAD and territorial public administration for the deployment of public electronic communications networks. Such collaboration comes in the form of a mandatory binding report issued by the MINETAD on any approval, modification or revision of urban planning instruments affecting the deployment of public electronic communications networks. These mechanisms rest on the need for municipalities to obtain a binding report from the MINETAD on their urban planning instruments. There exists an active communication between both public authorities, where different agreements and understandings are met, respecting both General Telecommunications Law dispositions and municipalities' urban planning needs. Since the entry into force of these coordination instruments in March 2014 more than 2.000 reports have been issued. Roughly one out of four have been unfavorable in first round. After the second round, only eight unfavorable final reports have been submitted, which is an indicative of the success of these coordination instruments.

3.2.3. Promoting infrastructure- and network-sharing

In June 2011, the RSPG and BEREC published a joint report[33] on infrastructure and spectrum sharing in mobile networks. The report describes the scope of network sharing and points out that "*in all EU 27 member states there are agreements based on passive network sharing, that is, at the level of site sharing; increasingly, active network sharing is also used by operators, as technology progresses and, in some cases, as regulation allows.*"

Moreover, this report sets out the potential advantages that could be realised by mobile operators through infrastructure sharing. The first reason for network sharing is cost savings; therefore, network sharing seems to be an appropriate response to facilitate mobile connectivity in non-profitable areas, where little income is expected. Facilitating sharing can provide an additional revenue source and lower costs. In this context, two or more incumbent operators may seek to join part or all of their individual networks and to build out additional coverage in a unified manner.

In **Austria**, there are site sharing agreements among all three MNOs based on commercial agreements. The operators may be required to share sites and masts (according to § 8 of the Telecoms act 2003). The NRA might impose such an obligation if an operator requests it. There is also a commercial infrastructure agreement (active sharing) in place between two MNOs on 2G and 3G services. Both MNOs operate their own 2G and 3G networks but use the others (in one case the 2G in the other case the 3G network) to complement their own network coverage. There are also MVNO access agreements and sharing agreements for special areas like underground and railways.

[33] http://berec.europa.eu/eng/document_register/subject_matter/berec/reports/224-berec-rspg-report-on-infrastructure-and-spectrum-sharing-in-mobilewireless-networks

In **Croatia**, the Government adopted in 2012 an act that regulates the building of electronic communication infrastructure, including the installation of antenna masts. Location planning is based on a common plan coordinated among all mobile operators called progression plan. This progression plan defines construction zones where only one mast can be built in general. The needs of other operators are taken into count in a way that the investor must collect the expressions of interest from other operators before the actual building starts, to provide a sufficient amount of space for antenna accommodation. Public consultation for this plan is obligatory and it must be approved by national regulator (HAKOM). To date the progression plan has been updated once, in 2015.

In **France**, Bouygues Telecom, Orange and SFR agreed in 2003, under the supervision of the Minister of Economy and French regulator ARCEP, to cover the centre of about 3500 villages in a program called “white areas Program”, using mast sharing or roaming in 2G and RAN-Sharing in 3G. Free Mobile also joined the agreement. In 2015, new provisions were made to extend the deployment of 2G mobile networks (by end 2016) and of 3G networks (by mid-2017) in white areas. ARCEP is empowered to intervene if operators do not implement the obligations.

In **Sweden**, the operators may be required to share sites and masts. Following an application from another operator, the NRA might impose such an obligation where there is a possibility for joint use, in return for market rate compensation. (Chapter 4, § 14 the Electronic Communications Act)[34].

Telenor and Tele2 have created a joint venture, Net4Mobility (N4M), in order to share LTE/GSM network. In 2011, N4M bought 5 MHz “extra” in the 800 MHz band with the obligation to provide a data throughput of 1 Mbit/s for the household or businesses that the National Regulator, PTS, identifies. The extension shall mainly be built with infrastructure supporting the 800 MHz band (some exceptions are allowed) and N4M has to invest 300 million SEK for this coverage obligation.

In **Spain**, network sharing is commonly used. The objective behind these agreements relates to minimising costs.

- In 2002, Telefónica and Vodafone concluded a deal to share passive infrastructure (sites), and a similar arrangement was reached in the same year by Vodafone and Orange.
- In 2006, Orange and Vodafone concluded an agreement covering radio access network (RAN) sharing (3G) in areas of the territory where population ranges from 1,000 to 25,000 inhabitants.
- In April 2008, Yoigo and Telefonica concluded a national roaming agreement including voice, data and SMS covering the territory of Spain. The initial duration of the contract was five years, and the financial arrangements include a price per traffic on incoming/outcoming traffic for voice, SMS and data services. The rationale behind

[34] http://www.riksdagen.se/sv/dokument-lagar/dokument/svensk-forfattningssamling/lag-2003389-om-elektronisk-kommunikation_sfs-2003-389

the agreement is to obtain full territorial coverage. Now, Yoigo after being acquired by Másmovil has concluded a national roaming agreement with Orange.

