REPORT FOR QUALCOMM

STUDY ON REGULATORY OPTIONS TO PROMOTE INVESTMENT IN 5G AND IOT INFRASTRUCTURE IN EUROPE

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1 Executive summary

This is the report of an independent study undertaken by Analysys Mason on behalf of Qualcomm. Qualcomm commissioned Analysys Mason to assess the business models for deploying 5G networks in Europe, from the perspective of a mobile operator, and to study the conditions under which business cases appear most favourable. From the results of the business modelling, the goal was to identify the strategic and regulatory conditions that are most likely to promote development of a successful market for 5G services, with a view to maximising investment in 5G networks to accelerate the availability of services.

1.1 Background and context

The vision for 5G technology is that networks will seamlessly support a diverse range of connected devices, services and industries. In doing so, 5G will take the business case for mobile infrastructure investment significantly beyond the scope of today's consumer-driven mobile broadband services, towards support for a diverse range of use cases across multiple European industries, including the 'Internet of Things' (IoT). With this potentially wide-ranging scope for connecting people, places and things, European policy makers envisage that 5G will lie at the heart of our future digital economy and society.

From their inception, 5G networks are expected to introduce new mobile broadband experiences for consumers, supporting ultra-high-definition video/multimedia streaming, real-time mobile gaming and other virtual- and augmented-reality experiences. 5G can support advances in robotic services, which could form an essential part of future industrial processes, and in key public services such as healthcare. These services will require ultra-low latency and reliable wireless connectivity to deliver real-time responsiveness. In addition, 5G will play a major part in the smart infrastructure which is expected to take on a significant role in many aspects of day-to-day life, from autonomous vehicles to smart buildings, energy networks and cities.

Delivering this mix of use cases will require mobile networks to be transformed into virtualised networks such that multiple services across numerous industry sectors can be delivered. Networks will use a range of radio access network technologies, including existing systems (such as LTE and Wi-Fi) as a complement to the proposed new 5G 'new radio' (5G-NR), which is currently being standardised by the industry.

It will be challenging for networks to support all use cases and network requirements across the variety of operating environments, and so it is important that policy and regulatory frameworks for 5G support the expected breadth of business models. This was acknowledged in a recent report issued by the European Commission on socio-economic data for the strategic planning of 5G in Europe.[1] The report discusses different operating environments for 5G, highlighting the case of

[1] See https://ec.europa.eu/digital-single-market/en/news/study-identification-and-quantification-key-socio-economic-data-strategic-planning-5g

'non-urban environments' where reduced network capex (through sharing of infrastructure) will be needed. As described in the report, there will be a need to adapt 'business models and regulations'.

The mobile market in Europe is competitive, with three or four mobile networks typically providing services in each country. Operators compete on both services and coverage, and, increasingly with 4G, on quality of network coverage (i.e. capacity) and speed. As mobile data services increase in importance (with market forecasts widely predicting continued growth in the volume of mobile traffic carried by mobile networks), the revenue that operators generate from data services (as a proportion of total mobile revenue) is growing. However, strong competition has resulted in a steady decline in monthly average revenue per user (ARPU) in Europe since around 2011, such that European ARPUs are low by comparison with other countries. There is no indication that this trend is reversing as 4G services evolve. The lower ARPUs associated with mobile services in Europe, combined with other trends such as lower mobile termination rates, are key factors which affect mobile revenue across markets in Europe. Future mobile network investment must therefore be considered in the context of these lower revenue levels. Cost-efficiency measures such as network sharing and network mergers are evidence of operators' desires to reduce network costs in highly competitive markets.

Until 5G networks move closer to commercial roll-out, it will remain unclear how services are to be priced. Nevertheless, it is possible that the scale of network investment needed to achieve all the use cases and services being envisaged for 5G may bring radical shifts, if not in pricing, then in market structure.

1.2 Scope of this study

The study has considered the deployment of next-generation mobile broadband services along with deployment of 5G in selected vertical sectors. The overall scope of work was as follows:

- Overall assessment of European opportunities for 5G deployment in next-generation mobile broadband (MBB), media and for IoT services to industries.
- Modelling of business models for 5G MBB deployment in three European countries – France, Germany and the UK – in the 3400–3800MHz frequency band. These three countries were selected based on (a) the size of the market for mobile services, (b) their market structure (e.g. with three or four operators), and (c) the likelihood of early 5G deployment, given regulators' current plans for spectrum award and market appetite.
- Assessment of alternative business models for 5G-based IoT service provision to selected industries (automotive and e-health) in these three countries, including:
  - for the *automotive* sector, the potential for cooperation between 5G networks and wireless intelligent transport systems (ITS) deployed in the 5.9GHz (5855–5925MHz) band, under a scenario of ITS deployment along major highways.

- for the *e-health* sector, alternative models to provide IoT connectivity for healthcare using cellular technologies, including narrowband IoT and use of dedicated spectrum (e.g. a 2×3MHz assignment in the 700MHz band).

- Conclusions on the 5G investments needed at a country level in Europe, and the impact that the European regulatory framework will have on these investments (e.g. in relation to the number of competing networks, availability of spectrum and conditions for provision of services).

1.3 Scenarios modelled

1.3.1 5G MBB model

The 5G MBB model aims to examine the investment opportunity for deploying 5G technology in the 3.5GHz band. It includes three scenarios:

- **Scenario 1 – 5G deployment following 4G market structure**: Population-led roll-out driven by market competition. 5G roll-out includes reusing a significant share of operators' existing sites (2G, 3G and 4G), although operators will need to build new sites if the existing ones are inadequate due to coverage or capacity reasons. A reasonably low 5G spectrum fee is assumed under this scenario.

- **Scenario 2 – Enhanced coverage with additional investment funded through spectrum fees**: Same approach as for Scenario 1. Under this scenario the upfront spectrum fee paid by operators is returned to operators once they meet their five- and ten-year coverage targets. This provides an incentive for MNOs to respect a coverage timetable mandated by the licence terms.

- **Scenario 3 – Fewer competing network builds**: In this scenario, 5G investments are put into a single shared infrastructure developed by multiple service providers. This should considerably reduce the 5G network investment that is required, and also reduce network opex (operating expenses), due to the efficiencies associated with site sharing (which will also reduce the number of sites that have to be rolled out).

1.3.2 Healthcare model

The healthcare model aims to present the investment opportunity associated with a mobile operator deploying services to the IoT healthcare vertical using the 700MHz band. We examined three different modelling scenarios, in addition to a base case:

- **Base case – MBB roll-out in the 700MHz band**. The base case reflects what is expected in most European countries, where MNOs will use the 700MHz band to provide MBB services (similar in form to the type of coverage provided by the 800MHz band). The base case assumes continuous roll-out of sites to meet 4G coverage obligations and to cope with growth in traffic using 4G spectrum for locations where sub-1GHz spectrum is particularly needed. The 700MHz spectrum is added to existing sites and to new sites later, whenever it is needed, based on the coverage obligations and an estimate of the share of MBB traffic that requires low-frequency spectrum such as the 700MHz and 800MHz bands.

- **Scenario 1 – Enhanced services for healthcare, with IoT-based healthcare applications overlaid on 700MHz MBB network**. In this scenario, healthcare services are provided on top of MBB services using the same 700MHz band. Incremental revenue relative to the base case is achieved from the health business. Incremental costs are incurred, due to: the higher population/geographical coverage that is required (because of the criticality of the healthcare applications); and the need to increase site roll-out to avoid an impact on MBB QoS, despite the loss of spectrum resource to IoT (i.e. in order to achieve similar QoS for MBB services to that in the base case and a reliable QoS for health services, we assume that additional capacity/sites are required).

- **Scenario 2 – Dedicated spectrum – set-aside of harmonised spectrum in Europe for 5G-IoT ('2×3MHz')**. In this scenario, healthcare services are provided using a separate assignment of 2×3MHz and so have no impact on the spectral resource or QoS of MBB services delivered in the existing 700MHz band. Relative to the base case, incremental revenue is achieved from the health business. We assume that only one operator (or one consortium of operators) is awarded the 2×3MHz dedicated spectrum and so it will capture all the incremental revenue. It is noted that other models are possible, depending on national market circumstances. Incremental costs are incurred relative to the base case, due to the need to roll out the 2×3MHz carrier on existing sites, the potential need for new sites (to extend population coverage beyond that required for MBB), and spectrum fees charged for the 2×3MHz band.[2]

- **Scenario 3** – **Dedicated infrastructure – new entrant (greenfield operator)**. This scenario assumes that the sole winner of the dedicated 2×3MHz spectrum is a new entrant which is not a mobile operator. The scenario foresees the deployment of a 700MHz network which is exclusively dedicated to provision of healthcare services. Coverage requirements for healthcare are similar to those in Scenarios 1 and 2, and as in Scenario 2 spectrum fees will be reimbursed once coverage requirements have been met. This scenario assumes that public authorities encourage the launch of a new player specifically to deliver healthcare services. On this basis, we assume that a fair proportion of the infrastructure required for the new network can be built on existing public infrastructure, which will reduce the need to deploy new sites (and hence reduce the capital investment that is required).

1.3.3 5G connected car model

The 5G connected car model analyses the business case for 5G MBB roll-out to cover major roads (highways and motorways) using the 3.5GHz band. We examined three scenarios:

- **Scenario 1 – 5G coverage along highways and motorways, under existing regulations (competing operators)**. Under this scenario an MNO will roll out 5G along roads using the

[2] Noting that these fees are returned to the operator once it meets its ten-year coverage targets.

3.5GHz band and is expected to capture some incremental revenue from subscribers who wish to use 5G services while travelling. MNOs will be able to reuse a small proportion of their existing sites near roads but will also have to roll out new sites to achieve good coverage with high QoS. Roll-out will primarily be driven by coverage, as we assume that traffic will not be a bottleneck (at least for a considerable time).

- **Scenario 2 – Collaborative 5G model**. The only difference between this scenario and Scenario 1 is that multiple MNOs collaborate to deploy 5G along roads using shared infrastructure (i.e. the operator pays 25% or 33% of network costs to capture a market share of 25% or 33%, compared to 100% of network costs to capture 25% or 33% of market share in the first case). Scenario 2 will always be more profitable than Scenario 1.
- **Scenario 3 – Collaborative ITS/5G model, involving reuse of ITS infrastructure for 5G**. This scenario considers ITS deployment along major roads (i.e. highways and motorways). In contrast to Scenario 2, MNOs will also be able to reuse/access the infrastructure of the ITS sites which are deployed. MNOs will first reuse their existing sites (i.e. similar to Scenario 2), and then reuse the ITS sites before they roll out new sites. As site reuse is more economic than building a new site, Scenario 3 will always be more profitable than Scenario 2.

1.4 Key conclusions

A summary of the study's key conclusions is presented below:

► *Assuming current European trends in mobile ARPU continue into the 5G era, there will be a limit to the investment that operators will commit, without further demonstration of demand for 5G services*

Although it will remain unclear how 5G services will be priced until networks have been defined more fully, it is far from certain that the introduction of new 5G services will bring substantial ARPU increases for European mobile operators. The strong competition between the multiple mobile networks operating in most European countries is expected drive further service improvements for consumers when 5G networks are launched, by expanding the range of services provided, the quality of those services, and the technology innovations that are provided. However, because it is unclear whether European subscribers will be willing to pay a higher premium to receive 5G services, throughout this report we have assumed that, in most cases, 5G ARPUs will follow similar trends to those of 4G – with a small uplift in ARPU modelled for certain of the use cases considered (e.g. in the automotive sector). Nevertheless, it is clear that more optimistic assumptions on ARPU would improve the profitability of the business cases presented in this report. Under the appropriate regulatory conditions, this could result in additional investment being targeted at improving the coverage reach of 5G networks.

► *Deployment of mobile broadband will dominate the early roll-out of 5G*

The initial focus of 5G is expected to be on MBB-type services, before expanding to other vertical sectors (including IoT and mission-critical services). It is quite clear that MBB will be the initial/main service, as it provides the necessary economy of scale to enable the rapid development of 5G technology. Furthermore, most of the 5G trials undertaken by major vendors and operators have been focusing on data rates and peak speed, which further supports the view that MBB is the main 5G opportunity being considered at present.

If mobile operators maintained current levels of investment (around EUR40 per capita of population per annum for overall mobile network investments in a country), an average operator would invest a total of around EUR13 billion, EUR22 billion and EUR13 billion in France, Germany and the UK respectively over a 20-year period (2020 to 2040) and would cover around 72% of the population with 5G in Germany and France, and 82% in the UK.

Infrastructure sharing makes a positive difference to the business case. Based on the analysis carried out in this study, it could extend coverage from the levels quoted above by up to 25% (i.e. to close to 100% of population). Deeper levels of sharing (e.g. the sharing of spectrum) might improve this situation further. Given the significant advantages that this additional coverage would provide for European citizens, the regulatory environment for 5G should therefore promote sharing where this is commercially and technically advantageous, to bring increased benefits to European citizens by bringing forward 5G availability and extending network reach.

Given the current infrastructure investment made by European operators, 5G coverage using the 3.5GHz band could reach up to 70% of the population in some countries (and could be as much as 99% in a scenario involving infrastructure sharing among MNOs). Increasing the level of investment by just 10% (which MNOs would probably consider in expectation of a corresponding ARPU rise) would achieve between 80% and 90% of population coverage, depending on the country (and potentially more than 99% with infrastructure sharing, as noted above).

► *Using 5G networks to deliver IoT services can bring benefits, but the addressable market for such services needs to be more clearly defined to stimulate investment*

Certain aspects of IoT services are different from what MNOs will design for delivery on standard mobile networks (i.e. those driven by voice and MBB services). In some cases, these require bespoke connectivity solutions, different device types and/or other network changes, which might increase costs for MNOs. Added to the uncertainty of whether there is an adequate addressable market in some IoT vertical sectors to justify the offering of tailored 5G solutions, there are therefore risks to MNOs associated with investing in 5G infrastructure, and leveraging valuable spectrum resources, in order to deliver IoT services without having a clearer picture of the demand for services. These risks need to be considered carefully in the context of business cases for mobile operators both to invest in spectrum and to roll out new technologies, which are today premised on delivering MBB services to European consumers. In particular, given that revenue from IoT connections might be low compared to that for handset and MBB connections supported over 4G/5G, it is clear that operators require a clearer view of the addressable market for IoT services.

► *There is a risk that the investment required by MNOs to deliver widespread IoT services might exceed their share of revenue, unless additional spectrum is made available (e.g. 2×3MHz at 700MHz) and widespread network sharing between operators is implemented*

Total investments over 20 years (2020–2040) of an average operator which used 700MHz spectrum to provide MBB and IoT services would reach around EUR11 billion in France, EUR18 billion in Germany and EUR12 billion in the UK.

Based on our modelling, the business case of a scenario where an MNO uses 2×3MHz of dedicated 700MHz spectrum[3] to provide health services over an LTE-based IoT network (e.g. NB-IoT) is more profitable than a scenario in which the MNO provides IoT applications over a common infrastructure with MBB (i.e. if health applications are provided on top of MBB in the 700MHz band this can lead to lower investment in the IoT-specific services, due to higher revenue driven by MBB). In our modelling, the use of a dedicated band for an IoT network improved the MNO's NPV by between 6% and 14%. This improved business case might enable operators to accelerate the network roll-out for IoT, for example.

► *5G coverage of main transport routes – with true 5G capacity and data rates – is critical to the future of connected and automated cars, but will be extremely challenging from an economic perspective. Allowing network sharing and pre-installing 5G (i.e. making cabinet, power and fibre available) are likely to be required to ensure coverage of main transport routes.*

The use of MBB networks to deliver services to other vertical sectors (such as the provision of connected car services) needs to be assessed carefully. In our analysis, we modelled the feasibility of providing 5G coverage along roads, as part of a deployment of 5G in the 3.5GHz band.

For automotive applications, 5G networks are likely to supplement planned Intelligent Transport Systems (ITS) in Europe and so it is possible that applications in this sector will be split between networks, with safety-related applications carried over ITS networks. In this scenario, 5G networks would provide MBB services tailored to the automotive sector (e.g. in-car entertainment, traffic, travel and parking information, e-booking, etc.).

The cost of rolling out ITS infrastructure along highways and motorways, mainly for safety reasons, is not excessive in our modelling, primarily as we assume that only around 35% of highways and motorways need to be covered, in accordance with European policy requirements (e.g. it is assumed that coverage is only needed at particular locations, such as at fatality hotspots and major junctions). This investment represents less than 1% of the total investment that national governments in Europe typically make to upgrade road infrastructure in their countries, and would have social benefits in the form of a reduction in road fatalities and injuries.

Extending a 5G MBB network to provide 100% road coverage along highways and motorways does not generate positive NPV for operators if we assume that competing operators will do this (and

[3] It is assumed that the MNO is awarded the 2×3MHz spectrum through a competitive award, and pays an upfront fee for spectrum similar to prices for the 2×30MHz of 700MHz that is being assigned for MBB use on a per MHz per pop basis.

hence the market share of one operator is limited compared to the network costs), based on our modelling. However, if we assume that competing operators collaborate to deploy a single shared infrastructure along major road routes, the business case improves.

If all operators deployed 5G coverage of all motorways and highways, an average French operator would need to invest around EUR2 billion, while the equivalent figure in Germany would be around EUR4 billion, due to the greater extent of highways. In the UK, the length of road network is significantly lower (due to the smaller geography of the country), and the required investment would be around EUR1 billion.

Our modelling suggests that a collaborative ITS/5G model between MNOs and the operator which manages the ITS network (whereby an MNO would be able to reuse ITS infrastructure for 5G) should be beneficial, as it could improve an MNO's incremental NPV from road coverage by between 15% and 20%.

It should be noted that, in practice, other bands (e.g. 700MHz) could be used in combination with 3.5GHz, which should improve the business case for coverage – although we assume that higher frequency bands (where greater bandwidth is available) are needed to deliver full 5G capability. As evidence of the capabilities envisaged for 5G networks, the Commission's recent report on socio-economic data for the strategic planning of 5G introduction in Europe suggests three key capabilities – 50Mbit/s speed, scalable solutions, and ultra-tactile Internet. Irrespective of the network performance requirements for ultra-tactile Internet, the provision of 50Mbit/s speeds alone will not be achieved in bands below 1GHz[4] based on the bandwidth available. Hence our 5G MBB business modelling has focused on initial deployment in the 3.5GHz band (although even that this band in isolation will not deliver the key capabilities indicated in the Commission's report).

Based on our modelling, the business case for an average MNO to deploy 5G MBB coverage along roads using the 3.5GHz band is almost always negative, if we assume that revenue is shared by three or four competing operators. This is the case whatever assumptions are made regarding levels of coverage and take-up, under a scenario which reflects current mobile market structure (i.e. multiple competing infrastructures providing services along roads). This suggests that, under the current regulatory model of competing infrastructures, widespread 5G coverage along roads will not materialise within the necessary timescales to stimulate early take-up of these services in Europe, as the cost to operators is too high.

However, in a situation where multiple MNOs collaborate to deploy 5G along roads using a single shared infrastructure (i.e. the operator pays 25% or 33% of network costs to capture 25% or 33% of market share, compared to 100% of network costs to capture 25% or 33% of market share in the base case) the results improve. We therefore conclude that the business case for a shared network in each country to cover roads with 5G is the most likely one. This is likely to be highly beneficial for

4 For example, a typical assignment of 2×10MHz per operator in the 700MHz band (e.g. with the available 700MHz spectrum shared among three or four operators) might achieve around 10Mbit/s per network.

achieving widespread benefits from 5G roll-out across Europe, since a shared infrastructure model could enable coverage to be rolled out sooner and hence services should be available more quickly.

It should be noted that our analysis assumes a small uplift in mobile ARPU for providing a tailored service to the automotive sector, in order to capture the additional usage/revenue that MNOs will obtain from improving coverage along main transport routes. As noted previously, it is far from certain that European consumers will be willing to pay a premium for 5G services, given current ARPU trends. However, consumers might be willing to pay more to receive 5G automotive services. Given that network competition is expected to lead to service and quality improvements and also deliver increased innovation, more optimistic assumptions on ARPU would improve the profitability of the business cases presented (i.e. if subscribers were willing to pay a higher premium for 5G automotive services).

► *Stimulating 5G take-up and penetration will promote more rapid and extensive deployments of 5G networks*

Mobile, in particular 4G, is playing an important role in supporting achievement of the EC's DAE (Digital Agenda for Europe) goals. The current DAE targets are linked exclusively to 'fast Internet access for all'. More recently, the Commission's Digital Single Market (DSM) strategy has evolved to embrace the potential for the Internet and digital technologies more broadly to improve connectivity – not just to people, but also between many disparate systems and things. It is therefore clear that moving towards a fully connected society in Europe (where connectivity is provided between people, objects and things irrespective of location) requires a different form of connectivity target from the 'Internet for all' targets of recent years.

The analysis presented in this report indicates that 5G networks have the potential to play a significant role within Europe's future connected society, supporting business cases ranging from MBB to IoT and critical infrastructures. However, the deployment of 5G will be determined by the investments that mobile operators can afford, which is closely linked to the revenue that services will deliver. Under the current market situation in Europe, mobile ARPUs have been steadily declining. There is no clear indication of this trend changing once 5G networks are launched. As a result, it is most likely that mobile operators will focus on deploying 5G for mobile broadband use, since these are the services that currently generate mobile revenue.

Achieving a more diverse range of service requirements and use cases will therefore depend on the market for those services being more accessible to mobile operators. This could require a re-think on certain European policies relating to mobile network roll-out. For example, improving the demand side of the 5G business case could bring in new 5G services more quickly (e.g. by introducing greater regulatory harmonisation, so that certain vertical sectors are encouraged to use 5G services when available). In addition, allowing changes to the overall model for network roll-out – such as greater use of shared infrastructure – could stimulate investment to bring about a faster availability of infrastructure.

As such, it seems clear that European regulatory goals and targets for 5G networks need to evolve from the primarily coverage-based goals that have been defined to date. In particular, new targets for promoting a fully connected society of people and things might address both the demand and supply side of 5G roll-out. This would support take-up and penetration of MBB as well as the different IoT vertical sectors that might use 5G networks, for which demand is currently highly uncertain.

Figure 1.1 below summarises a range of possible targets for 5G networks. Further study on how such targets might best be implemented and achieved in Europe is recommended:

Figure 1.1: Suggested 5G targets [Source: Analysys Mason, 2016]

5G vertical	Category of target (supply/demand)	Policy goal (examples)
MBB	Supply	EUR3 billion annual 5G investment across the EU
MBB	Supply	Coverage of the EU's business districts by 2025
MBB	Supply	All urban zones in the EU to have 5G connectivity by 2025
MBB	Supply	Sustained 100Mbit/s in when on the move for 95% of covered population
MBB	Demand	50% of the EU population to be using 5G by 2025
MBB	Demand	50% of MBB connections to be 5G by 2025
Healthcare	Supply	5G MBB coverage (from at least one mobile network) to include specific geographical locations where hospital buildings are located within urban centres
Healthcare	Supply	All hospitals and public buildings to have 100% 5G indoor coverage within five to ten years respectively (in line with population coverage)
Healthcare	Supply	All ambulances and other emergency vehicles (e.g. police cars/fire engines) to have a 5G base station embedded for ad-hoc 5G coverage during interventions within the next five to ten years
Healthcare	Demand	All ambulance dispatch services to use 5G technology within five to ten years (in line with population coverage)
Healthcare	Demand	Possibility for 5G phone users to undertake healthcare-related financial transactions (paying doctors, ordering medicines, etc.) within five years
Healthcare	Demand	Availability of health applications (e.g. drug reminders, activity trackers, emergency calls) for 5G phone users within five years, sponsored by governments
Healthcare	Demand	Year-on-year reduction in hospital nights as a result of 5G-driven e-health
Healthcare	Demand	Specified medical devices (e.g. pacemakers, diabetes trackers, medical alarms) to have 5G connectivity embedded within five to ten years
Automotive	Supply	V2I and 5G coverage targets along key roads
Automotive	Supply	In areas where 5G V2N is available but not V2I, V2N should support services offered by V2I
Automotive	Supply	Every road that is built/upgraded must include pre-installation for 5G network (fibre and power along the road, and cabinets at appropriate locations)

5G vertical	Category of target (supply/demand)	Policy goal (examples)
Automotive	Demand	70% of vehicles placed on the EU market in 2025 to be 5G equipped (100% by 2030)
Automotive	Demand	All smart traffic/ parking/toll systems offered in European cities to be delivered over 5G infrastructure by 2030
Automotive	Demand	Insurance costs for 5G-equipped cars to be reduced by 5–10% under appropriate insurance schemes.
ITS	Supply	Monitor/certify performance of artificial intelligence (AI) engines used in safety/security services for connected cars (i.e. autonomous driving)
ITS	Supply	Every road that is built/renovated must include pre-installation for ITS equipment (fibre and power along the road, cabinet and antenna at appropriate locations)
ITS	Demand	Car manufacturers to include ITS equipment in new cars (50% in 2020 and 100% in 2025) (similar target to that for 5G above)
ITS	Demand	1–5% reduction in road casualties/injury thanks to V2X
ITS	Demand	Lanes/parking spaces reserved for cars equipped with V2X
ITS	Demand	Differentiated speed limits for cars equipped with V2X
ITS	Demand	Public system for car platooning creation/platooning slot reservation
ITS	Demand	Reduction in maximum driving time for self-drive truck drivers due to time spent in platooning
Smart city	Demand	Monitoring of specified infrastructure services in European cities (e.g. traffic lights, bus stops, bus lanes, dustbins, connected signs, etc. to use 5G connectivity
Smart city	Demand	All new homes within designated smart cities to be intelligent buildings with 5G connectivity (e.g. small cells)
Smart city	Supply	All government buildings to deploy 5G coverage
Smart city	Supply	5G connectivity to be provided to customers on all forms of public transport

2 Introduction and context

This report describes an independent study undertaken by Analysys Mason on behalf of Qualcomm, to investigate the typical investments needed at a country level to deliver the next generation of services in Europe, and the strategic and regulatory frameworks that might best promote this investment.

The context for the report is the significant European industry and political interest in the fifth generation (5G) of mobile telecoms technology which is now being developed. There is widespread recognition that 5G will expand the services and capabilities of mobile networks, giving mobile technologies the potential to support a wider range of consumer, business and industrial services.

For the purposes of this study, 5G services include ultra-fast mobile broadband, as well as 5G connectivity within the IoT and ultra-reliable connectivity, all of which represent a significant enhancement of the capabilities available on today's 3G/4G mobile networks.

As the basis of this study we have considered the investment needed at country level to deliver 5G services in Europe, under different assumptions regarding market structure (e.g. the number of competing networks) and other key inputs (e.g. spectrum). To do this we have modelled the 5G business case for generic operators in selected European countries, using assumptions on 5G prices which reflect 4G price metrics in Europe today, including the average revenue per user (ARPU). ARPU is still declining in Europe and we have assumed that the decline will continue over the short term while stabilising over the long term. It should be noted that more optimistic assumptions on the uplift in ARPU that 5G might provide over 4G would improve the business cases presented in this report. However, as discussed in this report, APRU trends in different European markets has had an impact on the achievable ARPUs from mobile services and price is recognised as being a major factor influencing consumer's decisions to switch between networks. Whilst it is recognised that competition has contributed to achieving benefits for the European market through improved availability of services and greater choice, the downside of this competition is that operators have absorbed a decline in ARPU in recent years as competition between networks has intensified. It is not yet clear whether 5G will result in a greater willingness to pay for MBB services and/or a shift in European ARPU trends. Given that lower ARPUs (along with other declining revenues such as mobile termination rates) affect the ability of operators to invest in 5G network growth, the purpose of this study has been to identify the scenarios under which 5G coverage (and hence the availability of services) can be maximised.

2.1 Context for the study

With 4G networks now widely implemented in Europe, the European mobile industry is actively considering future mobile network iterations, with a view to both expanding 4G services and capabilities, and evolving towards 5G. The 'Third Generation Partnership Project' (3GPP) – the industry's standardisation body for mobile communications technologies – is working on a wide range of updates to the latest 4G (Long Term Evolution Advanced, or LTE-A) standards, as well as embarking on a preliminary standardisation phase for 5G. The intention is that 5G standards will be developed over the next three years, with initial 5G network deployments expected from 2018 onwards. Proposals to accelerate the development of 5G 'new radio' (NR) specifications in 3GPP have resulted in a timetable whereby two phases of standardisation will be released – initial standards will focus on mobile broadband in standalone and non-standalone (i.e. in cooperation with LTE) deployment in bands below 6GHz and in the 25–32GHz range, and further standards, including 'full IMT-2020[5] capability' will be developed thereafter. This is shown in the diagram on the next page.

With discussions on 5G having moved quickly during 2016 from 'vision' towards implementation, successful deployment of 5G is now one of the top priorities for European regulators and policy makers. It is widely anticipated that 5G will deliver consumer and enterprise mobile broadband solutions, expanding on current 4G mobile broadband capabilities off (e.g. to address the increasing use of cloud-delivered content and development of 'mobile cloud' solutions). However, it is also expected that the development of 5G will appeal to a mix of other vertical markets, specifically in the context of delivering the 'Internet of Things' (IoT). Although the wireless business opportunities within the IoT are broad (spanning a range of technology solutions), the target applications for 5G might include a range of specific vertical market opportunities in the healthcare, automotive, health and energy sectors. There are also applications for 5G within the audiovisual (AV) media sector, and in digital transformation more broadly (e.g. 'smart cities'). The European Commission (EC) has developed an EU-wide '5G action plan',[6] which builds on inputs from a range of sources, including leading European mobile network operators (MNOs) and vendors, which have presented a '5G manifesto' to the EC setting out the industry's priorities for coordinated action to ensure successful and timely deployment of 5G in Europe.

However, with 5G potentially embracing a wide range of services and use cases, there are concerns that the levels of network investment needed to cater for all potential use cases will be prohibitively high under current market structures (i.e. with multiple competing infrastructures being rolled out independently). Network sharing and scenarios involving cooperation by MNOs and the vertical industries that stand to benefit from 5G connectivity can provide options to address this issue.

With this in mind Qualcomm – a global leader in next-generation network technologies – commissioned Analysys Mason to conduct an independent study into alternative business and regulatory models for 5G and the models which are most likely to foster a successful deployment of 5G in Europe.

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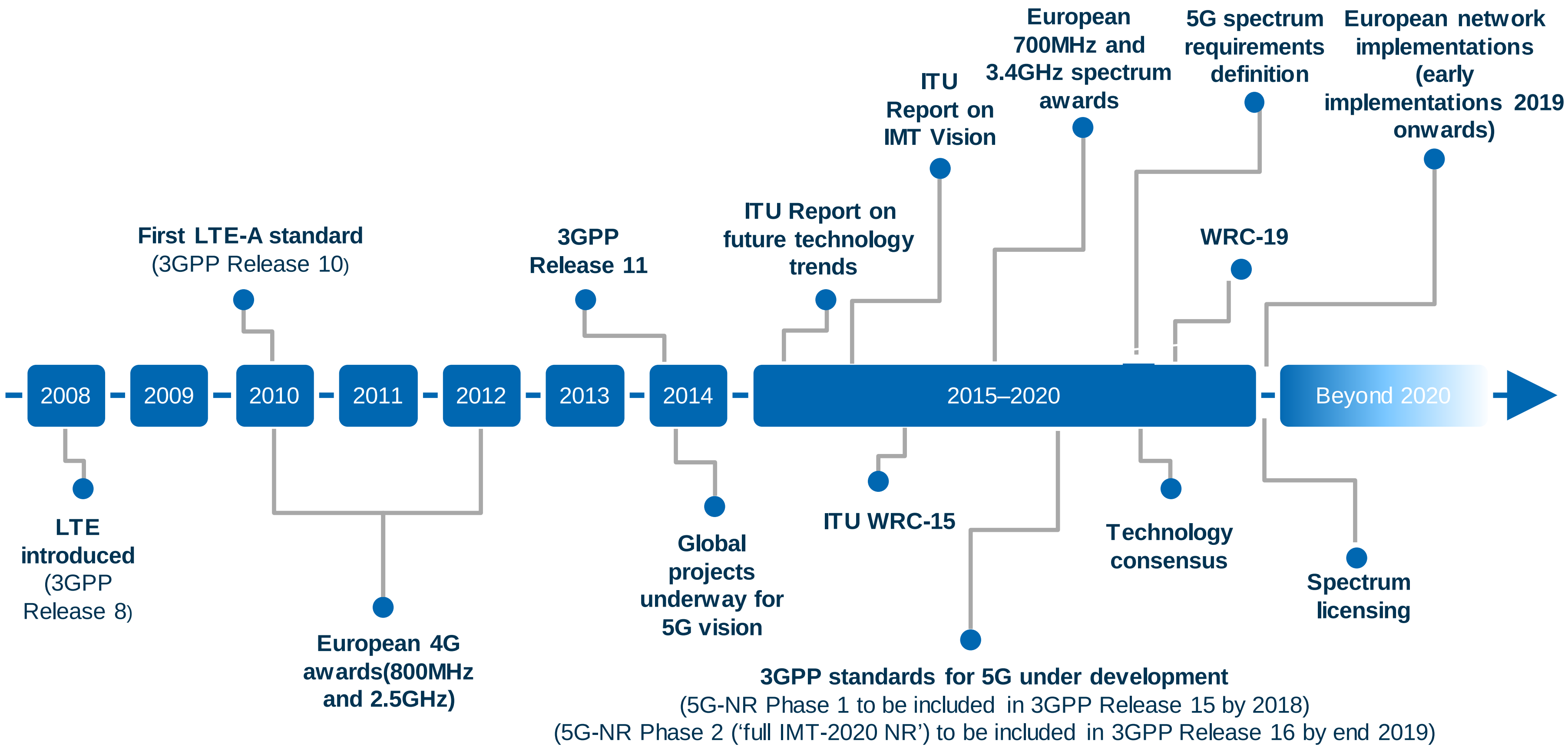
5 IMT-2020 is the agreed ITU vision for 5G under the 'International Mobile Telecommunications' umbrella. The IMT 2020 vision encompasses a range of 5G use cases across three types – enhanced mobile broadband, massive machine-type communication and highly reliable services (e.g. critical or emergency services). Under the 3GPP work plan there will be forward compatibility between the initial 5G (MBB) standards and subsequent 'full IMT-2020' implementation, as well as between stand-alone and non-stand-alone (5G with LTE) specifications.

6 *5G for Europe: An Action Plan*, communication from the EC to the European Parliament and others (published on 14 September 2016).

Figure 2.1: 5G standardisation timeline, and expected implementation in Europe [Source: Analysys Mason, 2016]



2.2 Scope of work

The study considers the deployment of next-generation mobile broadband services along with deployment of 5G in selected vertical sectors. The overall scope of work is as follows:

- Overall assessment of European priorities and targets for 5G deployment in next-generation mobile broadband (MBB), media and for IoT services to industries
- Modelling of alternative business models for 5G MBB deployment in three European countries: France, Germany and the UK. These three countries were selected on the basis of (a) the size of the market for mobile services, (b) their market structures (e.g. with three or four operators), and (c) the likelihood of early 5G deployment, given regulators' current plans for spectrum award (particularly in the 700MHz and 3.4–3.8GHz bands).
- Assessment of alternative business models for 5G-based IoT service provision to selected industries (automotive and e-health) in these three countries, including:
  - for the *automotive* sector, the potential for cooperation between 5G networks and wireless intelligent transport systems (ITS) deployed in the 5.9GHz (5855–5925MHz) band
  - for the *e-health* sector, alternative models to provide IoT connectivity for healthcare using cellular technologies, including LTE-based IoT solutions deployed within operator's existing licensed spectrum and use of a separate spectrum assignment to provide a dedicated infrastructure for IoT services (e.g. a 2×3MHz assignment in the 700MHz band).
- Conclusions on the 5G investments needed at a country level in Europe, and the impact that the European regulatory framework will have on these investments (e.g. in relation to the number of competing networks, availability of spectrum and conditions for provision of services).

2.3 Structure of this report

The remainder of this document is laid out as follows:

- Section 3 describes the overall connectivity, use cases and technology vision for 5G
- Section 4 provides analysis of business models for 5G MBB networks
- Section 5 considers 5G connectivity for e-health
- Section 6 looks at 5G connectivity for the automotive industry, and the benefits of cooperation along with networks providing ITS in the 5.9GHz band
- Section 7 considers 5G connectivity for smart cities
- Section 8 discusses 5G as an enabler for innovative audiovisual media services
- Section 9 presents conclusions and recommendations from the study.

The annex to the report provides a glossary of terms.

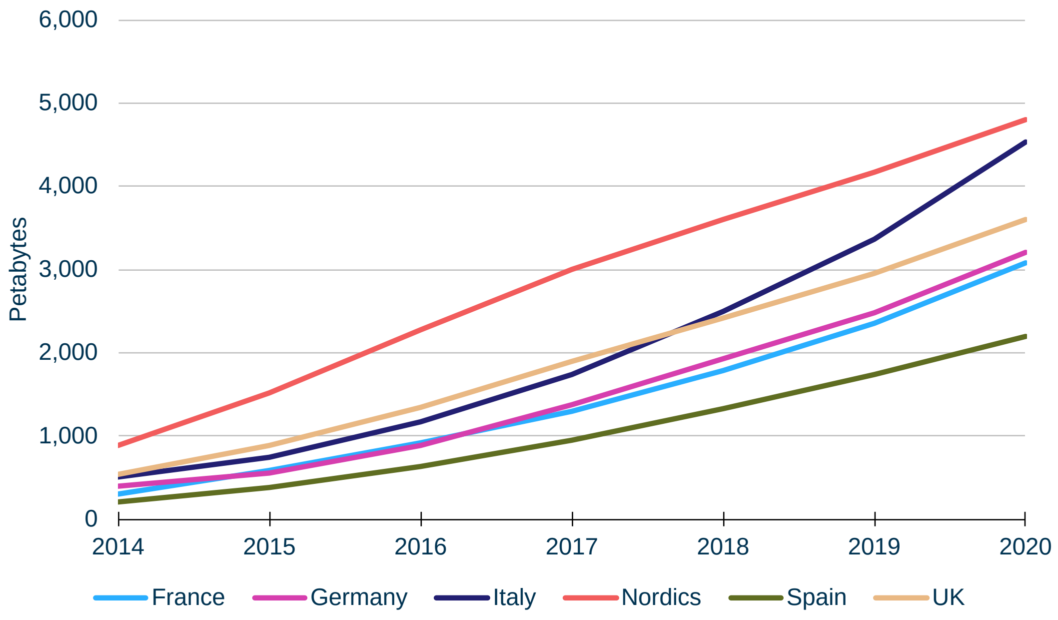
3 The mobile evolution and developments towards 5G

In this section, we summarise the key market and industry drivers contributing to the development of 5G. We firstly consider the evolution of the mobile broadband market since the introduction of 4G, taking account of rapid growth in mobile data traffic and the increasing consumer demand for mobile broadband services including content sharing, web browsing and video. We then consider evolution of radio access network (RAN) technologies from 4G to 5G, and the key drivers, and use cases, for 5G networks. The availability of spectrum as a key element for 5G introduction is then discussed, and European progress towards 5G implementation, in the form of 5G trials and industry partnerships is summarised.

3.1 The mobile broadband market, and evolution from 4G to 5G

Since the introduction of 4G mobile networks began in Europe, from around 2010, networks have continued to undergo rapid market and technological development, driven by the continued take-up of *mobile data* (i.e. mobile Internet) and *mobile multimedia* (e.g. video) services, and growing consumer demand for high-quality mobile connectivity irrespective of the user's geographical location. This has brought a rapid increase in mobile data traffic, which is forecast to continue, as illustrated in Figure 3.1.

Figure 3.1: Cellular data traffic forecasts in selected Western European countries [Source: Analysys Mason, 2016]



Note: 'Nordics' represents an aggregate of Denmark, Finland, Norway and Sweden.

Mobile equipment vendors have made a significant contribution to standardisation bodies such as 3GPP to ensure that mobile network technology continues to develop in line with market demand.

Hence, technology has evolved rapidly from the original designs of mobile networks for voice communication, towards providing increasing data capacity, higher-bitrate services and the ability to transmit high-quality images and video whilst on the move. Mobile operators are progressively expanding 4G services by deploying the latest LTE-A solutions, to offer significantly greater peak download speeds than those originally offered when 4G networks were first launched. Various operators in Europe are now using tri-carrier aggregation (i.e. combining three carriers together), offering peak speeds of up to 300Mbit/s. Operators have also started to trial use of additional LTE-A advanced features such as the higher modulation levels (i.e. 256QAM), which will offer further speed improvements. Ultimately it is likely that operators will use LTE-A technology to push peak downlink data speeds up to around 1Gbit/s, taking MBB services close to the speeds envisaged for 5G.

Internationally, the drive towards greater mobile data capability towards 5G is managed by the International Mobile Telecommunications (IMT) project of the International Telecommunication Union (ITU).[7] The ITU uses IMT to refer to internationally harmonised and standardised mobile broadband technologies. IMT was originally defined in the late 1990s to establish a global framework for the launch of 3G networks worldwide. Today, however, the term IMT is used to encompass the various generations of 3G, 3.5G and 4G systems now in operation worldwide. More recently, a further era of the ITU's IMT systems – IMT-2020 – has been introduced, referring to the early-stage research and pre-standardisation activity now underway around the world aimed at the definition of a next-generation, ubiquitous wireless broadband system (5G).

Whilst IMT 3G technologies such as high-speed packet access (HSPA) or HSPA+ are still widely used in Europe today, there has been a rapid migration towards IMT 4G (LTE and LTE-A).

As LTE deployments have gathered momentum, many mobile data subscribers are migrating from 3G to 4G. The increasing availability of smartphones is one of the key developments in the consumer mobile market that has driven the migration from 3G to 4G. The take-up of 4G in many European countries has been rapid, and the increasing penetration of 4G smartphone use is particularly pronounced in Europe, as shown in Figure 3.2 and Figure 3.3.

7 Specialist agency of the United Nations responsible for international regulation of telecoms, including radio spectrum.

Figure 3.2: 4G take-up in Western Europe [Source: Analysys Mason, 2016]

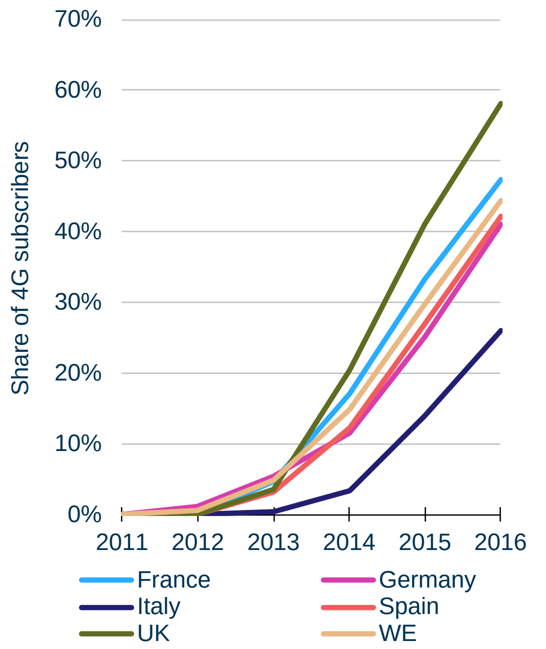
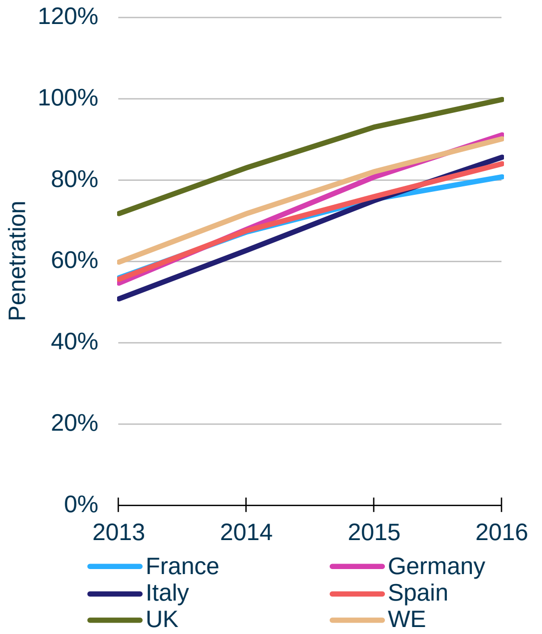


Figure 3.3: Smartphone penetration in Western Europe [Source: Analysys Mason, 2016]



The LTE technology deployed in early 4G networks is now evolving into LTE-A, which offers greater capabilities and flexibility for mobile operators to increase capacity and to enhance the provision of high-speed mobile data services. The deployment of LTE-A and the new features it offers (such as carrier aggregation to achieve higher peak speeds) has had various effects on the mobile market in Europe. In particular, the higher capacity that LTE-A networks provide means that operators are better positioned to cope with the substantial increase in mobile data traffic that 3G/4G networks are carrying (see Figure 3.4). The availability of LTE-A networks is also contributing to increasing consumer expectations on the speed, quality and availability of mobile broadband services. As a result, mobile operators are continuing to invest in the latest iterations of LTE-A to provide higher headline speeds for 4G, in order to differentiate their networks in the market (see Figure 3.5).

Figure 3.4: Mobile data traffic in Western Europe [Source: Analysys Mason, 2016]

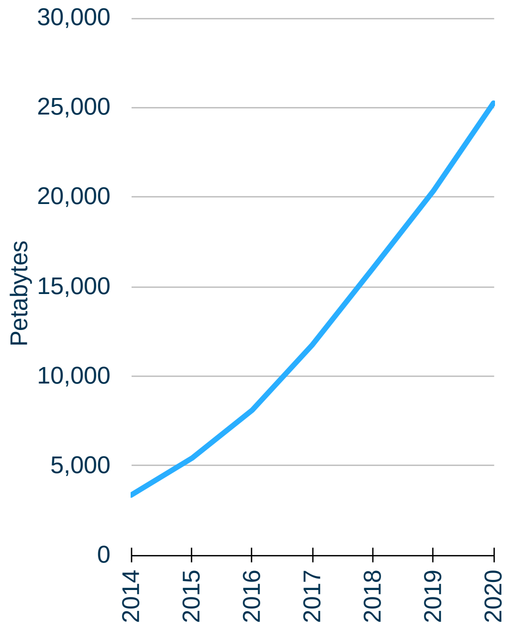
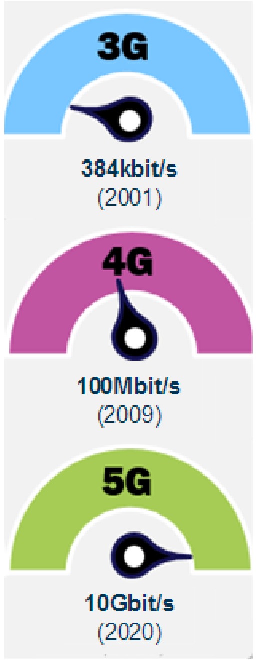


Figure 3.5: Mobile headline speeds by technology [Source: Analysys Mason, 2016]



Note: The 3G speed shown on Figure 3.5 refers to W-CDMA technology; HSPA can reach 7.2Mbit/s, and HSPA+ (also referred as 3.5G) can offer up to 21.6Mbit/s.

A key feature of LTE-A is carrier aggregation, which enables operators to provide higher peak speeds by aggregating two or more non-contiguous frequency carriers from the same or different standardised frequency bands. This is driving demand for spectrum across a range of frequency bands, and European regulators have been proactive in ensuring that sufficient 4G spectrum continues to be available to meet market demand. Whilst many 4G spectrum awards in Europe initially focussed on two frequency bands harmonised at the EU level – 800MHz and 2.6GHz – there are now a range of frequency bands that are being widely used for 4G (including bands re-farmed from 2G/3G use), and additional spectrum awards are being planned. The European 4G spectrum roadmap is illustrated in Figure 3.6. It is noted that, in line with market demand and technology evolution, it is expected that some of the bands in the figure below might play a role in the initial deployment of 5G. We address the spectrum implications of 5G in a subsequent section.

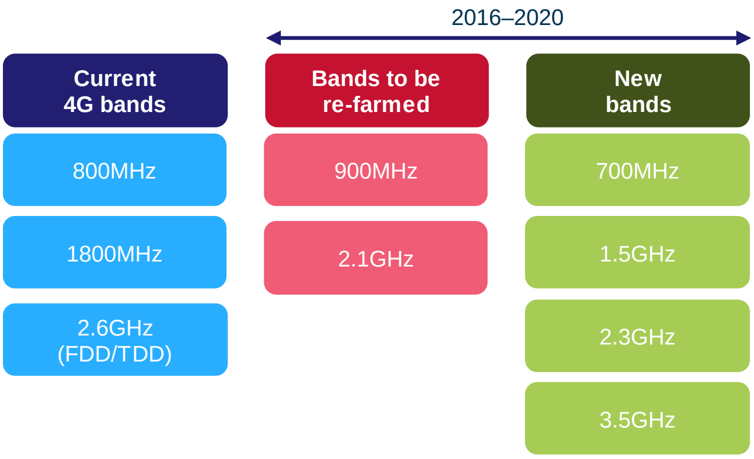


Figure 3.6: Current 4G bands and potential new mobile (4G/5G) bands [Source: Analysys Mason, 2016]

Note: Some European countries such as France and Germany have already awarded the 700MHz band for 4G whereas the 700MHz band is still being planned for award in many other countries. The timing of these awards (e.g. 2018–20) suggests that 700MHz and certain other new bands listed above (e.g. 1.5GHz) might play a role in deployment of new mobile services envisaged under 5G. 3.5GHz is mostly expected to play a role in 5G, as it is the only sub-6GHz band supporting larger channel bandwidth (e.g. around 100MHz.)

Alongside these technological developments in mobile networks, increasing competition among operators and market saturation has exerted downward pressure on traditional voice revenue, as shown in Figure 3.7 below. In contrast, mobile data has become an increasingly important part of the offering to subscribers, and the share of revenue generated by data has increased (see Figure 3.8). It is clear from this that operators will increasingly rely on mobile data demand for their revenue, which has been one of the key drivers for the further development of LTE-A technology within 3GPP, for networks to support more intensive data usage (as discussed in the next section).

Figure 3.7: Mobile blended ARPU in Western Europe [Source: Analysys Mason, 2016]

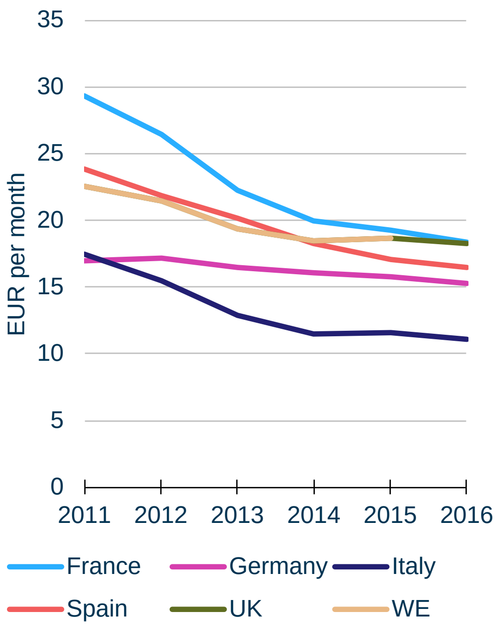
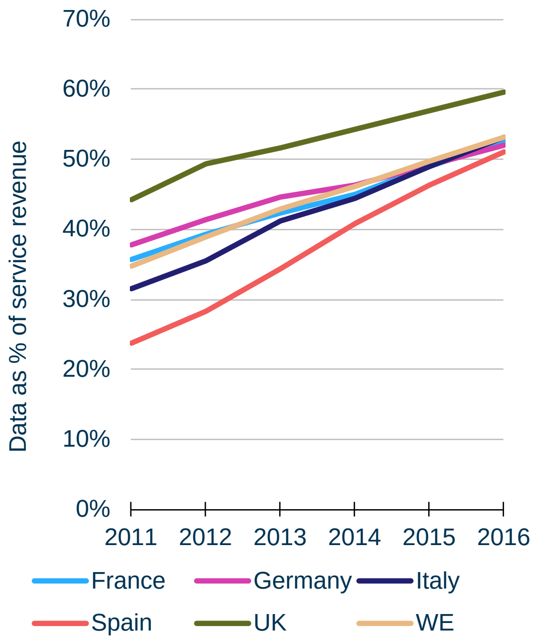


Figure 3.8: Data share of mobile revenue in Western Europe [Source: Analysys Mason, 2016]



Note: The ARPU increases shown for the UK in 2014 and 2015 were due to fluctuations in the GBP–EUR exchange rate (in GBP terms, ARPU declined during these two years).