- In 2016, Másmovil and Orange concluded a deal to share sites to deploy their active elements.
- New provisions for spectrum in the Spanish regulation for electronic communications framework have introduced different models of spectrum sharing, so operators have new tools to use in 'challenge areas'.

In 2014, **the UK**, there are two separate major network sharing agreements that have been reached by industry. In 2007 Mobile Broadband Networks Limited was established as a joint venture between (T-Mobile and Three) to deliver a shared infrastructure to its shareholders (Three and Everything Everywhere are the current shareholders, following the merger of T-Mobile and Orange in the UK). In 2012, Vodafone and Telefonica O2 also set up an independent company – Cornerstone Telecommunications International Ltd – to manage a site sharing arrangements between the two parties.

4. Other challenge areas

4.1. Protected areas such as national parks and historical sites

4.1.1. Main issue: constraints on construction

Mobile operators sometimes have to face difficulties in bringing mobile connectivity within national parks and historical sites. These difficulties principally occur because the planning requirements to protect the beauty or historical interest of a landscape or area can place a higher burden on network operators to deploy sites differently in these locations, at higher cost. For example, much smaller masts must be deployed or masts with greater levels of camouflage.

Securing the required permission to access a site can also take time. Many such sites can also be found in quite remote areas, bringing the additional challenges mentioned for this category of coverage.

4.1.2. Observed practices to address this challenge

In **the Netherlands** it has been decided that specific nature reserves might be exempted from the coverage obligation, to respect the natural environment. A proper balance between connectivity and the natural environment should be found.

In 2015, planning reforms have been introduced in **the UK** [35]. These have introduced a new permitted development right: network operators are now allowed to install masts on

[35] www.ofcom.org.uk/spectrum/information/masts-planning

protected land, subject to a height limit of 20 metres (under 'prior approval rules' operators must submit plans to a local planning authority). A code of best practices[36] is also in place in England between agencies responsible for planning and agencies responsible for national parks and historic sites, and the mobile operators.

In **Hungary**, the license holders reported that, in a few cases, they had some deployment problems within the territory of national parks. Generally, there is a co-operation between the license holders and the labours of the national park in order to find an appropriate place and height (defined by test radiation) for the base stations. In a specific case it was reported that the deployment of mast for base station is not allowed in the national park according to the corresponding regulation. The adopted solution was to find an appropriate pylon for the deployment of the base station within the municipal boundaries of the locality taking into

4.2. Areas where some but not all operators are present

In some areas, a few operators will have coverage, while others will not. Such areas can be defined as having 'operator-specific' coverage, or as being 'partial' not-spots. People living in partial not-spots will have a more limited choice of mobile operators and MVNOs for their mobile service. Like white areas, partial not-spots can extend to a wide geography (especially in rural areas) or be more localised (particularly in urban areas).

This situation leads to localised lack of consumer choice.

In order to address partial not spots, **the UK** Government conducted in 2014 a consultation that considers options for tackling partial not spots. Options considered included forms of infrastructure sharing (including mast sharing, site sharing and RAN sharing); the role of mobile virtual networks and national roaming. Discussions begun as part of this consultation concluded with an agreement that all 4 UK MNOs would commit to providing 90% Geographic Voice Coverage by December 2017.

4.3. Areas with coverage but very low quality of service

4.3.1. Reasons for poor quality of service

Even when a mobile signal is present, consumers can still experience a lower quality of service. This can be for a wide variety of reasons, including:

- Insufficient field strength for consistent and reliable communication between handset and base station;
- Other transmissions or network noise causing interference between handset and base station resulting in insufficient signal interference to noise ratio to perform the desired operation effectively e.g. voice call or data session;

[36] www.mobilemastinfo.com/2013/new-code-of-best-practice-on-mobile-network-development-in-england-published.html

- Insufficient capacity at base station to support desired operation (due to congestion issues);
- Fading effects, often exacerbated when the user/handset is in motion;
- Hot spots (e.g. events like big concerts) where, even if there is good coverage the demand is higher than the supply available in the mobile network and the QoS is very low;
- Large variation in antenna performance between different handsets, and also varying antenna performance depending on if the handset is held in the left hand or right hand when making a voice call).

4.3.2. Observed practices to enhance quality of service

The first measure that NRAs can adopt in order to promote quality of service (QoS) is to *define clearly what a "good" coverage is*. In this respect, NRAs should define thresholds and indicators that bring an appropriate mobile coverage and that can be measured.

In **the UK**, early steps have been taken to seek to define what coverage should be delivered to support a given experience. For the 90% voice coverage obligation in place on all operators, the following threshold applies:

Technology and Band Minimum	*Signal Threshold*	*Channel*
GSM900	*-93 dBm*	*GSM BCCH*
GSM1800	*-93 dBm*	*GSM BCCH*
UMTS2100	*-103 dBm*	*UMTS CPICH*
LTE800	*-115 dBm*	*LTE Reference Signal*

Table 2: Signal thresholds for the 90% voice coverage obligation in the UK

For the 4G obligation to cover 98% of premises indoors, this is defined as an SINR threshold, dependent on the bandwidth of the LTE channel being assessed. The SINR threshold is derived from TR 36.9423 as shown below, however a minimum SINR cut-off is assumed at -5 dB and this is reflected in the threshold applied in the verification process. [37]

Bandwidth (MHz)	**Theoretical SINR Threshold**	**SINR Threshold applied in verification**
10	-4.1 dB	-4.1 dB
15	-6.1dB	-5.0 dB
20	-7.5 dB	-5.0 dB

Table 3: SINR thresholds for the 4G obligation to cover 98% of premises indoors in the UK

A second step leading to the improvement of QoS consists in *promoting coverage and QoS maps*, since they are an excellent way to enhance competition between operators. Indeed,

[37] https://www.ofcom.org.uk/__data/assets/pdf_file/0026/58292/4gcov-verification.pdf

coverage maps aim at giving precise details to the consumer, such as whether the mobile service is available in a specific place or not. These maps are helpful tools that allow more transparency.

In this respect in **France**, beyond licences, Arcep's 2017 decision requires that the French mobile operators have to provide maps with 3 qualities of voice coverage. Arcep checks each level using filters: 0 dB for the "limited coverage" level (minimal coverage), 10 dB for the "good coverage" level and 20 dB for the "very good coverage" level. MNOs have to provide maps which will pass through this check (with the 95% tolerance seen above)[38].

The third practice that RSPG and BEREC observe is that some NRAs conduct *walk tests and drive tests* in order to assess the maps and to compare the national MNOs on an equal footing.

In **the UK,** Ofcom provides information on the quality of network coverage that can be expected from a given operator in a given location[39], based on signal predictions provided by MNOs. Through an ongoing programme of drive testing, Ofcom keeps under review the assessment of the quality of service that can be expected to be available in a given area, based on these signal predictions. Through this process the UK NRA also makes an assessment of the Quality of Service that can be delivered at different signal strengths, and provides information on coverage at a different quality levels.

In **France,** the French NRA also conducts field measurements (walk tests and drive tests) on the one hand to verify the reliability of coverage maps and on the other hand to measure the QoS of MNOs' networks. The measurement results are regularly published and data is made public[40].

In hot spots (e.g. events like big concerts), the mobile network operators are implementing solutions to improve the capacity of the network and the respective QoS, with solutions such as the implementation of small/micro cells, mainly based on temporary/transportable base stations.

In **Austria,** the Austrian Regulatory Authority (RTR) collects coverage and QoS information using a crowdsourced QoS measurement tool (RTR-NetTest) and publishes a map on RTRs website.[41] Similar situation also exist in **Slovenia**[42].

5. Limitations of solutions

It is important to note that while the various solutions described in this report can play a part in addressing mobile connectivity challenges, it is likely that no one solution will be sufficient on its own; and that the combination of solutions to be employed will depend on the particular circumstances and problem to be addressed. In particular, it is important to be

38 www.monreseaumobile.fr
39 checker.ofcom.org.uk/
40 www.data.gouv.fr/fr/datasets/monreseaumobile/
41 Source: https://www.netztest.at
42 https://www.akostest.net/

aware of the limitations and possible consequences of any proposed solution, though some of these may in turn be mitigated with careful implementation. Some of the principal limitations are discussed briefly here, although this is not intended as an exhaustive analysis.

5.1. Limitations in Indoor Coverage Solutions

A number of indoor coverage solutions require the deployment of fixed infrastructure, which will have its own costs and availability challenges. For example, the deployment of Femto Cells and Wi-Fi calling will depend on the availability of a suitable (fixed) broadband connection, while a DAS solution requires upfront investment in cabling buildings which may not always be economic.