An important consideration in the context of achieving return on investment from expanding the capabilities of high-speed mobile network across Europe is that although the share of revenue generated by data services is increasing, overall mobile ARPUs in Europe are declining, as the charts above show. In Europe, the overall ARPU has declined from well over EUR20 per month in some markets in 2011, to below EUR20 per month in 2016. With consumers expecting this price point for MBB services, it is therefore far from clear that 5G-based MBB services can be charged at a premium over 4G. Since operators will plan investments for 5G in accordance with expected revenue, the implication of declining ARPU is that investments will be tailored under such conditions.

3.2 Technology evolution from 4G towards 5G new radio (5G-NR)

The use of LTE is now firmly established for the provision of 4G mobile broadband services, demonstrating the success of the 3GPP global standards.

LTE-Advanced or LTE-A features are continually being added to 3GPP specifications in line with market requirements. These new features help to improve the delivery of 4G MBB services in a number of ways:

- **Carrier aggregation** makes it possible to aggregate multiple frequency carriers across different bands and between network deployments employing frequency or time division duplex, to achieve several-fold increases in peak user speeds, as well as improvements in capacity utilisation across multiple bands
- **Dual connectivity** allows devices to maintain simultaneous connections to different cell layers (e.g. macro and small cell layers), as a means of improving cell-edge throughput and peak speeds (e.g. devices can be connected to a macro cell on one frequency whilst also receiving higher data speeds via a small cell on another frequency). Dual connectivity was first introduced in 3GPP Release 12, and will continue to develop in subsequent 3GPP releases
- **Multi-antenna beamforming** brings performance benefits, including better cell-edge performance and higher throughput
- **Machine-type communication for the IoT** involves the application of cellular technology in vertical IoT markets, based on LTE (with subsequent evolution to 5G). This term encompasses various LTE-based IoT developments such as narrowband IoT (NB-IoT), LTE machine-type communication, specific connectivity solutions being standardised for mission-critical radio (e.g. for emergency services), as well as the potential for IoT services using 5G-NR. In the shorter term (ahead of 5G roll-out), it is therefore widely expected that operators will increasingly deploy LTE-based solutions such as NB-IoT or LTE machine-type communication to deliver IoT-based services. This has the benefit for mobile operators of engaging a greater proportion of IoT users into the cellular operating domain, allowing for a subsequent transition from 4G to 5G based on market demand.

At present, only a portion of IoT connections use cellular networks. The remainder use a variety of low power, short-range wireless technologies, broadly referred to as low-power radio solutions, operating in unlicensed spectrum.

The developments in LTE-based IoT solutions demonstrate the cellular industry's commitment to connecting a greater proportion of IoT connections using 4G networks, and subsequently with 5G, based on market demand. However, it is not yet clear whether the revenue that IoT services will generate justifies the investments needed to tailor wide-scale IoT network connectivity using 4G and 5G, given the additional functionality, resilience and security that some IoT applications need, compared to the expected revenue (e.g. when compared to MBB). Hence, there is a risk in 5G (as with 4G) that operators will invest primarily to deliver MBB connectivity, without specific measures in place to improve the business case for delivery of IoT-based services.

As 4G networks evolve towards the 5G era, it is envisaged that there will be increased inter-working among different existing RAN technologies to make optimal use of available technologies within a common infrastructure. For example, increasingly seamless interworking between LTE-A and Wi-Fi will give mobile operators greater control over quality of service (QoS) and more flexibility to use licence-exempt spectrum bands such as 5GHz, under the control of a licensed network. Greater use of spectrum sharing is also envisaged and in Europe, licence assisted access and licensed shared access offer two emerging forms of shared spectrum use.

Licence assisted access is the use of LTE technology to aggregate licensed and unlicensed spectrum. The unlicensed spectrum is in the 5GHz band, also used by Wi-Fi, and licence assisted access enables LTE carriers in macro cells using licensed spectrum to be aggregated with 5GHz LTE carriers in small cells, to provide increased speed and possibilities of improved LTE in-building coverage using 5GHz small cells.

Finally, increased used of shared spectrum has been identified by many European policy makers as a goal for improving access to spectrum for wireless data services. For mobile operators, a key concern is that quality of experience (QoE) needs to be maintained for users of mobile networks when using shared spectrum. Licensed shared access is one way that is being suggested to manage this, and in this context refers to the managed sharing of spectrum between commercial and incumbent use (mainly where the incumbent user is a government department, such as military). Licensed shared access offers a framework whereby the incumbent user can continue to use spectrum at the same time as new commercial use(s) are introduced, subject to sharing terms setting out the conditions for use on both parties. The most promising scenario for use of licensed shared access for mobile operators in the short to medium term might be to enable additional access to harmonised spectrum in the 2.3GHz band which, in many European countries, is allocated for Ministry of Defence (MoD) operations and hence not available for commercial use.

3.3 5G technology and use cases

Whilst the development of 4G networks has been broadly linked to the rapid increase in data traffic being carried by mobile networks, and the need to accommodate increasing consumer demand for MBB services, drivers for the development of 5G are more diverse.

The internationally agreed vision for 5G includes a diverse mix of services and devices. Use cases for 5G have been studied extensively with publications such as those from the 5G-Public Private Partnership (5G-PPP), which is the partnership between the Commission and European industry to develop 5G solutions, proposing a wide range of 5G service requirements.[8] Similar research projects to the 5G-PPP in countries around the world have conducted their own analysis into alternative 5G use cases. Over the past year, the mobile industry has focussed considerable effort towards consolidating the different proposed use cases for 5G. There is now widespread recognition that there will be three broad use cases for 5G, which are:

- enhanced MBB services to consumer mobile devices (building on today's 4G services),
- massive machine-type communication, embracing a wide variety of new IoT-type use cases such as automated vehicles, robotics, smart homes and buildings, e-health and smart grids
- wireless connectivity for highly reliable and critical infrastructures (e.g. emergency services and other public services requiring ultra-reliable, very low latency communications).

This mix of applications implies that 5G networks must support a range of service characteristics to be fully featured (i.e. to address each of the three use cases above). These service requirements range from very high (Gbit/s) data speeds for mobile broadband services, through to very high network availability, low latency and increased reliability of connections that will be needed for some IoT applications, and to deliver critical communications infrastructures.

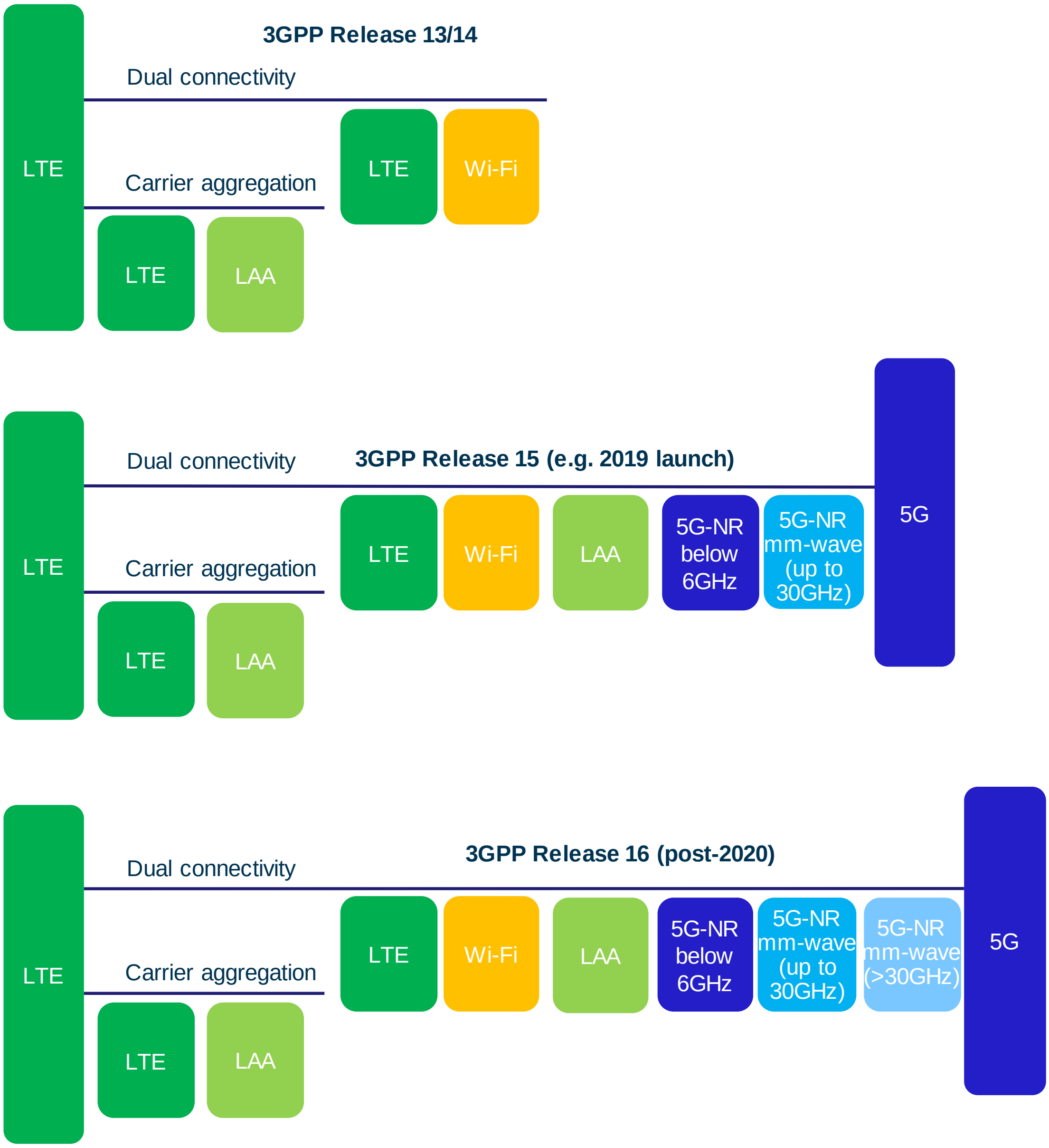
5G-NR is the term used to describe the new air interface that is being developed for the 5G era to address the key use cases that have been identified globally. 5G-NR and evolved LTE-A are expected to complement one another to provide continuity as 4G-based MBB and machine-type communications evolves into 5G. Whilst the initial focus of 5G-NR deployment is expected to be on the provision of enhanced MBB services to enable economies of scale to be generated, it is expected that 5G-NR will expand to other services (including vertical services), based on market demand. Underpinning these developments will be the ability of 5G-NR to provide upwards of 5Gbit/s connectivity, as well as a range of other performance improvements (including lower latency and flexible, cloud-RAN architecture and capabilities such as network slicing, which provides the potential for new service models under which QoS requirements can be matched to user needs).

Figure 3.9 below provides a summary of the 5G-NR development programme in 3GPP and how this is linked to the evolution of LTE-A technology. This demonstrates the increasing integration of 4G and 5G RANs, with 5G-NR expected to replace LTE in the longer term, in line with market evolution and demand. In the initial deployment of 5G, it is expected that LTE and 5G-NR deployment will

8 Source: www.5G-PPP.eu

be combined via the 'dual connectivity' feature of the 3GPP standards (as described in the previous section).

Figure 3.9: Evolution of LTE and introduction of 5G-NR [Source: Qualcomm, Analysys Mason, 2016]



Given this very broad range of use cases, a mobile operator's business model for 5G might involve connecting a wide range of service and device types over a common infrastructure – including IoT-based services as well as consumer-driven MBB applications. Operators could potentially offer different levels of service priority, capacity, coverage and latency to address individual use cases in an optimal way. With the introduction of 5G, mobile networks will become more integrated into the Internet, incorporating increased virtualisation and cloud services.

Network virtualisation could potentially enable operators to meet the needs of different vertical users of mobile networks using a common network infrastructure. Virtualisation encompasses various emerging and future technological developments, including cloud infrastructure, network function virtualisation and software-programmable networks. This will potentially allow mobile operators to support a variety of new business models and new ways of delivering services, which will be essential in the 5G era of different connected device types, service requirements and vertical use cases. For mobile operators, this virtualisation of network functions presents both challenges (e.g. ensuring privacy and security) and opportunities (e.g. the ability to offer different levels of service, security and privacy protection required by some use cases), to the extent that regulations allow. In this regard, it is noted that there is some concern reported within the industry that European net neutrality regulations, as currently proposed, could hamper operator's ability to innovate with different service levels.[9]

These net neutrality concerns are particularly relevant in 5G since specific features of 5G, such as 'network slicing', will enable the quality of experience to be dynamically optimised to individual user groups in a way that has not been possible in mobile networks to date. This creates a platform for 5G to deliver new mobile experiences to consumers and to vertical industries. However, the range of services and devices that 5G networks might be optimised to provide also creates significant challenges for operators, as they will need to design networks to meet a diverse range of capacity, coverage and quality requirements. Such significant innovation will require significant investment. There is some concern that uncertainty concerning the regulatory implications of providing differentiated quality of experience for different 5G users could dampen this investment. Hence, further clarity is needed in the intended regulations for net neutrality.

A further key implication of the broad range of use cases being proposed for 5G is that a range of frequency bands will potentially be needed to deliver the required network reach, capacity and capabilities. The spectrum needs for 5G are now generally considered as ranging from bands below 1GHz for wide area coverage, bands in the 1–5GHz range (3.4–3.6GHz being key in Europe) through to the millimetre-wave bands being considered in the context of the studies defined by the ITU World Radiocommunication Conference in 2015 (WRC-15). Since studies within ITU-R Task Group 5/1, which is the group formed to address the 5G agenda item for WRC-19, will not commence until May 2017, the spectrum needs for 5G are still being defined internationally. However, European policy makers have recognised the importance of early indications of spectrum needs for 5G to accelerate the availability of services in the European market. This is further discussed in the next section.

3.4 Spectrum implications for the development of 5G

This section provides a summary of spectrum considerations from a European perspective, focusing on those which are relevant to the 5G business models presented in the remainder of this report.

Compared to 4G MBB services, 5G is being developed to achieve specified performance benefits, including multi-gigabit speeds, decreased end-to-end latency and a more uniform experience across locations and environments (including much greater capacity). 5G-NR will use a combination of

9 Source: http://www.bbc.co.uk/news/technology-36763903

additional spectrum, dual connectivity with LTE and multiple antennas ('massive multiple in, multiple out') to achieve this improved performance and reliability.

Key to 5G-NR operation is the use of wider bandwidth channels (100–500MHz or more), which allows for significantly higher data rates to be delivered in areas of very high MBB traffic density, compared to today's mobile networks. In addition, using millimetre-wave bands enables advanced antenna technologies and may more antennas such as massive multiple in, multiple out to be deployed effectively. These offer a number of performance improvements such as better range and reliability.

Although deployment in millimetre-wave spectrum is required to achieve the full capability and data speed potential of 5G-NR (due to the potential for very large carrier widths of 100MHz or more to be used), it is increasingly being recognised that initial deployment of 5G-NR in Europe might take place in frequency bands lower than this, such as the 3.5GHz (i.e. 3.4–3.8GHz) band. European regulators are actively discussing the bands that might be used for early 5G deployment in Europe, with early deployments potentially taking place in 2018 (noting that the millimetre-wave spectrum bands for 5G will not be agreed internationally until the WRC in 2019). In particular, the EU's Radio Spectrum Policy Group (RSPG) published a draft opinion on 5G spectrum in July 2016, 'Strategic roadmap towards 5G for Europe' pointing to initial deployment of 5G services requiring both low (e.g. 700MHz) and mid (e.g. 3.5GHz) spectrum as well as millimetre-wave bands. The subsequent 5G Action Plan[10] published by the Commission in September 2016 also points to spectrum in the 700MHz, 3.5GHz and millimetre-wave bands being needed in Europe to address the full scope of 5G network requirements. From the perspective of the millimetre-wave bands under study for 5G internationally in preparation for WRC-19, the RSPG and the Commission point to three of these as being the most promising from a European perspective: 24.5–27.5GHz, 31.8–33.4GHz and 40.5–43.5GHz, with indication that the RSPG intends to identify which of these can be harmonised for early implementation in Europe as a 'pioneer band' for 5G.[11]

In the short term, industry efforts appear more focused on development of 5G-NR in sub-6GHz bands, such as the 3.4–3.8GHz band, as well as in the 24.5–29.5GHz range. The 700MHz band is already incorporated into equipment standards for 4G, but operators are likely to view this band as having opportunities to deliver both 4G and 5G services due to its potential to provide additional capacity across wider areas (potentially addressing coverage-driven use cases for 5G, such as in healthcare or for 'smart' vehicles).

The analysis carried out by Analysys Mason as described in the remainder of this report considers scenarios for the use of both 700MHz and 3.4–3.8GHz bands for early 5G launch in selected European markets, and the associated business case(s).

10 See https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan

11 See https://ec.europa.eu/commission/2014-2019/oettinger/blog/vital-support-industry-eu-5g-action-plan_en and https://ec.europa.eu/digital-single-market/en/radio-spectrum-policy-group-rspg

3.5 European progress towards 5G

The Commission has identified early introduction of 5G as being a key priority for Europe's communications industries. With full commercial introduction of 5G networks taking place after 2020, it is nevertheless expected that the early introduction of 5G in Europe will benefit from trials and pilots of new 5G networks taking place well before this.

Mobile operators and manufacturers have already begun to invest in research on 5G technology, as well as carrying out initial trials. These trials are expected to increase in scale and number over the coming twelve months as European policies to encourage the development of 5G (such as proposed in the 5G Action Plan) are further developed.

Figure 3.10 provides some recent examples of mobile operators and manufacturers working in partnership on 5G mobile technology in Europe.

Figure 3.10: Examples of 5G trials involving mobile operators and manufacturers [Source: Analysys Mason, 2016]

Country	Mobile operator	Manufacturer	Comments
Austria	Hutchison Drei	ZTE	Agreement to build the first pre-5G trial site in Europe. ZTE plans to use core 5G technologies on 4G networks to alleviate the pressure created by data traffic
Italy	TIM	Ericsson	The '5G for Italy' programme is carrying out research on the implementation of innovative projects enabled by 5G. 5G for Italy will also develop pilots of possible 5G solutions (in areas such as smart cities, IoT, transport and smart agriculture)
Germany – South Korea	Deutsche Telekom / SK Telekom	Ericsson	The three partners will cooperate on development of a trial 5G core network in Korea and Germany, based on 5G technologies such as network function virtualisation and distributed cloud. The alliance will lobby for potential technology standardisation
Russia	MegaFon	Nokia	Both firms agreed to research on the joint development of 5G networks in Russia. The partnership will test new solutions under joint pilot projects and will deploy a 5G testing cluster in stadiums being used to host the FIFA World Cup in 2018
Russia	MTS	Nokia	The two firms have a strategic agreement on the realisation of 5G. They will work on joint trials that use 4G LTE-A and 5G to enable faster speeds, lower latency, new spectrum efficiencies, innovative projects using NB-IoT, etc.
Switzerland	Swisscom	Ericsson	The two companies, together with the École Polytechnique Fédérale de Lausanne (EPFL) will work on understanding how 5G can enhance their business and develop industrial applications to implement and trial. The partnership believes that 5G technology will bring new services such as smart transportation, autonomous driving, smart grid, IoT, virtual reality, etc.

Country	Mobile operator	Manufacturer	Comments
Turkey	Vodafone	Huawei	The two companies have an agreement to develop 5G technology by establishing a joint work group. A key aim of the agreement is to determine the standard to be used to implement 5G
Turkey	Türk Telekom	Nokia	Türk Telekom and Nokia recently signed an MoU to accelerate the development of 5G and the applications which will drive IoT technologies for tracking, metering, smart cities, smart homes and latency-sensitive applications. Their findings will be used to develop 5G-ready products for Türk Telekom
Spain	Telefónica	Ericsson	The two firms have agreed to focus on the 5G PPP and ETP Networld 2020[12] initiatives promoted by the EC. They will also research and carry out trials of technology and equipment to support the 5G architecture, services and applications
UK	BT	Nokia	BT and Nokia are collaborating on research to develop 5G technology. They will work on potential customer use cases for 5G, the creation of 5G 'proof of concept' trials and development of technology standards and equipment. The first trials involve 4×100MHz carrier aggregation, providing speeds which allow simultaneous streaming of data-heavy content such as live 360-degree videos
UK	Vodafone	Huawei	The two firms have completed a 5G trial at 70GHz, which reached data rates of over 20Gbit/s and was able to support multiple users who received 10Mbit/s each. Vodafone said that the research is focusing on bands above 24GHz for 5G enhanced mobile broadband

Although several 5G trials are emerging in Europe, it is noted that other markets seem be further ahead than Europe at present. In particular, agreements between Japanese, South Korean and North American mobile operators and international manufacturers look to be more established, widespread and developed. Possibly for this reason, the EC's recently published 5G action plan promotes a variety of measures supporting the need for further backing for 5G trials in Europe, with key actions to be achieved during 2017. The EC calls on both European governments and industry to increase the scope of 5G trials in Europe. For example, the EC's action plan calls for each EU Member State to identify at least one city to be '5G enabled' by 2020, and to develop national broadband roadmaps (encompassing 5G) by the end of 2017. The EC is also seeking governments and industry to collaborate towards development of plans for trials of key technological elements of 5G, with the goal of these being established by early 2017. Cross-industry partnerships are also being encouraged.

12 ETP Networld 2020 – European Technology Platform for Communications Networks and Services.

4 Analysis of business models for 5G MBB

As discussed in the previous section, the use cases for 5G are widely reported to span three potentially diverse applications – enhanced mobile broadband, massive machine-type communication (i.e. IoT) and ultra-reliable (low latency) connectivity. There is wide recognition that the MBB use case is likely to form the basis of initial deployment in Europe, for operators to build upon existing mobile businesses. This section describes Analysys Mason's assessment of business models for 5G MBB, using spectrum in the 3.4–3.6GHz band.

In this section, we firstly summarise the 5G MBB opportunity, followed by a summary of our modelling scenarios. Results and implications for European roll-out of 5G are then discussed. We highlight the implications of the modelling results in terms of the European regulatory framework for 5G, and whether this needs to adapt compared to the current (4G) mobile market structure. Considerations include the number of competing infrastructures per country, the extent of infrastructure sharing and assumptions on the prices paid to acquire suitable 5G spectrum. Finally, we consider the extent of network coverage that can be achieved under reasonable assumptions on the levels of investment that operators will make in 5G infrastructure, and how this coverage might be extended. The potential to increase investment/coverage through use of coverage and other targets (either in 5G licences, or as part of European 5G policy such as future Digital Single Market (DSM) strategy development[13]) is also discussed.

4.1 Overview of the 5G MBB opportunity

Improving broadband connectivity across Europe is one of the key steps in achieving the EC's Digital Agenda (DA). 4G mobile broadband services are already available to large numbers of European population and operators are expected to push downlink data speeds for 4G further beyond those available today. The latest operator trials of advanced LTE-A deployment are achieving downlink speeds of up to around 1Gbit/s or above, based on using the maximum carrier aggregation capabilities in LTE-Advanced[14] together with the highest modulation levels. However, the limits of 4G technology are being reached. For example, a maximum five 20MHz carriers can be aggregated in LTE-A (this is not yet commercially implemented). But even the current 3-carrier aggregation introduces a complex range of carrier aggregation combinations for devices to support, given the large number of frequency bands that 4G devices must support to fit different regional spectrum availability.

The new technology that 5G will deliver provides an opportunity to support at least 100MHz channels and to achieve this more natively in higher frequency bands (where greater amounts of contiguous bandwidth is likely to be available). This, will lead to simplified radio access networks compared with complex carrier aggregation configurations. Over time this is expected to lower the

13 See https://ec.europa.eu/priorities/digital-single-market_en

14 Carrier aggregation is applicable to both the uplink and downlink direction of LTE networks and increases the channel bandwidth by combining multiple radio frequency (RF) carriers.

cost of super-fast mobile broadband delivery. The introduction of 5G is therefore likely to enhance the availability of fast and even superfast broadband services, enhancing mobile network capabilities to bring higher throughput, better capacity and availability, and lower latency.

To meet the EC's priorities and the future demands of wireless data traffic, the Radio Spectrum Policy Programme (RSPP) previously set a target for Member States to make at least 1200MHz of spectrum available for MBB. However, by the end of 2015, EU-harmonised spectrum had reached just 71% of this target, and on average 30% of harmonised spectrum remained unassigned.[15] Delays in assigning spectrum could potentially hamper the roll-out of MBB networks and thus the provision of MBB services. The Commission has recognised this in its recent communications on 5G, which focus on various measures to accelerate 5G network trials and commercial launches.

We note that LTE penetration in Europe is at least two years behind that in developed economies of South-East Asia and the USA.[16] One reason for this is the timing of 4G licence award in Europe, which happened later in many European countries compared to the earlier awards that took place in South-East Asia and the USA. Hence, the Commission's prioritisation of early policy action to promote suitable spectrum being identified and licensed for 5G (e.g. as proposed in the Commission's 5G Action Plan, supported by the opinions being developed by RSPG) is aimed at providing greater certainty on when 5G services will be available in Europe. Of particular note is that the recent 5G action plan for Europe commits the EC to working with EU Member States to identify a list of 'pioneer bands' for early 5G deployment. As identified in Section 3.4 earlier, these are likely to include 700MHz, 3.4–3.8GHz and selected bands from the millimetre-wave range (e.g. 24.25–27.5GHz, which has recently been reported to be RSPG's preferred millimetre-wave band to make up the core of 5G bands[17]).

The initial focus of 5G service deployment is expected to be for MBB use, before expanding 5G services to specific other vertical industries (including IoT applications, and mission-critical connectivity, including intensive mobile data usage and streaming video). It is quite clear that MBB will be the initial/main service, as it provides the necessary economy of scale for operators to enable the rapid development of 5G technology on the back of LTE network investments that have been made in Europe over the past 5 years. Most of the 5G trials undertaken by major vendors and operators to date have been focusing on data rates and peak speed for intensive MBB usage, providing further indication that MBB is the main 5G opportunity to drive investments in the initial stage.