Depending on the solution implemented, the Quality of Experience provided to end users may not be on a like-for-like basis compared with outdoor coverage provided over the microcell network. For example, whilst repeaters offer a potential solution to improving in building coverage in more remote locations, they do not provide additional capacity in busier areas. They also depend on a reasonable donor signal being available in the area, and there may also be challenges in providing the concurrent availability of a range of networks in this way. And the success of Wi-Fi calling solutions may depend on how this has been implemented on different networks and the availability of handsets with this functionality built in ‘natively’.

5.2. Limitations on Solutions for Coverage When Travelling

Some of the solutions noted here are analogous to those identified for indoor coverage challenges, including the use of repeaters and Wi-Fi, and so come with similar limitations. Others bring different limitations. One solution noted above is co-ordination between owners of transport infrastructure and mobile operators. In this regard it can be easier to align interests earlier in the build process for transport infrastructure (and potentially when the state has a role and therefore levers to use in the building of transport infrastructure).

5.3. Limitations on Remote Area Solutions

A number of NRAs have used coverage obligations to promote the availability of mobile services in areas where the market might otherwise have been slower to deploy. However, these obligations, in certain situations, may have an impact on spectrum valuation.

Network sharing can be very useful for allowing end-users to have increased access to mobile services in areas not commonly served by mobile networks as it reduces the costs of deployment for operators. Competition concerns that may arise due to increased network consolidation might be overcome by these benefits, in particular in non-profitable and remote areas where there is no connectivity available. Moreover, in these situations, potential impact on network resilience has to be weighed against the advantages of achieving increased levels of coverage for the population.

6. Conclusion

While there is a growing expectation from end users to have mobile connectivity everywhere, European mobile network operators faces multiple challenges in trying to achieve such connectivity. This Report describes the specific difficulties to provide mobile connectivity for terrestrial communications in some challenge areas, such as inside buildings, in transportation means, within non-profitable areas, etc. These difficulties can stem from technical causes (e.g. obstacle to radio propagation or difficult access to sites), economical causes (e.g. high costs, low revenues) and regulatory causes (e.g. specific regulations having impact on network roll-out).

Public entities like NRAs, governments and local authorities, in cooperation with mobile operators and other private stakeholders, have already identified and implemented some solutions to tackle the obstacles to mobile connectivity in these challenge areas. This Report describes some of these solutions and in particular:

- Dedicated technical solutions to address specific and localised lack of connectivity (e.g. Wi-Fi and repeaters can be rolled-out in trains or inside buildings)
- Network sharing, essentially to minimize costs (e.g. site sharing or RAN-sharing in non-profitable areas, in tunnels or in areas where some but not all operators are present)
- State involvement through planning reforms and specific laws (e.g. concerning national parks), through coverage license obligations[43] (e.g. specific requirements concerning indoor coverage, non-profitable areas coverage or railway connectivity) and through public funding programs
- Cooperation and a steady dialogue between public and private stakeholders.

This Report also recognises that the described solutions can have some limitations and possible undesired consequences and it describes some of these limitations. Still, it proposes a non-exhaustive list of possible solutions which NRAs and other competent Authorities can consider to enhance the coverage and performance of European mobile networks.

[43] In this regard, RSPG will publish a second Opinion on 5G in early 2018 which addresses 5G coverage

7. Abbreviations

AKOS	Agency for communication networks and services of the Republic of Slovenia
ANCOM	National Authority for Management and Regulation in Communications of Romania
Arcep	Autorité de Régulation des Communications électroniques et des Postes (France)
BEREC	Body of European Regulators for Electronic Communications
CPE	Customer-premises equipment
DAS	Distributed Antenna Systems
DL	Downlink
FWBA	Fixed wireless broadband access
HAKOM	Croatian Regulatory Authority for Network Industries
IoT	Internet of things
MINETAD	Ministry of Energy, Tourism and the Digital Agenda
MNO	Mobile network operator
N4M	Net4Mobility
NGA	Next Generation Access
NRA	National regulatory authority
Ofcom	Office of Communications (UK)
PEBA-NGA	Programa de ayudas para la Extensión de la Banda Ancha de Nueva Generación
pGSM network	Private GSM network
PTS	National Post & Telecommunications Agency (Sweden)
QoE	Quality of experience
QoS	Quality of service
RAN sharing	Ran Access Network sharing
RSPG	Radio spectrum policy group
RTR	Regulatory Authority for Broadcasting and Telecommunications (Austria)
SINR	Signal-to-interference-plus-noise ratio
TKK	Austrian Regulatory Authority Telecom-Control-Commission
UL	Uplink
Vo-WI-FI	Voice over WiFi