We note that 5G will have ability to be deployed in a broad range of bands, including high-frequency millimetre-wave bands where sufficient spectrum is likely to be available to achieve the highest speed services. These bands are well suited for the widespread deployment of small cells in targeted coverage areas. However, 5G is also expected to enhance existing MBB services using other

15 European Commission, *Connectivity, Broadband market developments in the EU*, Europe's Digital Progress Report 2016.

16 Idate Consulting, November 2015, *Mobile Operators' Investments: Europe Needs a Pro-investment Mobile Regulatory Framework*; see https://www.ericsson.com/res/docs/2015/mobile-operators-investments-whitepaper.pdf.

17 See https://www.policytracker.com/headlines/rspg-chooses-26-ghz-for-european-5g-mmwave-spectrum

frequency bands, which might not provide the same peak speeds as the full capabilities of 5G-NR in the millimetre-wave bands, but will enhance the coverage and the throughput achieved across a wider coverage area, when combined with LTE. Hence, the opportunity for operators from 5G MBB will be to extend current MBB services through the provision of:

- extremely high throughputs (in Gbit/s), which would allow the provision of broadband 'fibre' services to the home including ultra-high definition video in real time, and ensuring sufficient capacity in demanding conditions of very high user density, such as in sports venues and stadiums.
- much lower latency, capable of delivering services such as virtual reality and augmented reality experiences.
- a uniform experience, with much more capacity than is needed for 3D/UHD video telepresence, for example.

One of the potential 'killer applications' for 5G, requiring the full capabilities of the 5G-NR interface might be virtual reality (VR) and augmented reality (AR) use.[18] Telecoms operators and networking vendors typically view VR and AR as a potential driver of 5G adoption and traffic growth. These are expected to be some of the most capacity intensive of the various 5G services being envisaged. Other services such as ultra-high definition video, will be less capacity intensive (assuming appropriate compression technology is used, for example) but 5G networks will be better able to deliver such video services in real time, with better availability and lower latency, based on the improved performance that 5G-NR is envisaged to deliver. Other more innovative services are being envisaged for 5G to address specific vertical markets (e.g. use of cloud robotics for healthcare, which could be delivered over 5G networks). More generally however it is expected that 5G will deliver a broad range of MBB services with similarities to 4G MBB services today (e.g. content sharing, web browsing), but potentially offering better capacity to deliver these services to a higher quality and to a greater number of users.

Since the provision of MBB services is expected to be a fundamental aspect which operators will require when rolling out 5G networks, to drive economies of scale in order to enhance their proposition towards other use cases, our analysis of the infrastructure requirements for 5G is initially focused on delivering MBB services, as described in the next section.

4.2 Summary of modelling scenarios and assumptions

As part of this study, Analysys Mason has developed a 5G MBB model. The aim of this model is to examine the investment opportunity for deploying 5G technology using the 3.5GHz band, from a mobile operator's point of view. It is assumed that, when deploying 5G MBB services, operators will follow the natural course of mobile technologies development towards implementing a new technology (5G) in the sense that, in the short to medium term, 5G technologies and services will operate alongside existing (3G/4G) ones. There is an expectation that over time and in line with market demand, operators will then migrate existing MBB users onto new 5G networks, assuming

18 During the launch of the Telecom Infra Project (TIP) at Mobile World Congress 2016, Mark Zuckerberg was quoted as saying that virtual reality would be one of 'the killer applications of 5G'.

5G networks will be more efficient than current solutions and will also allow significantly higher mobile broadband speeds to be offered (although they have not yet been defined).

The outputs of the modelling scenarios include the total investment required, and the 5G-specific investments (which vary depending on the levels of population coverage to be reached and the demographics of different countries).

4.2.1 Modelling scenarios

Within the model, we have developed three different scenarios:

- **Scenario 1 – 5G deployment following 4G market structure**: Population-led roll-out driven by market competition. 5G roll-out includes reusing a significant share of operators' existing sites (2G, 3G and 4G), although operators would need to build new sites if the existing ones are inadequate due to coverage or capacity reasons. A reasonably low 5G spectrum fee is assumed under this scenario.
- **Scenario 2 – Enhanced coverage with additional investment funded through spectrum fees**: Same approach as for Scenario 1. In this case, we make a hypothetical assumption that spectrum fees that operators pay upfront for a 5G licence are returned to operators once they meet potential five- and ten-year coverage targets, to be invested in further network expansion. This would provide an incentive for MNO to respect the coverage timetable mandated by the licence terms.
- **Scenario 3 – Fewer competing network builds**: In this scenario, 5G investments would be put into a single shared infrastructure developed by multiple service providers (i.e. by deploying a common infrastructure in terms of physical sites, towers, passive infrastructure and backhaul between all operators, but with separate base stations and antennas differentiating the operators' services). This should considerably reduce the upfront 5G network investment that is required, and would also have a beneficial impact on network opex, due to the efficiencies associated with site sharing (which would also reduce the number of sites that had to be rolled out).

In Figure 4.1 below we summarise the main differences between the three scenarios.

Figure 4.1: Main differences between the three 5G MBB scenarios [Source: Analysys Mason, 2016]

Scenario	Spectrum fees	5G investment in new site roll-out	5G investment in upgrades to existing sites
Scenario 1	5G spectrum fees are based on the average European price for the 2.6GHz band (estimated at EUR0.05 per MHz per pop)	Roll-out of new sites including civil works and mobile equipment	5G additions/upgrades on existing mobile sites
Scenario 2	Same as Scenario 1 but spectrum fees are returned to operators once they met five- and ten-year coverage targets	Same as Scenario 1	Same as Scenario 1
Scenario 3	Similar to Scenario 1	Infrastructure is shared by all operators (i.e. civil works for new sites are split among all operators)	Infrastructure is shared by all operators, which makes it more efficient to upgrade existing sites (an estimated 10% reduction in investments when 5G is added to existing sites)

4.2.2 Main principles and assumptions

When developing the modelling scenarios, the main principles and assumptions that we have used are as follows:

- **4G coverage and capacity**: we assume that operators will continue to roll out their 4G networks in line with existing coverage obligations for the 700MHz and 800MHz bands. We also assume that operators will re-farm existing 2G/3G spectrum, and so the number of bands and the amount of spectrum used for 4G technologies will increase over time. By 2030, we assume that almost all existing spectrum will be used for 4G technology (i.e. 2G and 3G will no longer be used for mobile services)

- **5G spectrum**: we estimate that 3.5GHz will be the first band to be used for 5G MBB, and that spectrum from this band will be available for mobile operators to use from 2020 in a number of European countries. We note that availability of this band for 5G in 2020 may be a ‘best-case’ scenario in some countries, as the spectrum needs to be re-farmed from existing use. While 5G spectrum is expected to be awarded in 2020, roll-out is assumed to start in 2021. We also consider that an operator will be able to use 100MHz of spectrum in this band, enabling it to provide a ‘real’ 5G service, differentiated from 4G in terms of speed and quality

- **Monetisation of 5G MBB services**: we assume that there will be no incremental revenue from 5G MBB services over 4G, and so the ARPU is estimated to be equal for 4G and 5G subscribers. In other words, rolling out 5G MBB is not assumed to create incremental revenue for operators (with the operators’ main aims being to keep up with their competitors, clients’ demands and technological developments). Year-on-year ARPUs in the model are based on recent European trends with ARPU decreasing over time (but with this trend flattening in the model after 2020)

- **Operator modelled**: we have modelled a generic operator (assumed to be an 'average' operator) in each of the three countries (France, Germany and the UK). This means that our modelling does not replicate an existing operator; instead, we have developed a business case for an 'average operator' based on an average market ARPU, average market share (25% in France and the UK, where there are four existing mobile operators and 33% in Germany, which has three operators), average number of existing mobile sites and 4G sites, and average EBITDA margin of the existing business
- **Network roll-out**: The roll-out of mobile networks is modelled using a 'geotype' approach; that is, we have split each country into three different geo-types defined by population density (urban, suburban and rural). We estimate that operators will start deploying their network in the denser areas (urban geotype) before extending to the less dense areas (rural geotype), since the cost of deployment per capita of population increases as population density decreases.

4.3 Modelling results

4.3.1 Summary of results

Although absolute figures vary considerably and modelling results differ slightly from one country to another, it is reasonable to expect that the French, German and UK scenarios will follow similar patterns in terms of 5G investment needed to achieve different levels of coverage for 5G services. It should be noted that because we do not monetise 5G services (as discussed in the previous section), the incremental business case for 5G MBB would be negative (as no incremental revenue is assumed). It should also be noted that an operator's full business case (i.e. including all mobile operations) is always positive, whatever the 5G coverage is assumed to be.

The evolution of an average operator's 5G investments and total investments as percentage of revenue with 5G coverage for the three scenarios in the three countries is presented in the figures below.

Results for France

Figure 4.2 Average French operator's 5G investments by level of 5G coverage [Source: Analysys Mason, 2016]

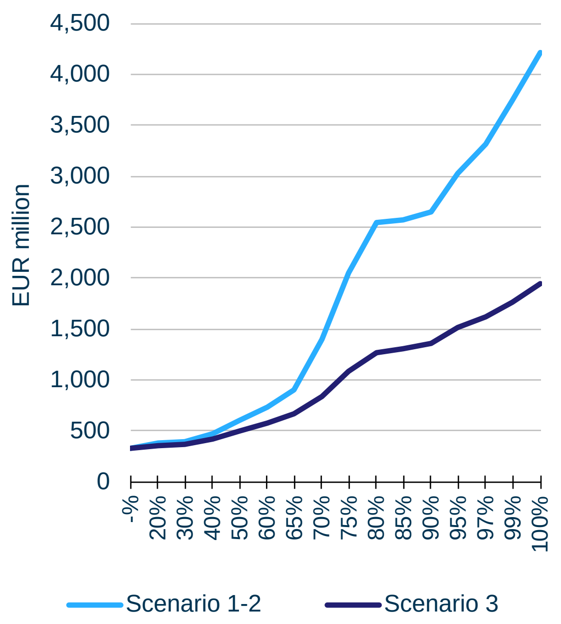
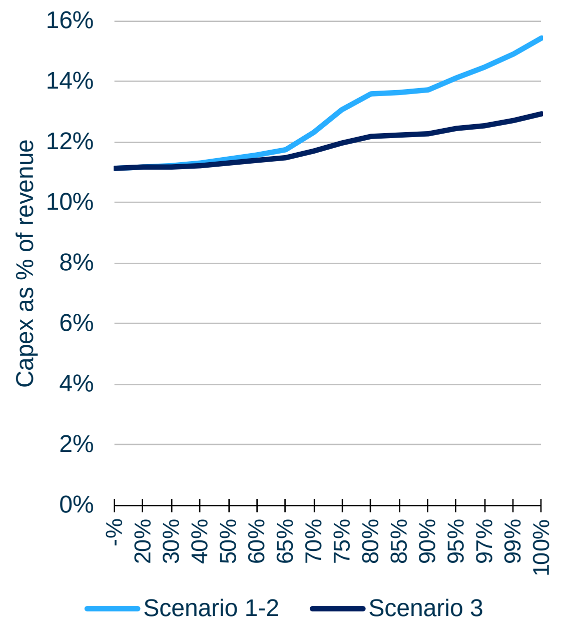


Figure 4.3: Average French operator's total investments as percentage of revenue by level of 5G coverage [Source: Analysys Mason, 2016]



Results for Germany

Figure 4.4: Average German operator's 5G investments by level of coverage [Source: Analysys Mason, 2016]

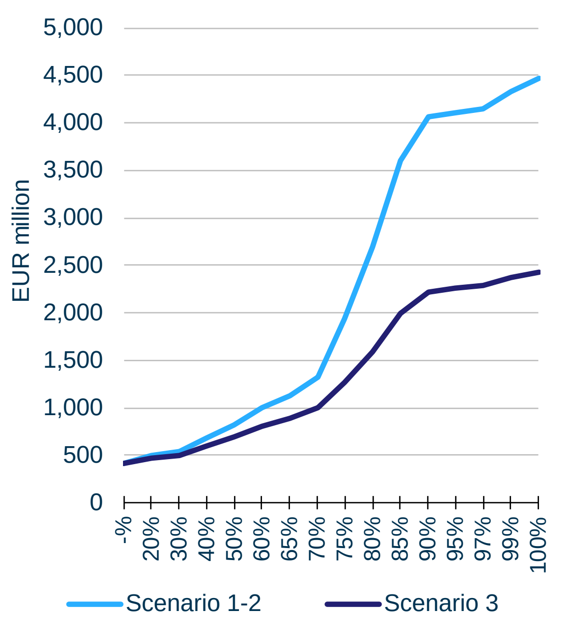
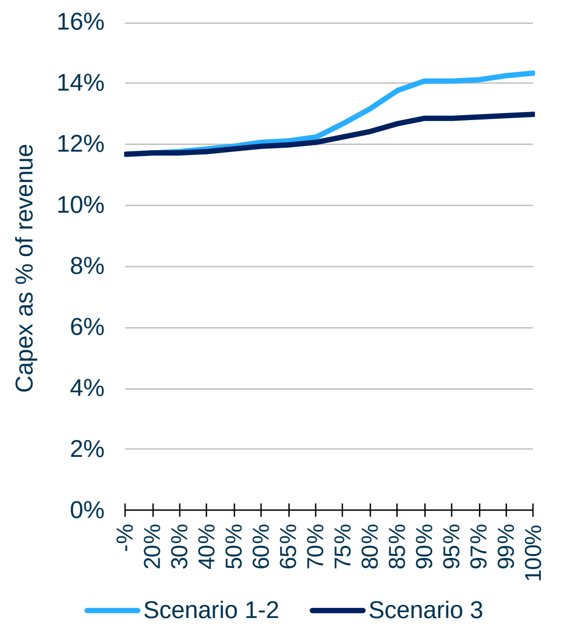


Figure 4.5: Average German operator's total investments as percentage of revenue by level of coverage [Source: Analysys Mason, 2016]



Results for the UK

Figure 4.6: Average UK operator's 5G investments by level of coverage [Source: Analysys Mason, 2016]

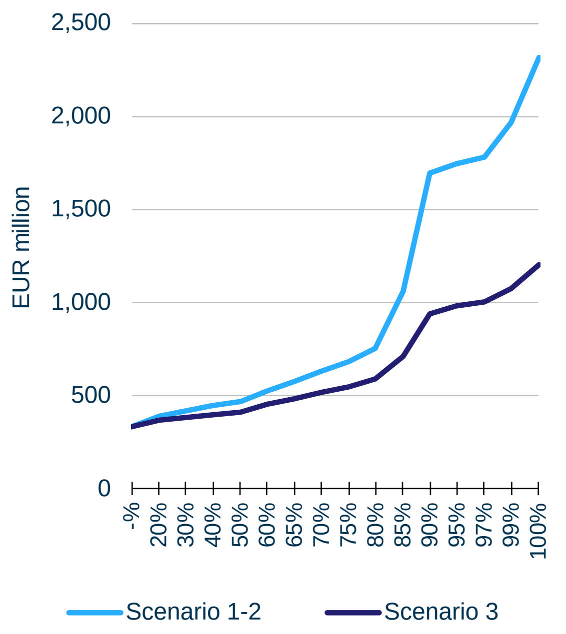
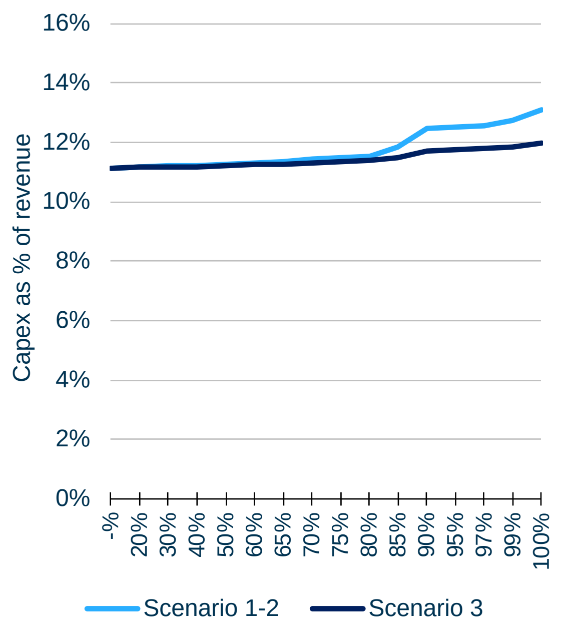


Figure 4.7: Average UK operator's total investments as percentage of revenue by level of coverage [Source: Analysys Mason, 2016]



The mechanism of returning spectrum fees to the operator is not taken into account in the previous figures, as it would require too many assumptions to be made. Therefore, the results for Scenarios 1 and 2 are similar, since the total amount of investment to reach a specific coverage is the same. The figures take into consideration cash outflows investments only. However, fees that are given back can be re-invested and therefore the network coverage in Scenario 2 would increase when compared to Scenario 1 without having to invest additional funds, as presented in the following section.

It should be noted that the result for Scenario 3 are closer to Scenario 1 and 2 for low coverage because in the initial steps of the deployment, efficiencies from a shared roll-out are considerably lower for two main reasons:

- First, due to density, in very urban areas a large proportion of population is covered with a 'low' number of sites. Therefore, required sites – and cost efficiencies associated to them – will be much larger as long as coverage increases
- Secondly, due to reutilisation of sites as despite, cost efficiencies being sizable when existing sites are upgraded to 5G, the efficiencies are considerably more substantial when rolling out new sites. With a rational approach, the average operator will always start the 5G deployment upgrading their existing sites before building new sites. For that reason, as coverage increases, the number of new sites increases and so do cost efficiencies.

Spectrum fees play an important role in the mobile operators' business plan. In the sensitivity analysis below, higher licence fees can diminish the economic profitability of 5G investments and roll-out (under our assumptions on network demand and pricing). Since operators have to respect profitability targets set by their investors, we assume they would only deploy in the most economic/attractive areas of the country. The figures below present the overall 5G investments of Scenario 1 assuming different levels of spectrum fees are incurred. We have analysed the results based on three cases:

- licence fee base case based on the average European price for the 2.6GHz band (estimated at EUR0.05 per MHz per pop)
- licence fee high price case based on the high range European price for the 2.6GHz band (estimated at EUR0.17 per MHz)
- licence fee low price case based on the low range European price for the 2.6GHz band (estimated at EUR0.01 per MHz).

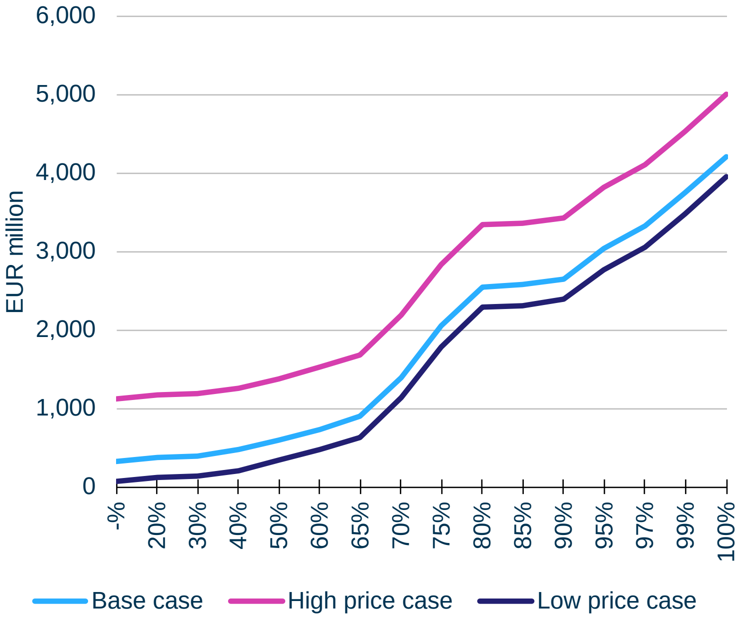


Figure 4.8: Scenario 1's 5G investments in France according to different levels of spectrum fees [Source: Analysys Mason, 2016]

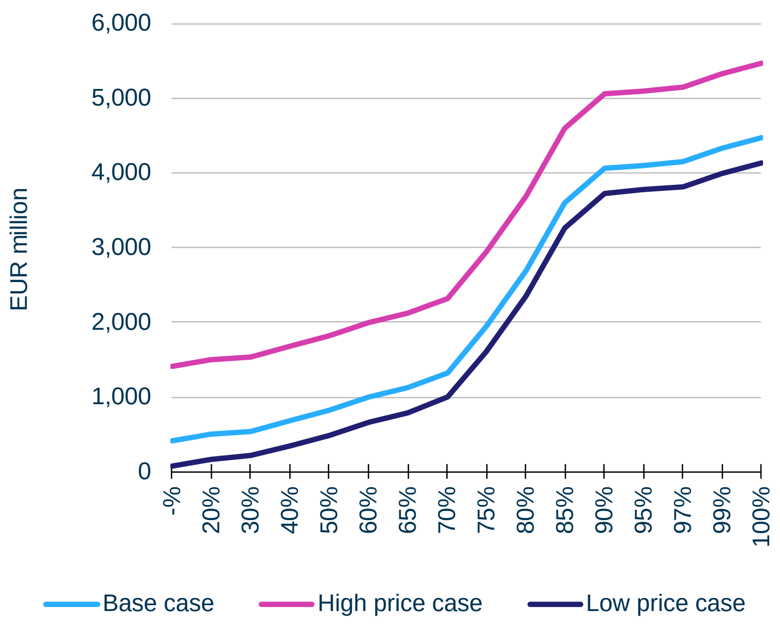


Figure 4.9: Scenario 1's 5G investments in Germany according to different levels of spectrum fees[19] *[Source: Analysys Mason, 2016]*

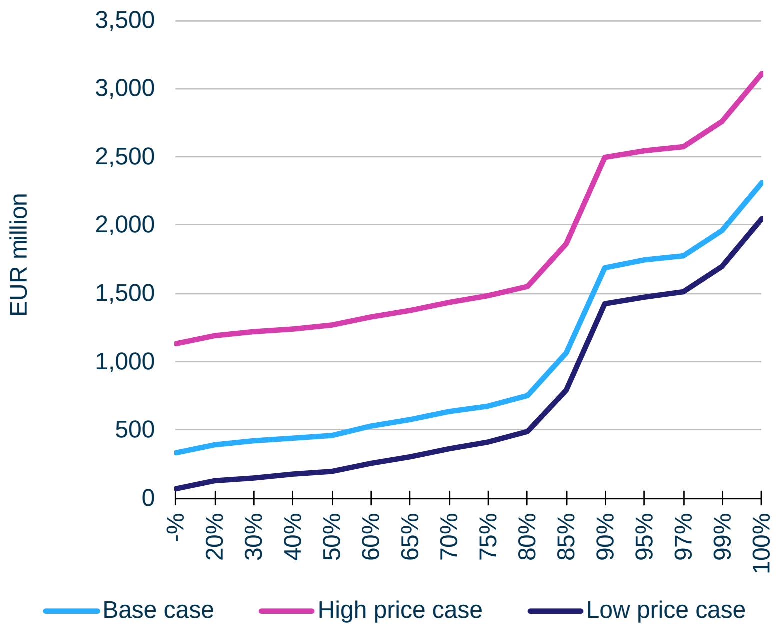


Figure 4.10: Scenario 1's 5G investments in UK according to different levels of spectrum fees [Source: Analysys Mason, 2016]

4.3.2 Interpretation of results

In general, investment per capita of population increase with population coverage; that is, it is typically more expensive to extend coverage from 90% to 95% of the population than it is to extend coverage from 60% to 65% of the population, due to lower population density in the areas that

19 It should be noted that the coverage curve flattens between circa 90% and 97% of the population, as Germany has a higher proportion of suburban geotypes and a very small rural geotype compared to, for instance, France. There are many new sites needed to reach 87% of the population (where the suburban geotype ends). Then between 87% and 97% coverage, existing sites are reused and very few new sites are built (due to the number of sites currently established in the country and due to the need for fewer sites for coverage in rural areas, due to the possibility of operating over larger cell areas without reaching capacity limits). However, from 97% of population almost all additional sites are new.

remain to be covered. However, it should be noted that we assume operators reuse existing mobile sites first before rolling out new sites and that there are typically more re-usable sites within more populated areas. Hence when the deployment reaches the least populated suburban areas there will be no more reusable sites on which 5G can be added. At this point, new sites will need to be built, which will increase the capex required. Furthermore, when the roll-out in rural areas starts, the BS density and hence costs are less intensive due to the use of a higher site radius for the rural geotype, and the ability to reuse existing sites where these exist. However, investment in the least populated rural areas will be considerably higher, due to the need to build new sites.

In the results presented in Figure 4.11, Figure 4.13 and Figure 4.15 below, the difference between Scenario 1 and Scenario 2 corresponds to the extreme assumption where the entire licence fee is given back to the MNO and reinvested in additional network coverage. The definition of an exact auction rule to achieve this is outside the scope of this report and should be studied by national regulatory authorities (NRAs).

Scenario 3 becomes more efficient (i.e. lower capex) the more that coverage increases. The main advantage of Scenario 3 arises when there is a need to build new sites (as costs are split between operators), which is normally after reusing existing sites and coverage reaches the last communes of each geotype (especially suburban and rural).

To consider what the viable level of 5G coverage will be for European operators, we can consider the link between expected revenue, and the investment that operators will consider to be financially viable (and hence the coverage achieved). Based on the results above and the assumption for Scenario 2 (i.e. operators reinvesting the received licence fees), we can draw parallels with the mobile investments per capita of population per annum for 5G to illustrate the levels that operators might consider to be viable for 5G. It is noted that mobile investment in the largest EU markets (i.e. France, Germany, UK, Spain and Italy) between 2008 and 2014 were generally between EUR35 and EUR40 per capita per annum (whereas countries such as Japan, South Korea and the USA have a much higher figure, of between EUR50 and EUR100).[20]

Taking into account different levels of mobile investment, it is possible to estimate what is a reasonable/viable coverage for an average operator in the three European countries modelled, as presented in Figure 4.11 below.

20 Source: *Mobile operators' investments: Europe needs a pro-investment mobile regulatory framework*, whitepaper based on IDATE study for Ericsson and Qualcomm, November 2015; see https://www.ericsson.com/res/docs/2015/mobile-operators-investments-whitepaper.pdf.

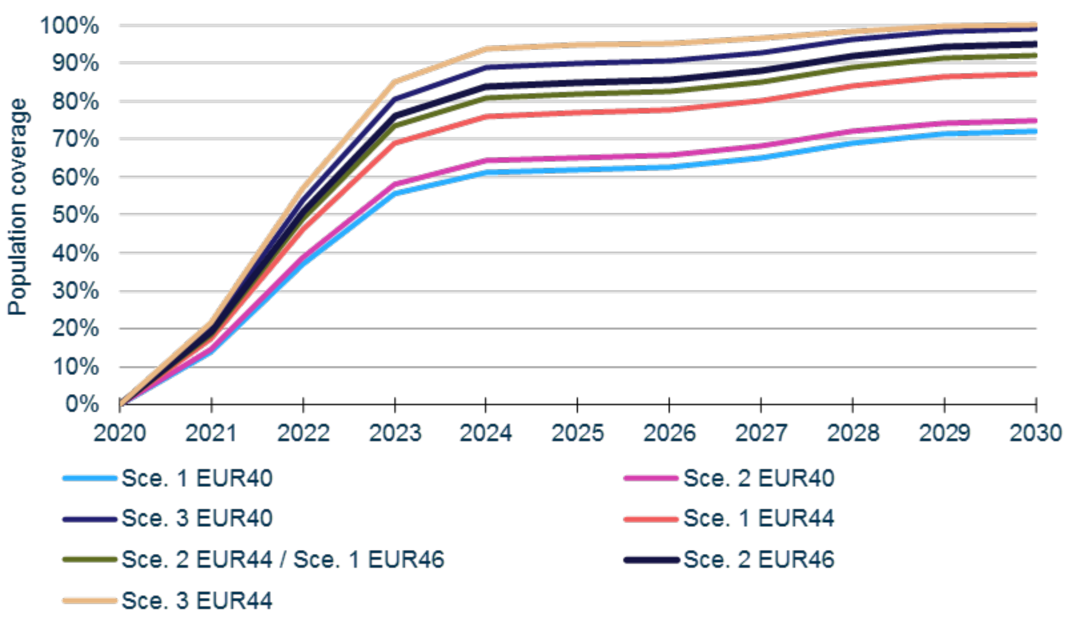
Results for France

Figure 4.11: Reasonable/viable 5G coverage depending on mobile investment per capita of population in France [Source: Analysys Mason, 2016]

Country	Scenario	Mobile investment per capita of population per annum, EUR	Reasonable coverage as % of population
France	Scenario 1	40	72%
France	Scenario 2	40	75%
France	Scenario 3	40	99%
France	Scenario 1	44	87%
France	Scenario 2	44	92%
France	Scenario 3	44	>99%
France	Scenario 1	46	92%
France	Scenario 2	46	95%
France	Scenario 3	46	>99%

5G coverage is faster when moving from Scenario 1 to Scenario 2 and to Scenario 3, and is also faster if additional investments to be made as presented in the figure below.

Figure 4.12: Population coverage evolution according to the different scenarios and levels of investments in France [Source: Analysys Mason, 2016]



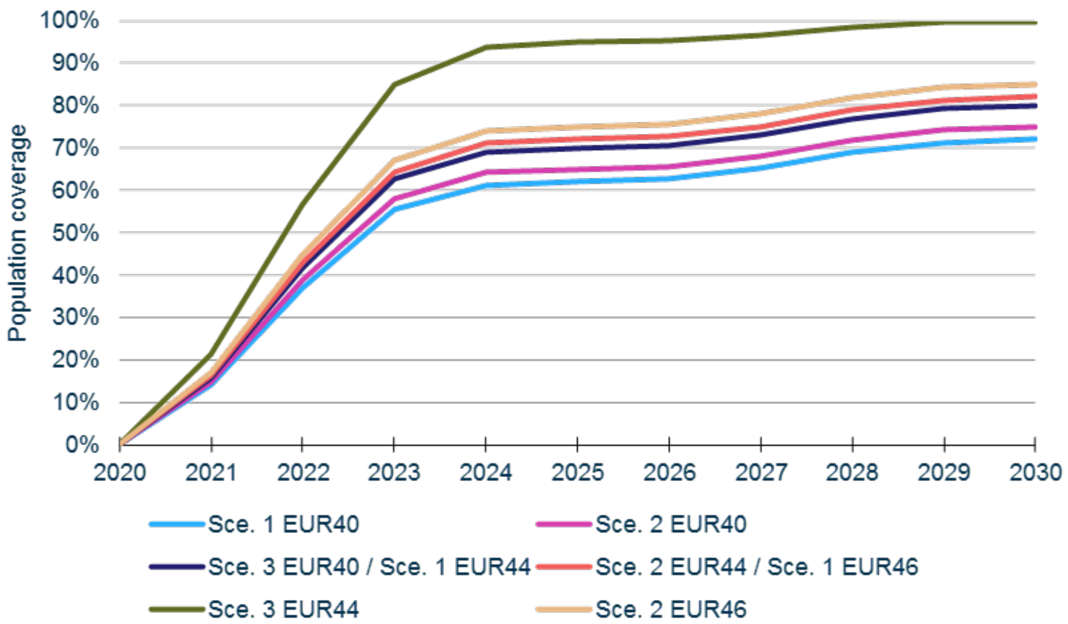
Results for Germany

Figure 4.13: Reasonable/viable 5G coverage depending on mobile investment per capita of population in Germany [Source: Analysys Mason, 2016]

Country	Scenario	Mobile investment per capita of population per annum, EUR	Reasonable coverage as % of population
Germany	Scenario 1	40	72%
Germany	Scenario 2	40	75%
Germany	Scenario 3	40	80%
Germany	Scenario 1	44	80%
Germany	Scenario 2	44	82%
Germany	Scenario 3	44	>99%
Germany	Scenario 1	46	82%
Germany	Scenario 2	46	85%
Germany	Scenario 3	46	>99%

5G coverage is accelerated when moving from Scenario 1 to Scenario 2 and to Scenario 3, and is also accelerated if additional investments to be made as presented in the figure below.

Figure 4.14: Population coverage evolution according to the different scenarios and levels of investments in Germany [Source: Analysys Mason, 2016]



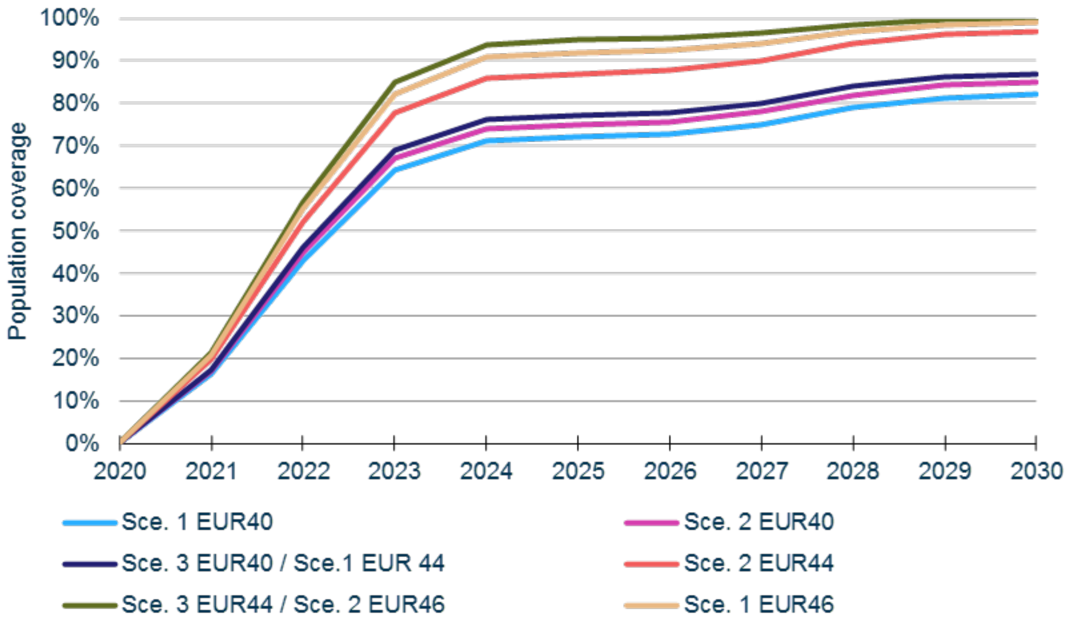
Results for the UK

Figure 4.15: Reasonable/viable 5G coverage depending on mobile investment per capita of population in the UK [Source: Analysys Mason, 2016]

Country	Scenario	Mobile investment per capita of population per annum, EUR	Reasonable coverage as % of population
UK	Scenario 1	40	82%
UK	Scenario 2	40	85%
UK	Scenario 3	40	87%
UK	Scenario 1	44	87%
UK	Scenario 2	44	97%
UK	Scenario 3	44	>99%
UK	Scenario 1	46	99%
UK	Scenario 2	46	>99%
UK	Scenario 3	46	>99%

5G coverage is faster when moving from Scenario 1 to Scenario 2 and to Scenario 3, and is also faster if additional investments to be made as presented in the figure below. In the UK case, as expected, reasonable coverage is higher than in France and Germany, due to its more urban geography.

Figure 4.16: Population coverage evolution according to the different scenarios and levels of investments in the UK [Source: Analysys Mason, 2016]



As shown in the figures above, when considering the same amount of investment per capita of population the country which reaches the highest levels of reasonable/viable coverage is UK, followed by France and Germany.

In particular, if the same level of current mobile investments per capita of population in the EU are maintained for 5G (EUR40 per capita of population), the coverage achieved in the UK would be 82%, 85% and 87% for the 3 scenarios respectively, higher than France (72%, 75% and 99%) and Germany 72%, 75% and 80%. Although it is noted our modelling is not fully representative of individual market situations, it does indicate that if current levels of investment are assumed, 5G coverage would not reach nation-wide coverage and deployment will not meet the expectations of the Commission's 5G Action Plan. Achieving a more rapid deployment would either require an uplift in revenue being achieved by 5G (which, as noted earlier, is by no means certain to occur), or for operators to be encouraged to optimise the investments needed (e.g. through infrastructure sharing), as it is especially noted in France with potentially reaching 99% through infrastructure sharing deployments.

Our modelling suggests that an increase in investment (of 10–15%, to EUR44–46 per capita of population per annum) would be sufficient to achieve what might be considered as more reasonable levels of 5G coverage in each of the three countries considered. However, it is unclear how operators would justify increasing investment with the prospect of declining revenue.

While our model expects marginal ARPU decreases from 2020 onwards, results suggest that operators may need to change ARPU trends if they are to make 5G investments in a viable and profitable way. We note that 5G could provide an opportunity to increase ARPU from delivering entirely new mobile experiences, as the new technology will make available potential new applications such as VR, AR or UHD video, which operators could leverage. In addition, revenue for mobile operators could also be boosted from deployment of innovative services to vertical industries – including to the public sector – particularly in places where upfront contracts are placed. Within the public sector, public funding could also be applied to accelerate the availability of 5G services for certain services. This is further discussed in subsequent sections of this report.

It is also evident from the modelling results that infrastructure sharing – Scenario 3 – is beneficial in enabling operators to reach higher levels of coverage, which is as expected.

In relation to the impact of spectrum fees on investment, the results also show that the level of spectrum fees paid impacts the network coverage that will be delivered under the given assumptions on investment. As previously noted, the only difference between Scenarios 1 and 2 is that, in the latter, spectrum fees are given back to operators upon completion of specific targets (the definition of how this might occur is beyond the scope of this report). If we assume that operators would reinvest the received spectrum fees, Scenario 2 reach higher coverage than in Scenario 1.

In relation to the licensing of 5G networks specifically, we can conclude from our modelling that certain elements of the current regulatory framework – such as the number of competing infrastructures and the spectrum fees that are required – have a measurable impact on the level of mobile coverage achieved, under reasonable assumptions on mobile investment. For example, Scenario 3 in our modelling – involving infrastructure sharing – becomes more favourable from a business case perspective (i.e. results in lower capex) the more that coverage increases. Cost savings are particularly apparent when there is a need to build new sites (as costs are split between operators), for which there is an expected requirement for 5G.

The results from Scenario 2 (when compared to Scenarios 1 and 3) also illustrates the impact of assumptions on spectrum fees, as described in the previous section. Hence, the most favourable regulatory regime for investment in 5G infrastructure in Europe is, not unsurprisingly, one in which infrastructure sharing is maximised and spectrum fees are minimised.

However, although infrastructure sharing is beneficial to reduce costs, there will be a continued need to ensure that competitive incentives to deploy networks remain in place (otherwise, a risk of slower deployment could arise). Hence, there is a potential need for more innovative regulatory solutions to enable the benefits of rapid deployment to be delivered in circumstances in which greater network sharing is used.

4.4 Regulatory implications for Europe-wide roll-out, and policy targets

Defining appropriate 5G coverage targets

In a future connected society in Europe, it is expected that mobile connectivity will span a wide mix of industrial devices and objects, as well as consumer MBB devices, as this report discusses. Hence, current population-driven coverage targets (e.g. as specified in previous European policies, such as the Digital Agenda for Europe), and in national licence conditions associated with new spectrum awards) will need to evolve. New targets are required such that connectivity is aimed at devices and things as much as it is to households and locations where people live and work.

From the perspective of delivering 5G MBB services (distinct from delivery of the broader range of 5G IoT, audiovisual, automotive and other vertical applications), regulators and operators already have experience of defining and delivering coverage-driven obligations, such as those set out in many 3G and 4G licences in Europe. For example, many European regulators imposed new coverage targets within 4G licences both in bands being made available for the first time for mobile use (e.g. 800MHz) and when renewing the licence terms for existing bands (e.g. 900MHz and 1800MHz). The objective of doing this is to extend the reach of mobile networks across greater proportions of population, or to specific locations, with various nationally defined obligations to extend population coverage of MBB services. For 5G, a re-think on the objectives of coverage obligations will be needed. For example, reasonable targets aimed at indoor coverage or uplifting network performance (i.e. improved latency and reliability, compared to 4G) might also be required.

New 5G mobile targets must be adopted to deliver new levels of coverage and speed (e.g. deeper coverage across geographies including key infrastructure routes such as roads), and to address the 5G service mix (i.e. connecting people, devices and things wherever those are located).

Hence, population-driven coverage targets alone may no longer be relevant in the 5G era, if the aim is to bring more intelligent, reliable, seamless and secure connectivity to new industries with different (non-population driven) service requirements.

Incentivising both and supply and demand

It is also likely that the current approach of defining only *supply-side* targets may need to be re-considered, if the objective is to incentivise the roll-out of 5G services to serve specific vertical sectors, for which the addressable market and revenue for mobile operators might not be entirely clear. In other words, there might be a need to consider *demand-side* targets to introduce greater regulatory harmonisation within specific industry sectors such that these sectors are motivated to adopt 5G solutions. This could give an incentive for mobile operators to start infrastructure deployment more rapidly for specific 5G services, compared to a situation in which investment is primarily driven by MBB revenue being generated (and hence network roll-out would follow a typical population-driven approach).

On this basis, we can identify three main categories of measures (or regulatory targets) that can be applied to promote the development of 5G:

- measures to develop the supply side – i.e. measures aimed at increasing the availability of 5G to end users
- measures to develop the demand side – i.e. measures aimed at increasing the interest of citizens for 5G services and foster take-up
- general measures aimed at adapting the regulatory and policy framework to support 5G development.

Since the MBB service category is well understood by mobile operators, it is likely that policy action might be needed to encourage deployment towards other 5G use cases (e.g. connected cars, healthcare or audiovisual services). Therefore, demand-side and other related policy action might be more specifically targeted at encouraging the deployment of non-MBB 5G services. Public procurement of 5G services for specific public authorities e.g. in healthcare, will also be one way to trigger 5G demand.

However, even though supply-side targets might be sufficient to deliver 5G MBB services to a reasonable proportion of the population, it might also be possible to consider better ways to define future MBB targets, to achieve specific outcomes (e.g. an overall uplift in service quality). Finally, we note that certain demand-side goals might also be relevant to accelerate the use of 5G MBB (i.e. to speed up the transition from 3G/4G devices). In this context, it is also noted that access to certain publicly-owned assets (e.g. sites and facilities for base stations to be deployed) will also help to create effective coverage.

Taking these broad considerations into account, Figure 4.17 below summarises possible supply and demand targets that might be considered. Further study on how such targets might be implemented (i.e. implementing the ‘tools’ indicated in the final column) is recommended to confirm the policy action that might be needed:

Figure 4.17: Examples of 5G MBB regulatory and policy targets [Source: Analysys Mason, 2016]

Category	Policy goal	Justification	Tool
Supply	EUR3 billion annual 5G investment across the EU	Based on modelling an average MNO's 5G investment over 20 years to achieve 95% population coverage in France, Germany and the UK, and extrapolated to the whole EU on the basis of yearly investment per subscriber and an average of three MNOs per country	Supply-side targets can potentially be included in MNO licences. However, public funding may also be needed to supplement private investments if specific policy goals are to be attached
Supply	Coverage of the EU's business districts by 2025	Business districts are usually in dense/urban areas. As a result, it is economically viable to cover these areas (during the initial phases of network roll-out)	Supply-side targets can potentially be included in MNO licences. However, public funding may also be needed to supplement private investments if specific policy goals are to be attached
Supply	All urban zones in the EU to have 5G connectivity by 2025	MNOs primarily target urban zones, which generally represent a modest area of the country (e.g. urban zones may represent around 50% of the population, but less than 10% of the territory)	This target could be included in MNO licences, if spectrum fees are reasonable
Supply	Sustained 100Mbit/s in when on the move for 95% of covered population	Ensuring a good QoS which should be differentiated from 4G services	This target could be included in MNO licences
Demand	50% of the EU population to be using 5G by 2025	Acceleration of device penetration. From historical European evidence, devices with new technologies or new spectrum achieve take-up of between 40% and 70% five years after launch	Device manufacturers could be required to support 5G in new handsets through measures within EU-wide requirements for placing of goods on the market. Marketing and incentives could be used to encourage EU citizens to use 5G (e.g. device sponsorship)
Demand	50% of MBB connections to be 5G by 2025	MBB connections are driven by coverage and devices take-up (as described above)	A target of this type would potentially require policy-led action from national governments rather than forming a requirement in operators' licences (since European mobile licences and technology and service neutral). Such a target could be supported through government marketing and other incentives, as noted above

5 Connecting vertical sectors – healthcare

In this section, we consider the vertical market opportunities for 5G within sectors of the market where 'IoT' services are likely to have increasing prominence. Specifically, we discuss the application of 5G within the healthcare sector.

We firstly describe possible use cases for 5G within this sector, followed by an assessment of infrastructure options and business case opportunities to deliver mobile broadband connectivity to the healthcare sector. We specifically consider the impact on a mobile operator's business case for 700MHz spectrum if healthcare applications are included as a possible source of revenue over and above MBB services (with corresponding investments made to ensure that networks are capable of meeting connectivity requirements for healthcare). We then consider how such healthcare applications might be delivered by an operator over a dedicated IoT infrastructure using separately assigned spectrum, such as a set-aside of 2×3MHz of spectrum in the 700MHz band that has been under discussion within Europe for IoT use. Finally, we assess the implications of the modelling results in terms of European regulatory policy including roll-out targets to incentivise investment in mobile connectivity for the healthcare sector.

5.1 5G use cases within the healthcare sector

Governments and healthcare stakeholders are seeking to transform healthcare and introduce sustainable delivery models. Telehealth applications have the potential to address some of the weaknesses in the current approach to delivering healthcare services. In particular, telehealth services could help reduce the cost of delivering healthcare and could also contribute to making healthcare more accessible and efficient (e.g. through remote service delivery).

Healthcare expenditure as a proportion of GDP is growing in both developed and developing markets. This is largely driven by the needs of an ageing population as well as the increasing prevalence of chronic disease. Demand for healthcare services is outpacing funding, placing increasing pressure on the overall offering. In the UK, for example, it is estimated that the funding gap will be GBP30 billion per annum by 2021.[21]

Four telehealth application groups which could contribute to sustainable healthcare are shown in Figure 5.1, and defined below. Of these, wellness is the least tangible proposition for MNOs.

21 Source: NHS England and Nuffield Trust.

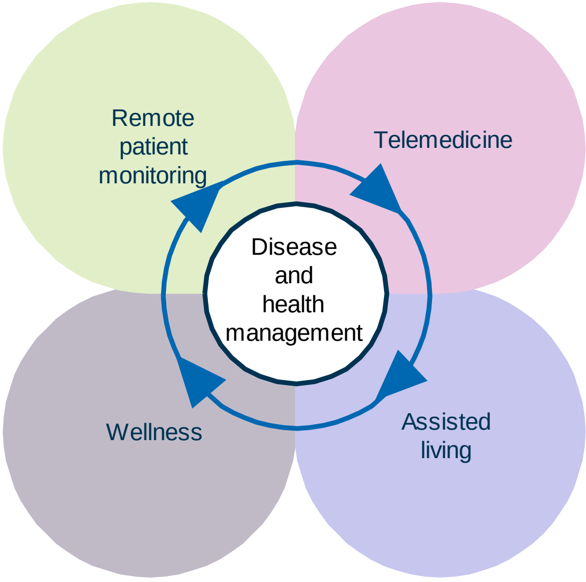


Figure 5.1: Converging telehealth application groups [Source: Analysys Mason, 2016]

Assisted living	Assisted living applications are remote devices that monitor elderly or infirm individuals in their homes or in residential care homes. Remote connected devices include location trackers, panic buttons and fall-detection devices. We focus on the market for personal emergency response systems (PERS) and mobile PERS (mPERS).
Remote patient monitoring (RPM)	RPM solutions transfer biometric data to a healthcare provider on a regular basis. RPM solutions are typically deployed to monitor patients with non-communicable diseases, acute conditions or those who have been discharged from hospital. They provide passive intervention via a machine-to-machine connection (M2M), but might also include patient input via tablets or smartphones. These solutions may be used in conjunction with telemedicine.
Telemedicine	Discrete telemedicine services enable healthcare professionals to provide detection, diagnostic or intervention services to patients over telecoms platforms. Typically, such services would be accessed via voice and video conference, as part of a contract that the healthcare provider has with a telecoms operator to provide broadband connectivity to hospitals, doctors surgeries and the like.
Wellness	Wellness programmes feature a broad range of medical services to promote the mental and physical wellbeing of employees and consumers. Technology such as smartphones and wearables is sometimes deployed to support health monitoring. Over-the-top (OTT) players are dominant in this space, and there is uncertainty about the business model for MNOs. However, MNOs could deploy wellness apps as part of a broader telehealth offering.

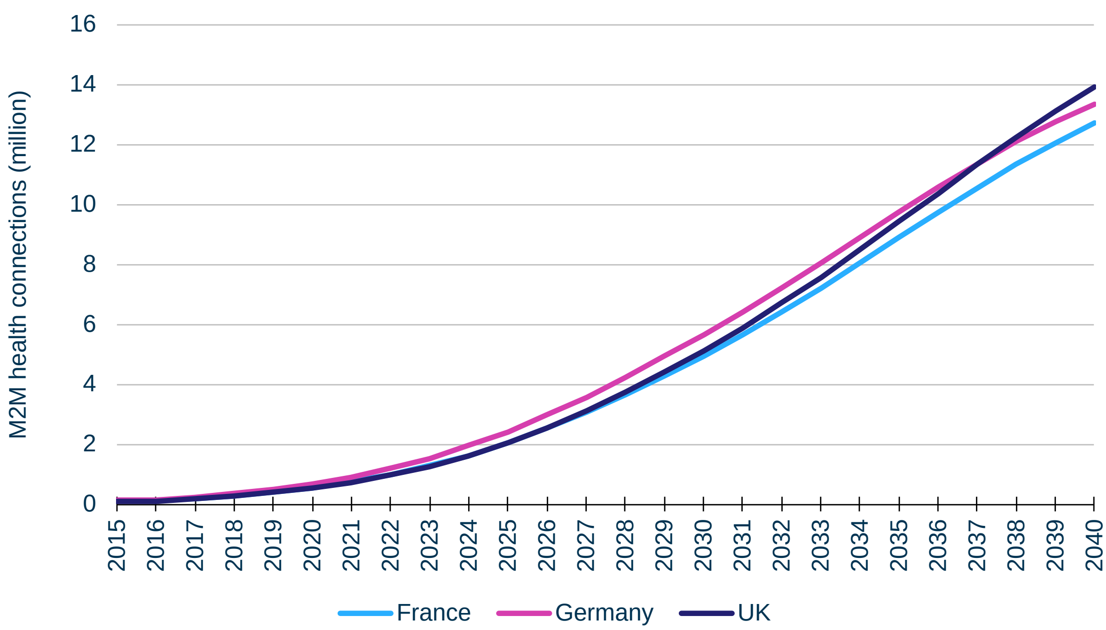
RPM and *telemedicine* applications are complex to deploy. The former requires significant investment in platforms and partnerships, and there are few large-scale projects to demonstrate the potential return on investment (ROI). However, RPM is widely recognised as a potential solution to reduce hospital admissions and the cost of treating those with chronic diseases. The provision of telemedicine services requires contracts with the medical profession and specialist platforms.

Assisted living is more straightforward to deploy and there are fewer medical regulations to adhere to, but funding may be difficult to procure because social and healthcare budgets are under pressure in most countries.

Wellness is often defined broadly, and the revenue opportunity is highly uncertain for MNOs. Wellness applications that target employers involve deploying technology platforms to provide health and fitness monitoring tools, but privacy issues and growing regulation around medical-grade applications are creating uncertainty about the future of these programmes. MNOs have not yet decided how to target this opportunity – the business models are immature and they face formidable competition from OTT and other Internet-based players as well as manufacturers of wearables.

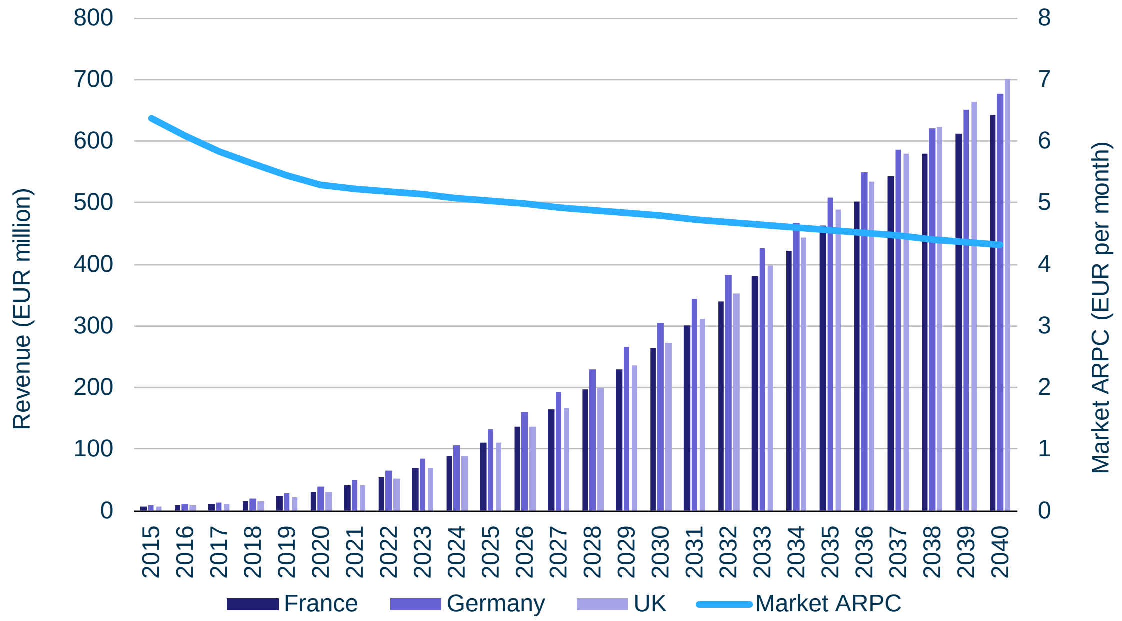
We consider that PERS and RPM are the main applications that MNOs could target, and we have included forecasts of these applications in our modelling scenarios (as described below). We forecast that the number of health M2M connections will increase from 0.1–0.2 million in 2015 to 13–14 million in 2040 in France, Germany and the UK, as illustrated in Figure 5.2 below.

Figure 5.2: Total health cellular M2M connections by country [Source: Analysys Mason, 2016]



Average revenue per connection (ARPC) is expected to decline from EUR6.4 per month in 2015 to EUR4.3 in 2040. However, as the market is expected to see substantial growth in terms of connections, market revenue is expected to rise from EUR7–9 million in 2015 to EUR640–700 million in 2040 in France, Germany and the UK, as illustrated in Figure 5.3 below.

Figure 5.3: Forecast of health cellular M2M market revenue by country and market ARPC [Source: Analysys Mason, 2016]



5.2 Approach to assessing possible infrastructure options for healthcare connectivity

Some aspects of IoT services for utilities, smart cities and healthcare will mirror those of any large business, which can be supported over standard mobile networks at no additional cost to the MNO. For example, from an MNO perspective there are close similarities between utility field services (which allow utility company employees to access data from corporate systems whilst on the move, e.g. on a tablet) and mobile enterprise systems.

However, some aspects of IoT services can lead to the need for bespoke connectivity solutions, different device types and/or other network changes, which increases the cost for MNOs. This cost needs to be considered carefully in the context of business cases for mobile networks, which are today premised on the delivery of MBB services to European citizens and consumers (particularly since there might not be the same direct relationship between the number of devices connecting to a network and the ARPUs generated for some IoT services compared to current MBB revenue models).

There are also some key aspects of healthcare applications which mean they may be better supported using dedicated resources (e.g. separate core network), rather than as an OTT service over the Internet alongside MBB services. These include:

- Applications requiring **resilient, highly available connections** (i.e. they are sensitive to QoS); if MNOs delivered those services over spectrum shared with mobile broadband data, they would need to prioritise this traffic over other MBB traffic. As noted earlier in this report, there is concern within the mobile industry that this prioritisation of traffic might have implications under currently proposed net neutrality regulations. It is noted that further clarity is needed in such regulations to ensure that regulations do allow operators to address IoT requirements adequately.

- Applications requiring **a high level of security** for connections, or where **privacy of data** (e.g. personal data) must be guaranteed. It is noted that many healthcare applications fall into this category if information involving patient records is being transferred between a mix of people, devices and systems without the patient's authorisation of each individual transfer of information.

- Applications requiring **connectivity in ultra-remote areas**; it might not be commercially viable for MNOs to provide coverage to very remote areas on an infrastructure competition basis (e.g. to serve utility applications such as gas or water control stations).

- Applications where **data-usage patterns** are different from those of handset/MBB traffic (e.g. utility, smart-city or health applications with high data upload requirements would require MNOs to dimension capacity in the uplink, instead of their normal practice of dimensioning MBB for the downlink).

Some mobile connectivity requirements for IoT such as quality and coverage are similar to those of MBB, and can be provided from existing networks. However, some IoT vertical sectors such as healthcare also exhibit a range of bespoke requirements, which presents investment risk for MNOs under current regulatory frameworks, as illustrated in Figure 5.4 below.

Figure 5.4: IoT-specific connectivity requirements, and implications for MNOs [Source: Analysys Mason, 2016]

Requirement	Implication for MNOs
Very high network availability	Implies prioritisation of traffic
Data security and privacy	Concern over 'public' networks
Need for remote connectivity	Additional sites needed
Data usage in uplink direction	Different capacity dimensioning
Varying user demand	Lack of economies of scale

Specific LTE-based solutions are being developed by 3GPP for IoT to optimise the technology capability and cost. For example, IoT services will not necessarily require ultra-fast broadband networks, but the devices used to deliver IoT services must be both low cost and more efficient in some respects than smartphones currently are (e.g. with lower power consumption and a much longer battery life). As such, requirements for IoT connectivity are somewhat different from the MBB traffic that mobile operators base their network planning on.

The nature of demand for IoT services (many disparate devices, but with limited traffic per device) suggests that there could be benefits from using separately assigned spectrum for IoT services and to some extent a specific infrastructure. The current MBB infrastructure could be leveraged, re-using sites and backhaul where possible, but some aspects of the roll-out would need to be IoT specific. For example, although many IoT applications only require relatively low data rates, the network connectivity must be reliable, robust and highly available. In contrast, MBB networks are dimensioned to provide the highest available speeds to as many users as possible, with speed being dependent on location both within the network as a whole and the user's precise position within a cell.

There is still much debate about whether the specific requirements of some IoT applications can be delivered within spectrum licensed to mobile operators for consumer MBB services, or whether alternative spectrum solutions might be required. To deliver IoT using its MBB spectrum, an MNO must to assign specific RF resource to IoT – this business decision would most likely be based on comparing the benefits from delivering IoT services to the opportunity cost of delivering other services with these resources. Alternative spectrum for IoT may remove such constraints. One example of such spectrum is the possibility of assigning dedicated sub-1GHz 'LTE IoT' frequencies (e.g. using 2×3MHz of spectrum in the 700MHz band[22]). To date, however, there are no clear policy conclusions on whether EU-wide harmonisation of such a dedicated band might be beneficial. However, there is growing acknowledgement that certain IoT services will require a quality of service level that goes beyond what networks designed to deliver consumer MBB services will provide. This is highlighted in the Commission's recent report on socio-economic data for strategic introduction of 5G, which discusses the strategic benefits of connected healthcare under scenarios in which 5G radically extends the reach and capability of wireless connectivity (beyond the expectations of what a consumer MBB network would achieve).

Hence, as part of this study, Qualcomm asked Analysys Mason to consider the potential business case upsides of using dedicated spectrum for specific IoT applications in Europe, such as healthcare (e.g. using spectrum such as the 2×3MHz in the 700MHz band). A summary of our analysis of this issue is provided in the next section.

5.3 Summary of modelling scenarios and assumptions

The model that we have developed aims to present the investment opportunity associated with a mobile operator deploying services to IoT healthcare vertical using the 700MHz band. There are two main options for deploying this vertical in the 700MHz band, as previously discussed:

- using the existing 2×30MHz band (sharing spectrum), which has been allocated for mobile services and awarded for MBB use in some European countries such as France and Germany

22 That is, 733–736MHz paired with 788–791MHz, which would sit adjacent to the 2×30MHz planned for MBB deployment in the 700MHz band in Europe.

- using a dedicated 2×3MHz in the 700MHz band (dedicated spectrum), which has been one of the scenarios under discussion in Europe (as well as in some other regions, such as the Middle East) in the context of harmonised band plans for 700MHz mobile use.

The outputs from the modelling scenarios include the NPV[23] of the opportunity, the total investment required, and specific investments related to use of the 700MHz band to provide MBB and healthcare services.

5.3.1 Modelling scenarios

We have developed three modelling scenarios, in addition to a base case.

- **Base case – MBB roll-out in the 700MHz band**. The base case reflects what is expected in most of European countries, where MNOs will use the 700MHz band to provide MBB services (similar in form to the type of coverage provided by the 800MHz band). The base case assumes continuous roll-out of sites to meet 4G coverage obligations and to cope with growth in traffic using 4G spectrum for locations where sub-1GHz spectrum is particularly needed. The 700MHz spectrum is added to existing sites and to new sites later, whenever it is needed, based on the coverage obligations and an estimate of the share of MBB traffic that requires low-frequency spectrum such as the 700MHz and 800MHz bands.

- **Scenario 1 – Enhanced service for healthcare, with IoT-based healthcare applications overlaid on 700MHz MBB network**. In this scenario, healthcare services are provided on top of MBB services using the same 700MHz spectrum. Incremental revenue relative to the base case is achieved from the health business however incremental costs are incurred due to the higher geographical coverage required because of the criticality of the healthcare applications, combined with the need to increase site roll-out to avoid impact on MBB QoS despite loss of spectrum resources to IoT (i.e. we assume in order to achieve QoS similar to the base case for the MBB services and a reliable QoS for health services, additional capacity/sites are required).

- **Scenario 2 – Dedicated spectrum – set-aside of harmonised spectrum in Europe for IoT (‘2×3MHz’)**. In this scenario, healthcare services are provided using a separate assignment of 2×3MHz of 700MHz spectrum. Hence network provisioning for IoT has no impact on the spectral resource of QoS of MBB services delivered in the ’core’ 2×30MHz bandwidth in the 700MHz band. Incremental revenue relative to the base case is achieved from the health business. In our model, we have assumed that only one operator (or one consortium of operators) is awarded the separate 2×3MHz spectrum and so it will capture all the incremental revenue. This would be consistent with a European country in which public funding is made available to deploy a dedicated IoT network, with a contract placed with one provider (or one consortium). It is noted that other scenarios are possible depending on market circumstances (e.g. two or more competing infrastructures providing service). Incremental costs are incurred relative to the base case, due to the need to roll out the 2×3MHz carrier on existing sites, the potential need for new sites (to extend population coverage beyond that required for MBB), and spectrum fees charged

23 Net present value. In this context we define NPV as equal to EBITDA minus capex.

for the 2×3MHz band.[24] Other IoT specific requirements on the infrastructure are not explicitly considered but could be considered by providers during roll-out of the 2×3MHz.

- **Scenario 3 – Dedicated infrastructure - greenfield operator ('new entrant')**. This scenario assumes that the operator of the dedicated IoT infrastructure is not an existing 4G MBB network operator. The scenario foresees the deployment of a 700MHz IoT infrastructure by an independent operator which, in our model, is exclusively dedicated to provision of healthcare services. It is noted that in practice, a decision to dedicate a separate infrastructure for IoT services could either be based upon having one anchor service (such as healthcare, in our example), or to support a range of public services (e.g. possibly including smart city or other applications). Coverage requirements for healthcare are similar to Scenarios 1 and 2, and as in Scenario 2 the spectrum fees will be reimbursed once coverage requirements are met. This scenario assumes that public authorities encourage the launch of a new player specifically to deliver healthcare services. On this basis, we assume that a fair proportion of the infrastructure required for the new network can be built on existing public infrastructure, which will reduce the need to deploy new sites (and hence reduce the capital investment that is required).

5.3.2 Main principles and assumptions

When developing the modelling scenarios, the main principles and assumptions that we have used are as follows:

- **MBB coverage and capacity**: as with the MBB model described in the previous section, we assume that operators will continue to roll out their mobile networks in line with existing coverage obligations for the 700MHz and 800MHz bands. We also assume that operators will re-farm their existing 2G/3G spectrum to 4G, and so the number of bands and the amount of spectrum used for 4G technologies will increase over time. By 2030, we assume that almost all existing spectrum will be used for 4G technology (i.e. 2G and 3G will no longer be used for mobile services)

- **Operator modelled**: As with the MBB model described in the previous section, we modelled a generic operator (assumed to be an 'average' operator) in the three countries (France, Germany and the UK). This means that our modelling does not replicate an existing operator; instead, we have developed a business case for an 'average operator' on the basis of an average market ARPU, average market share (25% in France and the UK, where there are four existing operators and 33% in Germany, which has three operators), average number of existing mobile sites and 4G sites, and average EBITDA margin of the existing business

- **Revenue from health services**: we have assumed revenue from health services as described in Figure 5.3. In Scenario 1, a generic operator captures revenue according to an addressable market typical of a market split among three or four competing networks. In Scenarios 2 and 3, the operator addresses the whole healthcare opportunity. Hence, in Scenario 1, we assume that the generic operator's market share is in line with current market shares in a mature market in

24 Noting that these fees are returned to the operator once it meets its ten-year coverage targets.

which shares are converging (i.e. 33% in a three-player market or 25% in a four-player market). In Scenarios 2 and 3, the generic operator captures all revenue. This might be representative of cases in which public authorities in Europe responsible for healthcare undertake a national procurement of connectivity solution(s) to select one operator to provide the service.

- **MBB traffic on the 700MHz band**: usually business models addressing the opportunity for low-frequency spectrum assume that there is a share of MBB traffic that can only be reached by low-frequency bands. For European MNOs, this share can be up to around 25% of their total traffic, based on Analysys Mason's experience. Therefore, in our model described here, the share of MBB traffic in the 700MHz band is derived from the operator's share of 4G/5G traffic, combined with the modelled 700MHz coverage, an assumed take-up of 700MHz devices, the assumed traffic captured by low bands and the proportion of this that will be carried on the 700MHz band (compared to other available low-frequency bands such as 800MHz). As a result, the traffic carried on the 700MHz band increases over time and does not exceed 12% of total traffic at any date.

- **Network roll-out**: The roll-out of mobile networks is modelled using a 'geotype' approach for MBB coverage; that is, we have split each country into three different geo-types defined by population density (urban, suburban and rural). We estimate that operators will start deploying their network in the denser areas (urban geotype) before extending to the less dense areas (rural geotype), since the cost of deployment per capita of population increases as population density decreases. As noted elsewhere in this report, this approach may not be optimal for IoT infrastructure but in a scenario in which an MNO addresses the healthcare opportunity using spectrum assigned for MBB services, we assume that roll-out will be largely dictated by MBB requirements. Coverage for MBB services in the base case is estimated to reach 80–92% of area depending on the country, resulting in 99.0–99.6% population coverage. Coverage for IoT services in all scenarios is assumed to increase to 92–99% of area in the model.

5.4 Modelling results

Results are shown below in turn for each of the countries modelled.

Results for France

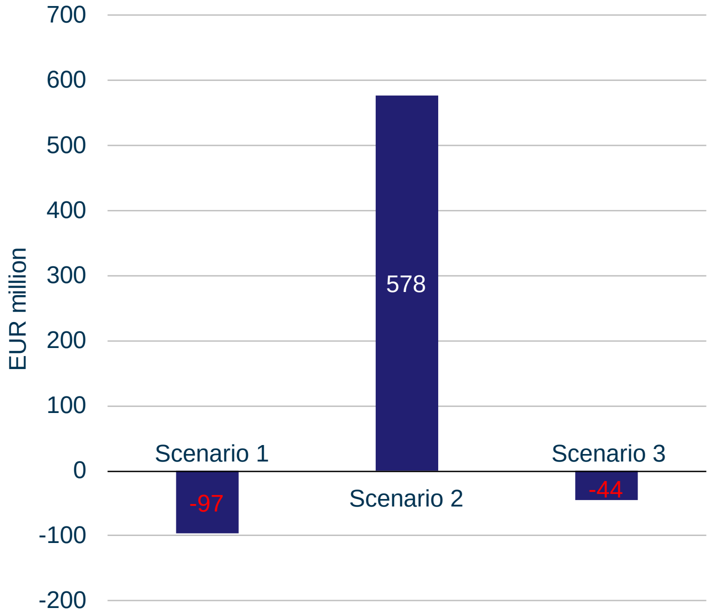


Figure 5.5: Average French operator's incremental IoT/Health business NPV [Source: Analysys Mason, 2016]

Figure 5.6: Average French operator's incremental IoT/Health business revenue over 20 years [Source: Analysys Mason, 2016]

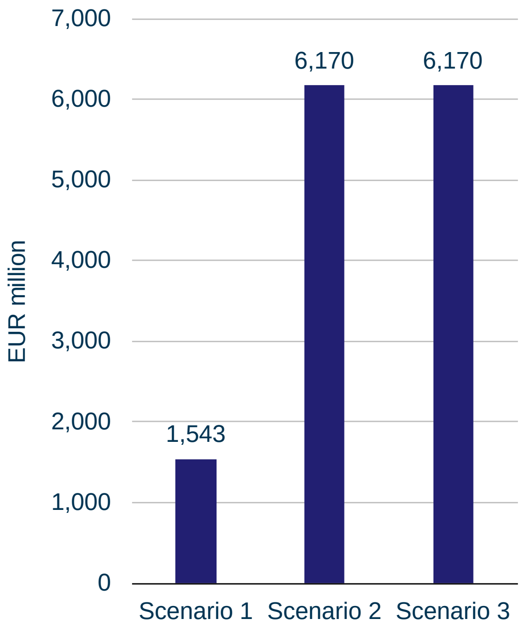
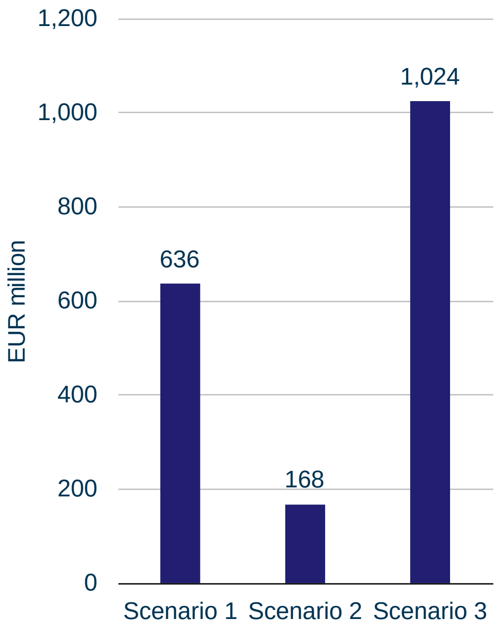


Figure 5.7: Average French operator's incremental IoT/Health business total investments over 20 years [Source: Analysys Mason, 2016]



Results for Germany

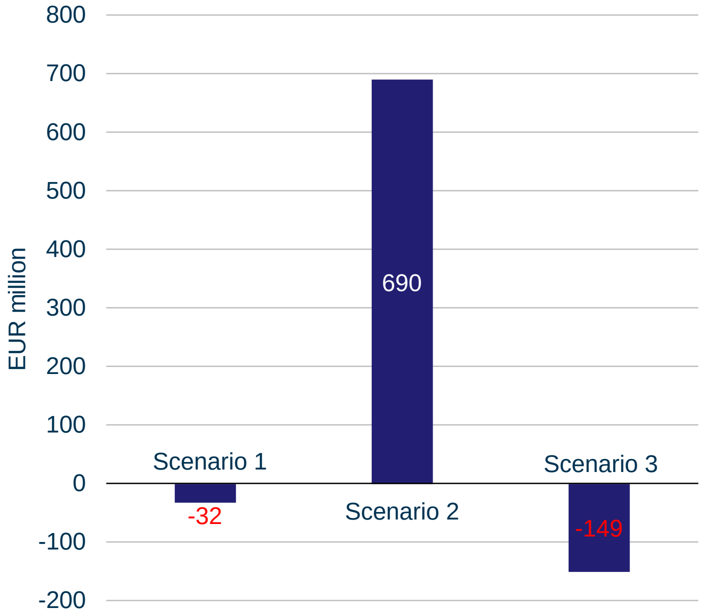


Figure 5.8: Average German operator's incremental IoT/Health business NPV [Source: Analysys Mason, 2016]

Figure 5.9: Average German operator's incremental IoT/Health business revenue over 20 years [Source: Analysys Mason, 2016]

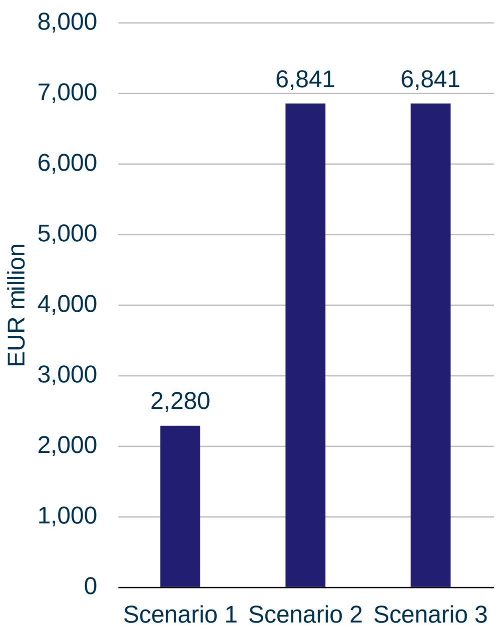
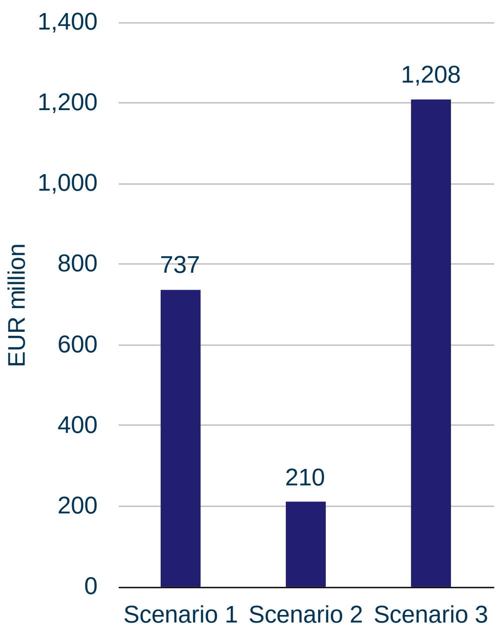


Figure 5.10: Average German operator's incremental IoT/Health business total investments over 20 years [Source: Analysys Mason, 2016]



Results for the UK

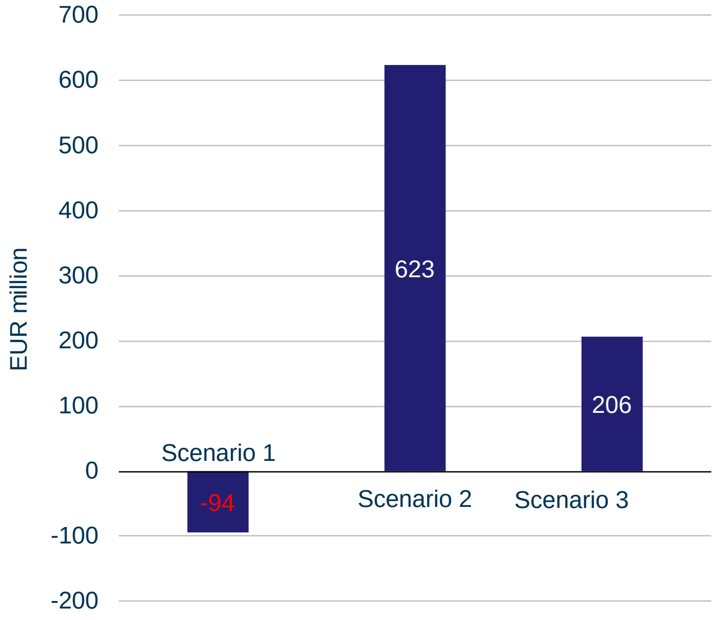


Figure 5.11: Average UK operator's incremental IoT/Health business NPV [Source: Analysys Mason, 2016]

Figure 5.12: Average UK operator's incremental IoT/Health business revenue over 20 years [Source: Analysys Mason, 2016]

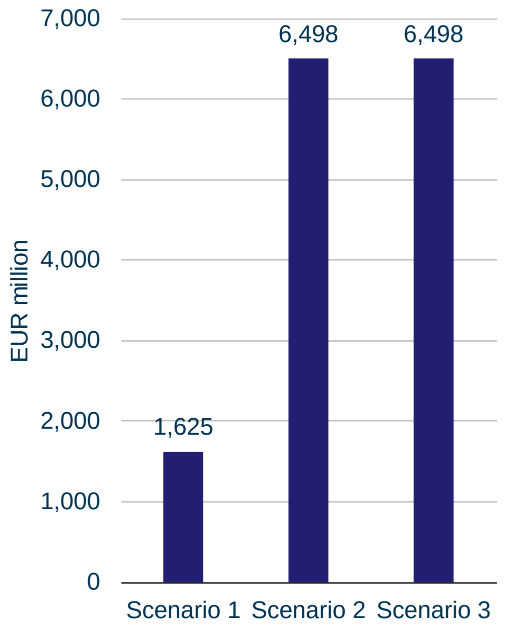
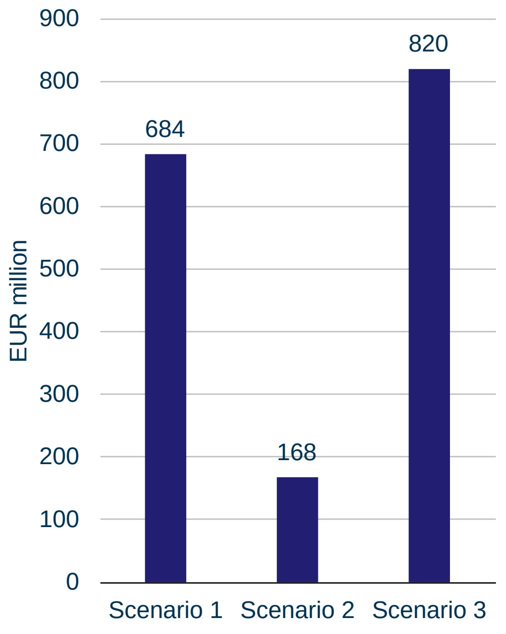


Figure 5.13: Average UK operator's incremental IoT/Health business total investments over 20 years [Source: Analysys Mason, 2016]



Discussion of results

The results of the different scenarios provide similar conclusions for France, Germany and the UK (as shown in Figure 5.5 to Figure 5.13 above). In all three countries, the business case for Scenario 1 is less appealing than the base case (i.e. Scenario 1 has a lower NPV than the base case). This means that the additional capex required in Scenario 1 (6%, 4% and 6% in France, Germany and the UK respectively) relative to the base case is not compensated for by the incremental revenue that is expected to come from the health business.

The business case for Scenario 2 is the most profitable. From an MNO's perspective, the preferred option would be to have a dedicated 2×3MHz of spectrum for the provision of health services, leading to lower investments and higher revenue from these services.

The business case for a new entrant with no current mobile business (Scenario 3) is unclear, as in two out of the three countries the NPV is negative, even though it is assumed that a proportion of sites will make use of public infrastructure. However, the business case could be positive if the new entrant provides other IoT services benefitting from having a dedicated 2×3MHz spectrum (as we have only considered the health vertical in our business case assessment).

It should be also noted that the IoT business as currently projected has very limited revenue compared to the current mobile business and represent less than 5% of mobile revenue for MNOs. Therefore, MNOs will always prioritise MBB over IoT services given the limited expected revenue of IoT, at least in the short and medium term.

Impact of different levels of spectrum fees

The following figures show the different NPV and total investment as percentage of revenue based on different levels of spectrum fees for Scenario 2 (Dedicated spectrum – set-aside of harmonised spectrum in Europe for IoT ('2×3MHz'). The different cases we have modelled for the price paid for the 2×3MHz are:

- Average price based on the average European price for the 700MHz band (estimated at EUR0.4 per MHz per pop) namely in France and Germany and used in all previous scenarios
- High price based on the French 700MHz price (estimated at EUR0.65 per MHz per pop)
- Low price based on the German 700MHz price (estimated at EUR0.16 per MHz per pop)
- Very low price at EUR0.1 per MHz per pop to reflect the nature of the IoT business (i.e. important investments required for modest incremental revenue).

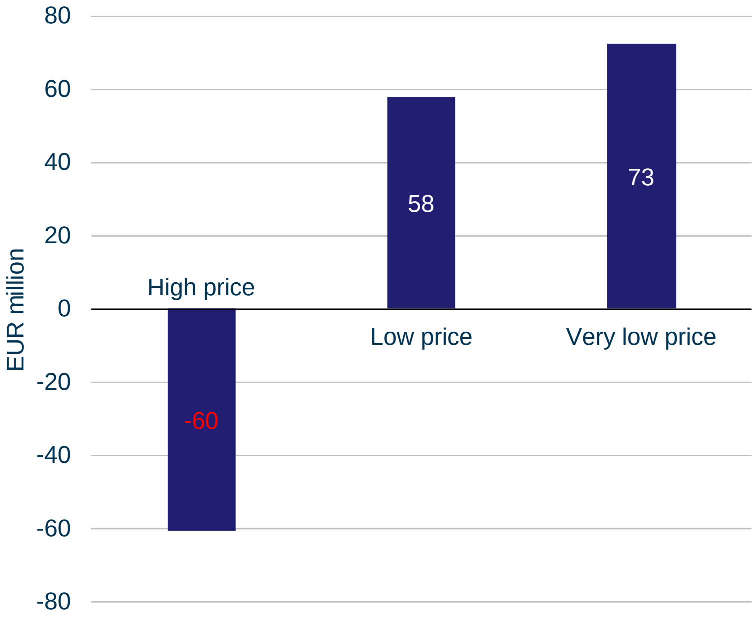


Figure 5.14: Incremental IoT/Health NPV to average spectrum fees according to different levels of spectrum fees in France for Scenario 2 [Source: Analysys Mason, 2016]

Figure 5.15: Incremental IoT/Health NPV to average spectrum fees according to different levels of spectrum fees in Germany for Scenario 2 [Source: Analysys Mason, 2016]

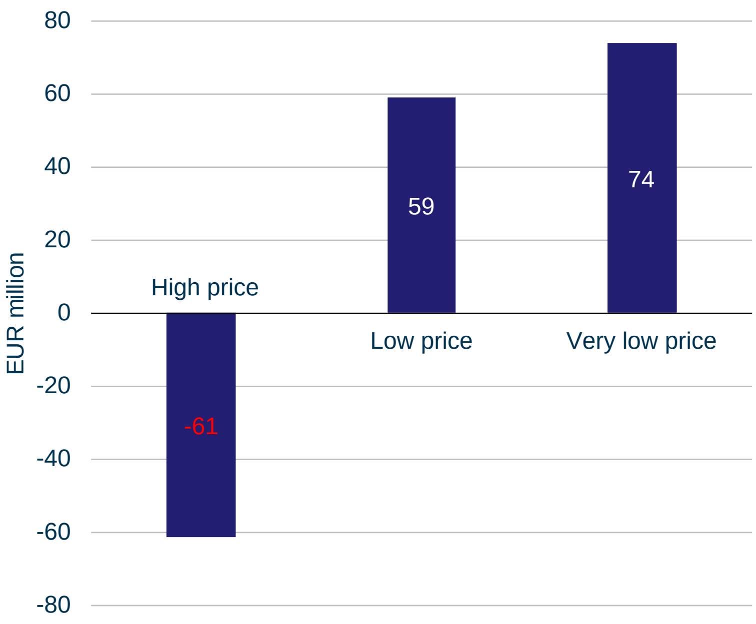


Figure 5.16: Incremental IoT/Health NPV to average spectrum fees according to different levels of spectrum fees in UK for Scenario 2 [Source: Analysys Mason, 2016]

Results show that the price paid for spectrum could have a modest an impact on the IoT business case (given that spectrum fees for the award the of 2×3MHz are limited by virtue of the small amount of spectrum being used. The impact on the NPV is around 10% for lower and higher prices when compared with the NPV at average prices.

5.5 Regulatory implications for Europe-wide roll-out, and policy targets

As noted in the previous section, 5G mobile broadband networks will play an important role in supporting the future European connected society. However, different policy action might be needed to accomplish 5G goals most effectively, since previous policy goals and targets on mobile (and fixed) broadband coverage have been linked to achieving service availability in locations where broadband users live and work. Hence, previously defined targets do not specifically capture the need for networks to connect a mix of different industries such as healthcare, where a higher network quality (and potentially tailoring of coverage and capacity compared to a MBB network) might be needed.

If 5G networks are to address a range of vertical market opportunities, the implication is that a different approach to defining regulatory goals and targets might be required. Suitable targets to encourage both investment and use of 5G networks could be based on supply and demand sides, as described previously. From an implementation perspective, such targets would need to be split between targets that could be included in mobile spectrum licences, and broader, policy-driven targets aimed at governments and policy makers. It is not clear how such targets might be implemented in practice, for which further study might be required. Public procurement will also play a role. Additionally, it might be necessary to direct certain targets at the vertical sectors themselves, i.e. in the case of healthcare, this would be the public authorities responsible for delivering health services in different European countries.

As with the 5G MBB modelling described in the previous section, our modelling of the business case for connectivity to the healthcare sector identifies that the viability of the business case is dependent on the addressable market assumed, which links to the number of operators it is assumed will serve this market. The modelling scenario in which a generic operator gains 100% of the addressable market for healthcare in the modelled country is beneficial compared to the one in which the addressable market is split between three or four players, as described above. Of particular note in the healthcare scenario modelled for this report is that the business case for Scenario 2 (dedicated 2×3MHz spectrum available) is the most profitable, as this can be optimised by targeting investments.

Hence, for 5G to address the range of vertical market opportunities that are envisaged within the 5G vision, the current approach of specifying supply-side targets focused on population coverage might not deliver the required investment in all 5G services As before, we have identified three main categories of measure that could be used to promote the development of a wider range of 5G services, including healthcare, as described previously:

- measures to develop the supply side – i.e. measures aimed at increasing the availability of healthcare services over 5G to end users
- measures to develop the demand side – i.e. measures aimed at increasing citizens' interest in healthcare services over 5G and fostering take-up
- general measures aimed at adapting the regulatory and policy framework to support the development of healthcare services over 5G.

The demand-side and associated regulatory harmonisation measures to support healthcare services could prove particularly important, since the uncertainty about the demand for such services over 5G might dampen mobile operators' willingness to invest unless the demand for services is more clearly established. For example, regulatory harmonisation to encourage healthcare providers to utilise 5G infrastructure would encourage uptake. Further measures such as public funding directed at delivering a dedicated infrastructure for IoT would bring additional benefits by making funding available upfront to accelerate investments. The Commission's recent report on socio-economic data for the strategic planning of 5G introduction in Europe highlights that 5G data capabilities will provide preventative strategic benefits of approximately EUR1.1 billion per annum in public healthcare costs and operational benefits of approximately EUR4.2 billion per annum in public healthcare costs. However, the scope of such demand-side targets could be extremely broad (and to a large extent will depend on individual Member State priorities regarding provision of healthcare services and budgets).

Figure 5.17 below summarises possible 5G healthcare targets that could be considered. As noted previously, further study on how these might be implemented is recommended to confirm the policy action that might be needed:

Figure 5.17: Examples of 5G regulatory and policy targets aimed at delivering connectivity to the healthcare sector [Source: Analysys Mason, 2016]

Category	Policy goal	Justification	Tool
Supply	5G MBB coverage (from at least one mobile network) to include specific geographical locations where hospital buildings are located within urban centres	Hospitals are usually located in towns and cities (although can be on the outskirts of urban areas) and so hospitals should be within the areas that MNOs will consider covering, although specific targets would ensure that they are prioritised.	This target could be included in MNOs' 5G licence(s). However, it is noted that situations in which significant additional coverage is being mandated beyond that which an operator would provide commercially might require public funding to be applied (see below). For example, this could include obligations to provide coverage to hospitals in less populated areas, and/or to provide guarantees of indoor coverage speed and quality.
Supply	All hospitals and public buildings to have 100% 5G indoor coverage within five to ten years respectively (in line with population coverage)	Similar to the point above, hospitals and most public buildings should be in areas that MNOs will consider and that are not problematic to cover.	Public funding could be used as well as imposing a target in MNOs' 5G licences to ensure coverage for specific locations which are remote or/and not well covered by existing infrastructure. Alternatively, this target could be included in the dedicated 2×3MHz licence, should such a licence be offered.
Supply	All ambulances and other emergency vehicles (e.g. police cars/fire engines) to have a 5G base station embedded for ad-hoc 5G coverage during interventions within the next five to ten years	The level of investment should be relatively modest in the context of a broader publicly funded MBB services to Emergency Services, and the social benefits should also be taken into account as these will outweigh investment in the long term.	This form of target could be achieved through public funding (e.g. MBB networks for emergency services).
Demand	All ambulance dispatch services to use 5G technology within five to ten years (in line with population coverage)	As above.	Similar to the above, this target could be achieved through public funding.
Demand	Possibility for 5G phone users to undertake healthcare-related financial transactions	The social benefits of such a system should be	Governments could be given responsibility for

Category	Policy goal	Justification	Tool
	(paying doctors, ordering medicines, etc.) within five years	considered, in addition to the investment required.	putting such a system in place. A potential incentive for MNOs to participate in putting such a system in place could be justified if payments for healthcare services could be delivered via mobile billing.
Demand	Availability of health applications (e.g. drug reminders, activity trackers, emergency calls) for 5G phone users within five years, sponsored by governments	As above.	Governments could be given responsibility for putting such a system in place.
Demand	Year-on-year reduction in hospital nights as a result of 5G-driven e-health	The justification for this type of target being defined would have to be nationally defined (e.g. based on political agenda in different countries), requiring analysis by public authorities responsible for healthcare to justify the societal and/or economic benefit achieved – for example to obtain commitment to a dedicated 2×3MHz network for healthcare services.	5G healthcare connectivity goals could be integrated with targets for national public authorities responsible for healthcare. This target could be achieved through public funding.
Demand	Specified medical devices (e.g. pacemakers, diabetes trackers, medical alarms) to have 5G connectivity embedded within five to ten years	As above.	As above.

6 Connecting vertical sectors – automotive

This section considers the applications and business cases for deployment of 5G in the automotive (i.e. connected car) sector.

We firstly describe possible use cases for 5G within the automotive sector, and the role of 5G networks to complement the ITS currently being envisaged to address automotive safety services in Europe. This is followed by an assessment of the cost of implementing ITS in the cars and the road infrastructure. We further consider the business case for connected car services and specifically the impact on a mobile operator's business case if operators are obliged to provide full 5G coverage along major European transport routes (such as implied within the Commission's 5G action plan, which highlights early deployment along 'major transport paths' as being a key element of the plan). Finally, we assess the implications of the modelling results in terms of European regulatory policy including roll-out targets (both for 5G and for ITS services more broadly) to incentivise adoption of ITS technology in cars and road infrastructure and investment in mobile connectivity for the automotive sector.

6.1 5G and ITS use cases within the automotive sector

The European automotive industry has identified key use cases for automotive wireless communications, including:[25]

- high-density platooning on major roads (e.g. the speed of a convoy of vehicles is controlled by the lead vehicle)
- see-through sensors (i.e. the information from sensors in one vehicle is shared with adjacent vehicles)
- tele-operated driving (remotely controlled vehicles)
- high-definition map updates for highly automated driving.

It is expected that wireless connectivity for smart vehicles and connected road infrastructure will be provided using solutions based on vehicle-to-vehicle, vehicle-to-infrastructure and (4G/5G) mobile network communications. Specific safety-related use cases for providing essential updates to cars regarding road accidents, speed controls for roadworks, weather warnings and other incidents are expected to use ITSs. These are being developed for use in the 5.9GHz band in Europe, with two technologies being currently discussed: ITS G5 based on 802.11p and C-V2X (see Section 6.2 below for more information). Although the initial phases of ITSs in Europe will not rely on 5G, it is expected that 5G networks will increasingly be used for transport applications.

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25 See https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-5G-automotive-vision and http://www.3gpp.org/news-events/conferences/1515-etsi-summit-on-future-mobile.

6.2 Deployment of intelligent transport systems (5.9GHz)

Deployment of intelligent transport systems is considered in Europe. Relevant technologies are 'vehicle-to-everything' or V2X technologies, incorporating vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-pedestrian communication. Candidate technologies in Europe are ETSI ITS G5, based on IEEE802.11p, and cellular V2X, based on LTE and 5G (i.e. 3GPP release 14 and 15 respectively). Spectrum in the 5.9GHz band has been harmonised in Europe for ITS. The main drivers for V2X technologies are to improve road safety and traffic efficiency.

The automotive industry has been studying ITS G5 for a number of years. Recently, cellular V2X (C-V2X) emerged. C-V2X uses LTE Direct and LTE Broadcast to provide wireless connectivity both for vehicle-to-vehicle and vehicle-to-infrastructure connection over the 5.9GHz band. Current C-V2X developments being progressed in 3GPP standards include:

- **3GPP Release 14** will include enhancements to LTE Direct, suitable for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) use at 5.9GHz. The enhancements will enable V2V/I/P services at higher vehicle speeds, and with lower latency, with target completion by the end of 2016. Release 14 also incorporate communication involving an LTE network broadcasting data to multiple vehicles. This uses an enhancement to LTE 'eMBMS'[26] technology, with a target for completion of the specifications mid-2017.

- **3GPP Release 15** will introduce 5G, which will enable features such as 1ms end-to-end latency and high reliability. 5G will build upon and enhance C-V2X.

- **Beyond 3GPP Release 15**, it is expected that future technology trends and later 3GPP standards releases for 5G will push automotive use cases further, towards providing increasing levels of car automation, 'smart vehicles' and 'transport as a service'.

V2V/I/P communication will initially be provided in Europe using either ITS G5 or C-V2X technology, based mostly on a V2V communication approach, and in some areas V2I. ITS G5 and C-V2X are both expected to be deployed initially in 5875–5925 MHz, according to ECC Decision (08)01 and EC Decision 2008/671/EC.

In its Decision (08)01, the Electronic Communications Committee (ECC) identified 30MHz of harmonised spectrum in the 5875–5925MHz band for use by ITSs, as well as designating a further 20MHz of spectrum in the 5905–5925MHz band for future ITS expansion. Roll-out of 5.9GHz ITS systems are being backed by EU-led action, and the RSPG is currently considering spectrum aspects of ITS in Europe.

It is envisaged that ITS infrastructure will be made available along roads, providing services for road and transport safety purposes. In general, ITSs operate at 5.9GHz and therefore it is expected that it will provide communication over shorter ranges than when using commercial LTE networks.

[26] Evolved Multimedia Broadcast Multicast Service, which is the specification within the 3GPP standards providing point-to-multipoint connectivity for broadcast and multicast services.

ITSs have not yet been deployed on a commercial basis in Europe, but large-scale trials have been conducted and these systems are being positioned to play a significant role in the areas of road safety and traffic management.

6.3 The role of connected car solutions for ITS and connectivity

Cars are increasingly becoming connected, i.e. cars are increasingly able to connect to the cloud, leveraging mobile broadband technologies and networks. Connected cars deliver a wide variety of services ranging from mobile broadband to car passengers for entertainment, to remote monitoring and configuration of cars, and to traffic and safety related services (such as 'eCall').

Connected car solutions differ from ITS solutions in the 5.9GHz band: principally this is because ITS solutions at 5.9GHz are mostly localised, do not require mobile coverage and do not require a mobile subscription, whereas connected cars solutions are based on the cloud, require mobile coverage and a mobile subscription. The automotive sector's plans for connected car services are extremely broad, for example infotainment, intelligent navigation, eCall and smart-city applications such as intelligent parking.

Vehicle to network (V2N) services are at the intersection of ITS and connected car services, in that they contribute to traffic safety and optimisation, but rely on network connectivity. V2N, just like connected cars services, leverage standard mobile broadband technologies such as LTE and 5G. Although V2N services can contribute to safety, for example for the download of high precision maps, they do rely on mobile network coverage, which cannot be guaranteed nationwide, or with 24/7 availability. V2N services also require a mobile broadband subscription, and it cannot be guaranteed that all users want to pay for such a mobile broadband subscription for their car. Therefore, it is expected that the critical road-safety applications will be delivered using ITS dedicated communication at 5.9GHz, whereas V2N services will complement ITS 5.9GHz services.

Each connected car service has precise requirements in terms of the wireless throughput required, latency of connection, service duration and reliability. Some applications are likely to place a premium on coverage and are therefore expected to benefit from networks with a large geographical footprint, such as using LTE 700 or MHz spectrum. However, such networks will provide limited cell capacity (in line with LTE channel widths and capabilities) and have latency limitations that may be inappropriate for the most demanding applications. For example, dense traffic situations (e.g. traffic jam on a freeway) may bring a very high density of mobile broadband user in defined geographical areas. In general, the wider availability of 5G network along the road will support the development of more advanced connected car services.

The range of in-car wireless solutions being developed has the potential to cause fragmentation within the automotive sector, unless consistent technology roadmaps are agreed among all European players. Hence, various policy-led actions are now underway in Europe to ensure that technology roadmaps are aligned and that cross-industry working (e.g. between cellular and automotive industries) takes place. The EC's 5G action plan recognises a need for greater cooperation among the various stakeholders to address more precisely the connectivity requirements for the automotive sector and the best options to achieve it. We note that the EC's 5G Action Plan refers to conclusions from a recent EC-funded study on benefits of 5G introduction that automotive will be the sector that might generate the highest benefits from 5G use at a European level.[27]

6.4 Envisaged benefits from ITS deployments in Europe

The main objective of investing in an ITS 5.9GHz road infrastructure would be to increase safety on roads. Although road safety has improved in Europe in recent years and the number of fatalities has declined considerably, European and national institutions are still seeking new initiatives to reduce road mortality rates. In 2014, there were around 26 000[28] road deaths in the EU28, which is an impressive 54% reduction from 2001 and 18% from 2010. Only two countries (Sweden and Lithuania) had more road fatalities in 2014 than in 2010 even though road safety improvements had been introduced in these two countries.

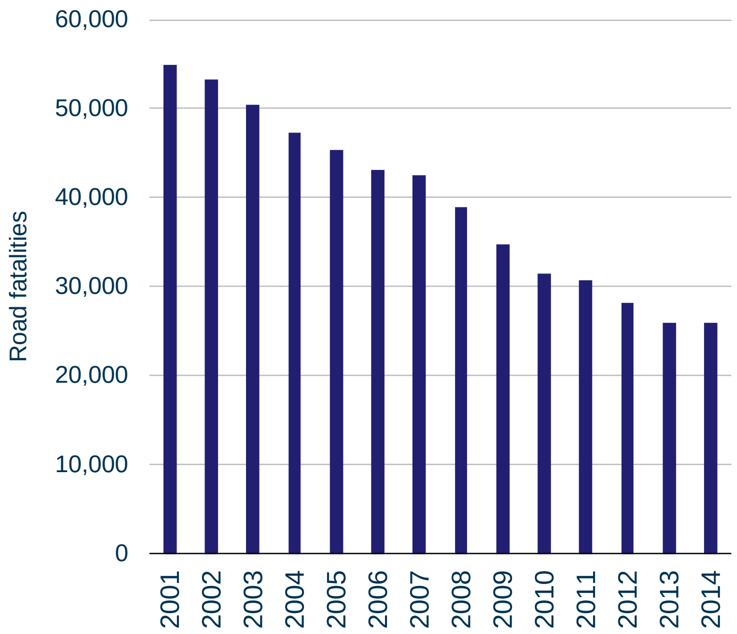


Figure 6.1: Trend in road fatalities in the EU28 [Source: European Commission – Directorate General for Mobility and Transport, 2016]

According to the European Transport Safety Council, there were 52 road deaths per 1 million people in the EU in 2015, compared with 63 deaths per 1 million people in 2010. However, there are considerable variations from one EU Member State to another, and the data shows a certain correlation between road safety and fatalities with the socio-economic situation in a country, related to several factors such as social awareness, speed control and, especially, the level of road infrastructure.

In 2015, nine EU countries (Norway, Malta, Sweden, the UK, Switzerland, Denmark, Spain, Ireland and the Netherlands) had fewer than 40 deaths per 1 million habitants, there were eight countries

27 See https://ec.europa.eu/digital-single-market/en/news/study-identification-and-quantification-key-socio-economic-data-strategic-planning-5g.

28 Source: European Commission – Directorate General for Mobility and Transport.

with 70 deaths or more per 1 million inhabitants (the Czech Republic, Greece, Poland, Lithuania, Croatia, Latvia, Romania and Bulgaria).

As it is already stated, the level of infrastructure is a key factor in road safety. Highways and motorways are proven to be safer than secondary and standard national roads.

Type of road	% of deaths, 2013
Urban area roads	39%
Rural area roads	54%
Motorways	7%

Figure 6.2: Distribution of EU road fatalities by road type [Source: European Road Safety Observatory (from CARE & Eurostat)]

The most commonly used approach for valuing initiatives to prevent fatalities is 'the one-million-euro rule', which was introduced by the EC for selected traffic-safety measures. It is used to test the effectiveness of traffic-safety projects. In theory, a project should be considered for implementation if one life is expected to be saved for every 1 million Euros invested. This test takes into consideration economic loss associated with a death and a certain share of the damage resulting from accidents and incidents in which injury occurs. It does not take into account the societal value of human lives being lost.

The roll-out of ITS networks in European countries using the 5.9GHz is targeted at safety services to improve driving from a road-safety perspective. In the next section, we discuss the possible upfront investments that will be needed in ITS infrastructure, before considering the role of 5G connectivity within the automotive sector.

6.5 Summary of modelling scenarios and assumptions

Since 5.9GHz ITS and 5G connected car solutions are both likely to play a role in providing wireless communication for automotive use cases, we have developed two sets of models. One set of models analyses ITS adoption and roll-out in the 5.9GHz band, i.e. the cost of technology implementation in the cars and the cost of rolling out and operating the corresponding infrastructure. The other set of models addresses 5G connected car services, specifically the business case for 5G MBB roll-out to cover roads (highways and motorways) using the 3.5GHz band.

6.5.1 Modelling scenarios

ITS (5.9GHz)

Two high-level models were developed, specifically to assess:

- **the cost of mandating V2X technology in cars**, by setting a target of equipping 50% of new cars from 2020 and 100% of new cars from 2025. This demonstrates the total cost of having all cars equipped with V2X technology and how many years this would take. Whilst our modelling is based on C-V2X technology, we believe the conclusions would be similar based on ITS G5 technology. In essence, we assume that the technology choice is of a secondary order within the business model for the deployment of ITS, with the main consideration being the cost to equip cars and to provide and operate infrastructure (as below).

- **the cost of rolling out V2X infrastructure along highways and motorways**, assuming around 35% of highways and motorways are covered by 2025. It is assumed that full coverage is not needed, with the priority areas for coverage being locations such as fatality hotspots and major junctions. Unlike population coverage, coverage in terms of kilometres of roads is nearly linear; because it does not depend on population density. It can be assumed that a similar length of road can be covered every year when working towards coverage targets. As expansion of highways and motorways is expected to be marginal, the total investment required is highly dependent on the equipment unit cost and annual opex for sites deployed.

5G connected car

The 5G connected car model is intended to illustrate the investment opportunity (from an operator's point of view) of deploying 5G along highways and motorways to provide mainly MBB services using the 3.5GHz band, considering the goals set out in the Commission's 5G Action Plan. Deployment is assumed in the 3.5GHz band to enable true 5G network performance. As substantial investment would be required to cover a high percentage of highways and motorways with 5G, the business case for road coverage includes a small revenue upside associated with subscribers who wish to use 5G MBB while on the road. From a pure connectivity standpoint, the business model may not be so appealing, especially since 4G network can also deliver coverage along the road, although at lower service QoS. However, the availability of quality connectivity in the car is going to be the catalyst for additional innovations for highly connected cars, and even more so for fully automated car. Therefore, it is critical to provide sufficient investment incentive in roadside connectivity to fuel EU innovation in connected/automated cars, such that it is appropriate to consider that there would be a revenue upside from making such investment.

The outputs from the modelling scenarios include the incremental NPV[29] of the opportunity (i.e. revenue and costs related to road coverage) under different levels of coverage and take-up and the specific investments required.

We have developed two different scenarios for the 5G connected car model:

- **Scenario 1 – 5G coverage along highways and motorways, under existing regulations (competing operators)**. Under this scenario, an MNO will roll out 5G along roads using the 3.5GHz band and is expected to capture some incremental revenue from subscribers who wish to use 5G services while travelling. MNOs will be able to reuse a small proportion of their existing sites near roads but will also have to roll out new sites to achieve good coverage with high QoS. Roll-out will primarily be driven by coverage, as we assume that traffic will not be a bottleneck (at least for a considerable time).

29 In this context we define NPV as equal to EBITDA minus capex.

- **Scenario 2 – Collaborative 5G model**. The only difference between this scenario and Scenario 1 is that multiple MNOs collaborate to deploy 5G along roads using a single shared infrastructure (i.e. the operator pays 25% or 33% of network costs to capture 25% or 33% of market share, compared to 100% of network costs to capture 25% or 33% of market share in the first case). Scenario 2 will always be more profitable than Scenario 1.

- **Scenario 3 - Collaborative ITS/5G model, involving reuse of ITS infrastructure for 5G**. The only difference between this scenario and Scenario 2 is that under Scenario 3 MNOs will also be able to reuse/access the infrastructure of a certain share of the ITS sites which are deployed. MNOs will first reuse their existing sites (similar to Scenario 2), and then reuse the ITS sites before they roll out new sites. As site reuse is more economic than building a new site, Scenario 3 will always be more profitable than Scenario 2.

6.5.2 Main principles and assumptions

When developing the modelling scenarios for the 5G connected car model, the main principles and assumptions that we have used are as follows:

- **5G spectrum**: as previously described, we estimate that 3.5GHz will be the first band to be used for 5G MBB services in Europe, and that this band will be available from 2020 in European countries. Availability of this band for 5G in 2020 may be a 'best-case' scenario in some countries, as the spectrum needs to be re-farmed, as noted previously. While 5G spectrum is expected to be awarded in 2020, roll-out is assumed to start in 2021. We also consider that an operator will be able to use 100MHz of spectrum in this band, which will enable it to provide a 'real' 5G service, clearly differentiated from 4G in terms of speed and quality.

- **Subscriber take-up of 5G connected car**: the number of subscribers who take up 5G connected car services is derived from an addressable market which is estimated as being the share of 5G subscribers (based on devices take-up) multiplied by 5G road coverage multiplied by number of vehicles per mobile subscriber. We have assumed that the take-up of 5G in roads service reaches 60% of subscribers having 5G in covered roads by 2040. We have also modelled the impact of having different take up scenarios.

- **Monetisation of 5G connected car services**: we assume that there will be a small amount of incremental revenue from 5G services, and estimate that the additional ARPU will be EUR2 per month. However, an uplift could be seen a bit optimistic within current market conditions as previously mentioned, given that there has been a steady decline in monthly ARPU in Europe since around 2011 and there is no clear indication of this trend reversing as 4G services evolve. However, assuming the services offered provide distinctly different features to those enjoyed by 4G MBB users, there seems to be some scope to develop specific prices plans for the uptake of specific in-car services

- **Operator modelled**: we have modelled a generic operator (assumed to be an 'average' operator) in each of the three countries (France, Germany and the UK). This means that our modelling does not replicate an existing operator. Instead, we have developed a business case for an 'average operator' based on an average market ARPU, average market share (25% in France and the UK, where there are four existing operators and 33% in Germany, which has three operators), average number of existing mobile sites and 4G sites, and average EBITDA margin of the existing business. However, we have modelled two cases:

- — in Scenario 1 all MNOs have to cover roads and so the incremental revenue from 5G connected car services is split between MNOs
- — in Scenario 2 and 3, we assume that multiple MNOs collaborate to deploy 5G along roads using a single shared infrastructure (i.e. the operator pays 25% or 33% of network costs to capture 25% or 33% of market share, compared to 100% of network costs to capture 25% or 33% of market share in Scenario 1).

- **Network roll-out**: the roll-out of mobile networks follows a geotype approach. However, road coverage is treated differently and is based on the number of kilometres that can be covered by a site. Therefore, in contrast to the other geotypes, road coverage does not depend on density and the deployment is virtually linear (that is, each 1.8km of road requires one mobile site).

- **Highways and motorways**: we have included both highways and motorways in our model which are around 21 000km, 52 000km and 12 000km in France, Germany and UK respectively.

6.6 Modelling results

6.6.1 ITS (5.9GHz)

Cost of mandating V2X technology in cars

The cost of mandating V2X technology in cars, and the year in which 100% of vehicles have V2X equipment embedded, based on equipping 50% of new cars from 2020 and 100% of new cars from 2025 is presented in Figure 6.3 below.

Figure 6.3: Total cost to equip 100% of cars with V2X [Source: Analysys Mason, 2016]

Country	Cost for 100% of cars to have V2X technology over the full period (EUR million)	Year when 100% of cars will be equipped with V2X technology
France	10 332	2035
Germany	12 193	2034
UK	9 968	2032

It should be noted that these calculations are based only on equipping new vehicles and do not take into account the potential for retro-fitting existing cars with V2X. The cost of equipping 100% of cars with V2X technology is similar to the current annual investment in roads in European countries (e.g. around EUR11 billion to EUR12 billion per annum in France and Germany and EUR7 billion to EUR8 billion per annum in UK). Furthermore, the cost of equipping a car with V2X technology represents around 2% of the total cost per vehicle, or around 15% of the electronics and electrical equipment in the vehicle.[30]

Cost of rolling out V2X infrastructure along highways and motorways

The cost of rolling out V2X infrastructure along highways and motorways is presented in Figure 6.4 below and assumes full availability of the service by 2025.

It should be noted that the total upfront investment is relatively modest. This is based on an assumption that only 35% of highways and motorways need to be covered. We note there are cost for ITS systems to maintain their operation – there will be in the ongoing annual expenditure related to backhaul, operation and maintenance of sites, for example.

Figure 6.4: Cost of rolling out V2X infrastructure along highways and motorways [Source: Analysys Mason, 2016]

Country	Investment required over the full period to meet coverage target by 2025 (EUR million)	Average annual operating cost over 2020–40 (EUR million)
France	158	57
Germany	378	135
UK	90	33

As discussed in Section 6.4, the drivers for roll-out of an ITS infrastructure are primarily to improve road safety and traffic efficiency. For example, road safety goals are potentially to save lives and reduce injuries from road accidents. Hence, the costs of rolling out ITS (which, as noted above, could be relatively modest) is likely to be more than justified by the significant societal benefits from the point of view of improving road safety and reducing road fatalities – whilst not quantified here, it is likely that cost-benefit assessment on deploying ITS in Europe will result in significant benefits being concluded.

6.6.2 5G connected car

The business case for deploying 5G along highways and motorways to provide mainly MBB services using the 3.5GHz band is considered as an *incremental* business on the top of existing operator business, which would in theory also include the roll-out of a 5G network to provide services to population in urban and rural areas. Therefore, the outputs of the 5G connected car modelling scenarios include:

30 Car costs are based on McKinsey report 'The Future of North American Automotive Supplier Industry: Evolution of component costs, penetration and value creation potential through 2020'

- the incremental NPV of the opportunity (i.e. revenue and costs associated with road coverage) under different levels of coverage, assuming that subscriber take-up reaches 60% by 2040, i.e. 20 years after launch.
- the incremental NPV of the opportunity (i.e. revenue and costs related to road coverage) under different levels of take-up (assuming that coverage reaches 100% of highways and motorways by 2025, i.e. 5 years after launch). By take-up, we refer to the proportion of subscribers adopting the service out of the maximum possible number of calculated subscribers, which depends on 5G mobile subscribers, 5G road coverage, and number of cars per mobile subscriber.
- the specific investments associated with road coverage under different levels of coverage

The results of the Scenario 1 (see Figure 6.5 to Figure 6.13 below) enable us to draw similar conclusions for France, Germany and the UK: the business case for an average MNO is almost always negative, whatever assumptions are made regarding levels of coverage and take-up.

However, in a situation where multiple MNOs collaborate to deploy 5G along roads using a single shared infrastructure (Scenarios 2 and 3), the results change meaningfully, with most of the simulations having a positive NPV in France and UK (but not in Germany). We therefore conclude that deploying shared infrastructure should be encouraged, as the business case would in most of the cases become positive for operators. It should be noted that the cost of rolling out a new site could be mainly split into three components where infrastructure and passive equipment represent between 60% and 70% of total costs, active equipment represent around 20% of total costs and backhaul represent between 10% and 20% of total costs. The elements that are important to MNOs and that could be built/provided within public infrastructure therefore could include mast/pylons, power to the site, backhaul/fibre to the site and potential cabinet.

We think it is important for NRAs to bear these findings in mind when specifying 3.5GHz road-coverage requirements, as from an economic perspective it may not make sense to have three or four different 5G mobile broadband networks covering roads. We consider that this is different from the situation with population coverage, where NRAs sometimes set coverage obligations of close to 99% of population, and require MNOs to cover non-profitable areas to provide a basic service to almost all the population. In contrast, a 5G service along roads would be used to a much more limited extent, and should be considered as an additional (rather than a basic) service. This could be considered in conjunction with a connected-car specific mobile subscription (and associated usage fees).

As mentioned earlier, the model assumes a limited level of incremental ARPU (of around EUR2 per month) for any subscriber who wishes to use 5G service while out on the road. If a higher level of incremental ARPU was achieved, this would enlarge the market and make room for more MNOs to deploy 5G along roads in each country.

In addition, the model assumes that roads would be covered by 5G in the 3.5GHz band in line with the implication in the EC's 5G Action Plan that 5G coverage along transport routes is viewed as being important for early 5G adoption. We note that operators could also carry out the roll-out of road coverage using a different frequency band, potentially using 4G technology. For example, use of the 700MHz band would make the roll-out considerably more efficient. However, given that the bandwidth available in the 700MHz band is insufficient to provide full 5G capability we have assumed that coverage using the 3.5GHz band is required, in line with the EC's plan.

In contrast to population coverage, the coverage of roads is nearly linear; that is, it does not depend on population density, and the same number of mobile sites are always needed to cover a certain number of kilometres of road.

An important point to highlight are the significant differences among the modelled countries. For example, Germany always has the most negative business case and the UK has the most positive one. This is because of substantial differences in the distance covered by highways and motorways across the three countries. As a result, many more sites are needed to cover the same proportion of total road length in Germany, than in France or (especially) the UK.

Results for France

Figure 6.5: Average French operator's NPV for different levels of motorways and highways coverage [Source: Analysys Mason, 2016]

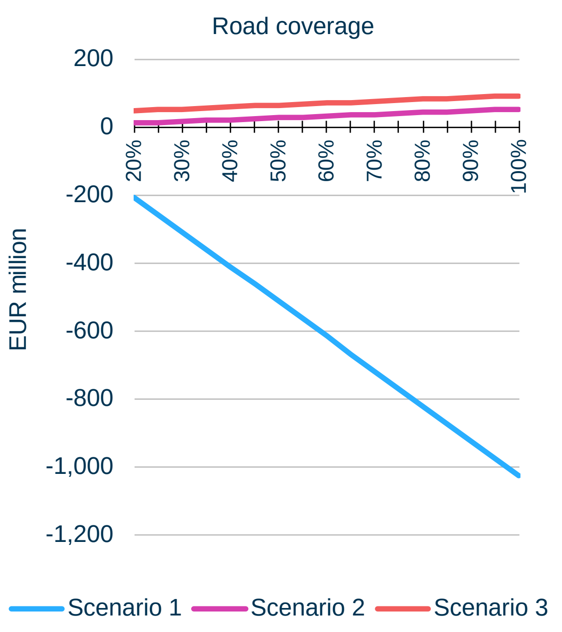
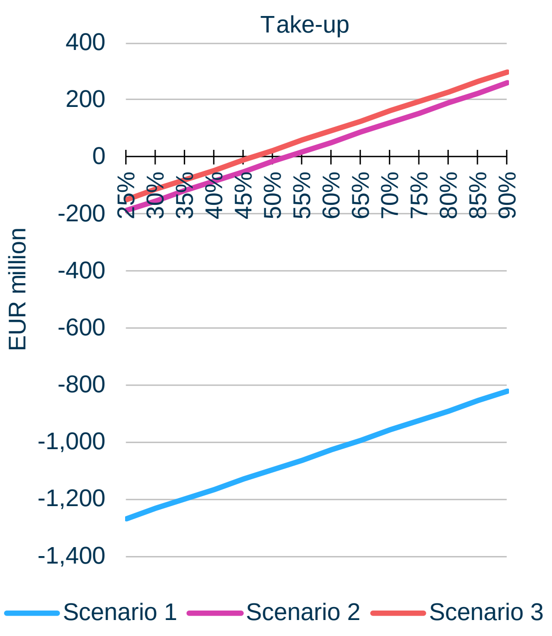


Figure 6.6: Average French operator's NPV for different levels of subscriber take-up [Source: Analysys Mason, 2016]



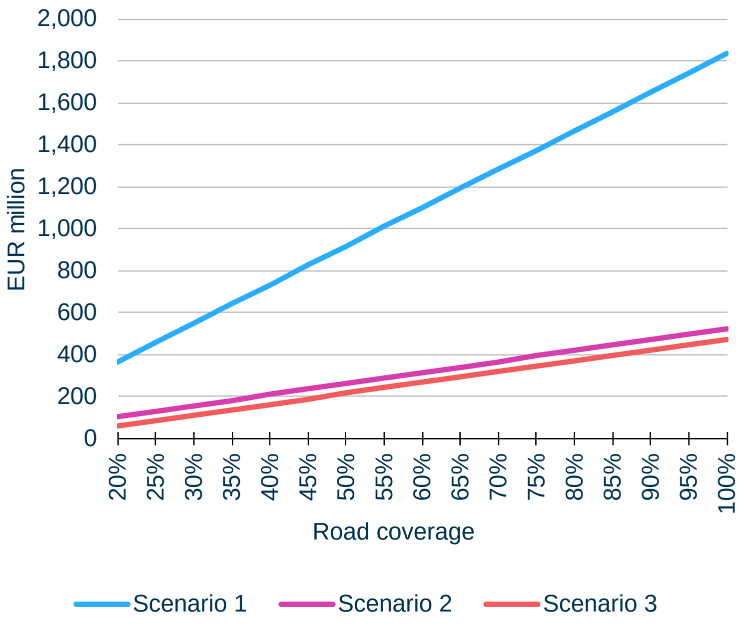


Figure 6.7: Average French operator's investments by level of motorways and highways coverage [Source: Analysys Mason, 2016]

In France, the 5G in roads business is never viable (i.e. it has a negative NPV) for all coverage and take-up scenarios in Scenario 1 (all MNOs roll out 5G along roads). However, if a single 5G network is deployed along roads (Scenarios 2 and 3), all the *coverage* scenarios for France have a positive NPV (with an estimated 60% take-up) (see Figure 6.5). The results for the take-up scenarios (see Figure 6.6) show that there are both negative and positive cases: the business case becomes profitable when reaching 55% take-up in Scenario 2 and 50% take-up in Scenario 3. It should be noted that the cost of 5G infrastructure is much higher than the cost of ITS V2X infrastructure due to mainly site acquisition cost and equipment cost which are higher for mobile networks.

Results for Germany

Figure 6.8: Average German operator's NPV for different levels of motorways and highways coverage [Source: Analysys Mason, 2016]

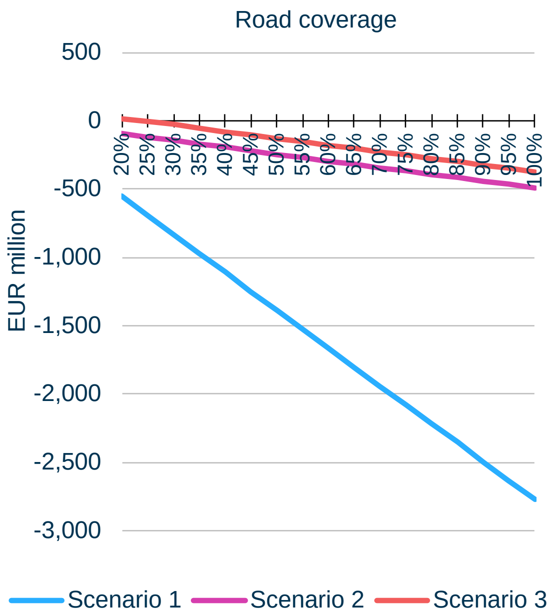
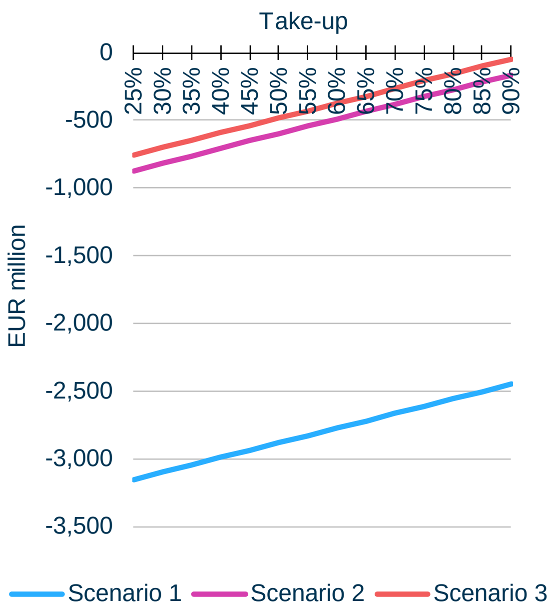


Figure 6.9: Average German operator's NPV for different levels of subscriber take-up [Source: Analysys Mason, 2016]



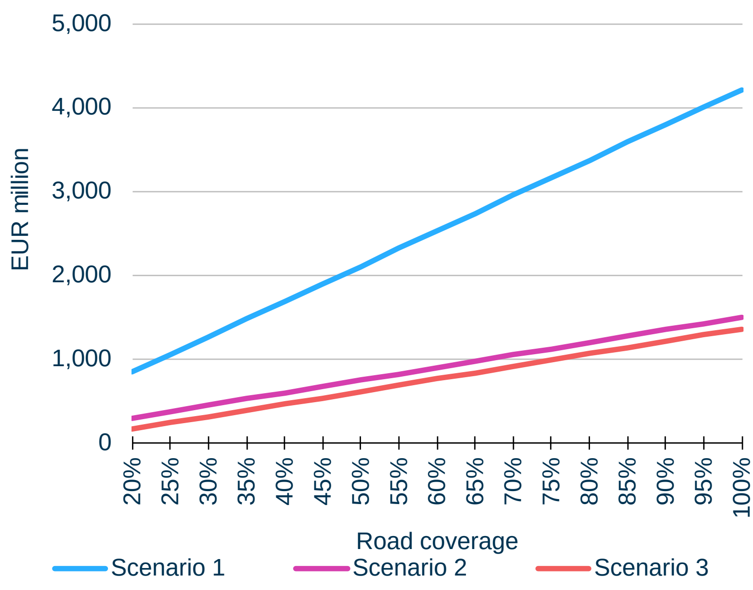


Figure 6.10: Average German operator's investments by level of motorways and highways coverage [Source: Analysys Mason, 2016]

In Germany, all but one of the scenarios analysed produce a negative NPV for the 5G in roads business. This is due to the huge network of highways and motorways in Germany. The only case with a positive NPV (Scenario 3) provides just 20% coverage (and requires 60% take-up). It should be noted that these results are mainly due to the assumption we have made regarding the addressable market which takes into account the road coverage. In reality, MNOs could cherry pick the roads that provide a positive NPV based on cost and service adoption of each specific road. In summary, our analysis highlights that the case to cover highways and motorways is difficult in general and therefore, NRAs need to be careful when defining roads coverage targets.

Results for the UK

Figure 6.11: Average UK operator's NPV for different levels of motorways and highways coverage [Source: Analysys Mason, 2016]

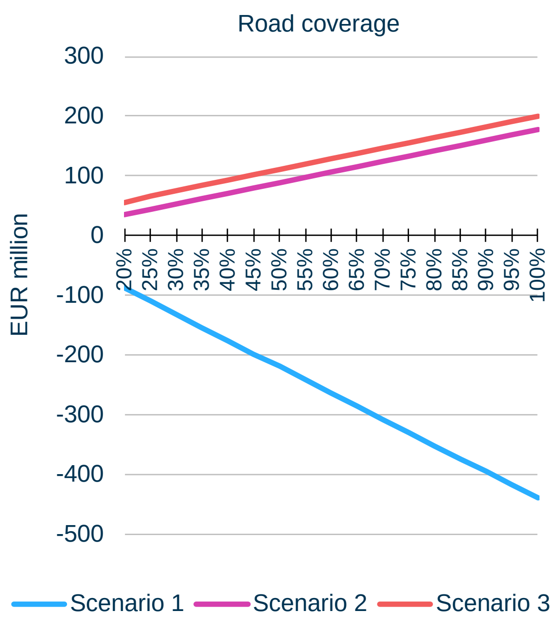
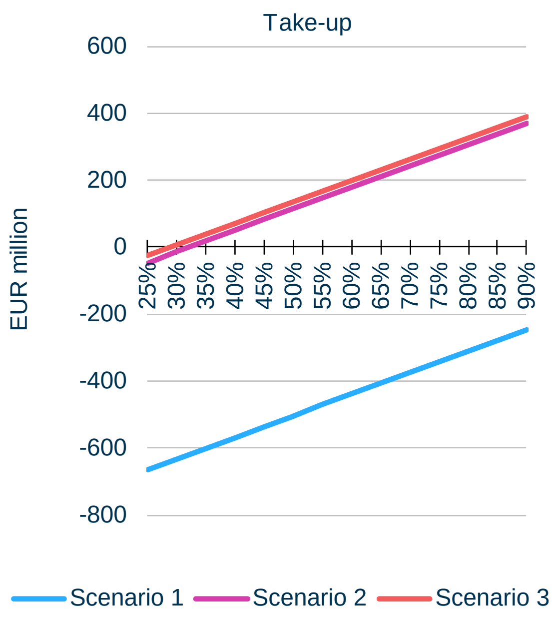


Figure 6.12: Average UK operator's NPV for different levels of subscriber take-up [Source: Analysys Mason, 2016]



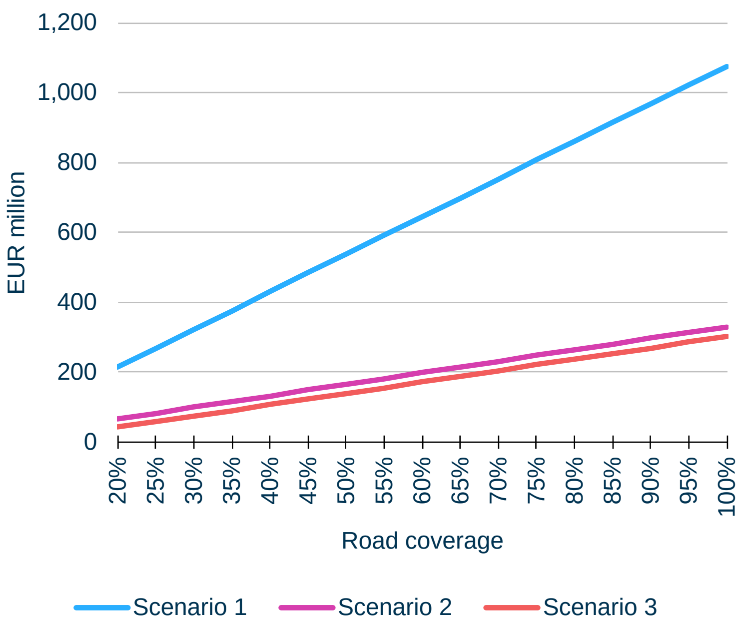


Figure 6.13: Average UK operator's investment by level of motorways and highways coverage [Source: Analysys Mason, 2016]

The UK case is the most profitable regarding the 5G in roads venture due to the relatively limited length of highways and motorways that need to be covered. As in the French case, the business case is never viable if *all* operators deploy 5G in roads (Scenario 1), and it is always profitable if only one operator rolls out 5G road coverage (Scenarios 2 and 3), whatever the coverage scenario (with an estimated 60% take-up). In the case of the take-up scenarios, the business case becomes profitable when reaching 35% and 30% take-up for Scenarios 2 and 3 respectively.

6.7 Regulatory implications for Europe-wide roll-out, and policy targets

As described in the previous section, there is an opportunity for 5G networks to play a significant role in the provision of 'connected car' and related applications. However, this opportunity will only occur if networks provide sufficient coverage and availability to guarantee the reach and network quality justifying an ARPU increase for network users. Connected-car applications which are primarily safety services are expected to be delivered in Europe using 5.9GHz ITSs for the foreseeable future. However, 5G can be expected to play a complementary role in delivering some connected-car applications, and this role is likely to increase over time.

The EC has identified services to the automotive sector as being an important driver to deliver the envisaged consumer benefits from the use of 5G; however, providing the sufficient 5G coverage along roads to deliver connected car services is likely to require significant network investment (over and above the investment that operators would make to provide 5G MBB services). Incentives are required for operators to provide this coverage. As discussed in the previous section of this report, regulatory harmonisation to encourage the automotive industry to look to 5G solutions for connected car services would be beneficial in this regard. Consideration of how connected car services are best provided (e.g. by one operator, or by multiple operators, or by neutral host, or by dedicated transport infrastructure providers) also requires further thought.

Our analysis of the use of 5G by mobile operators to provide enhanced MBB services (in Section 4) shows that commercially driven roll-out (with multiple networks rolled out to meet population-driven demand) is unlikely to be sufficient to provide the seamless service that the connected-car application would require. As indicated in Section 4.3.2, it is expected that European MNOs will need to increase their overall levels of investment in order to achieve wide-area coverage of 5G for widespread MBB use. Even then, however, it is not clear that sufficient coverage would be provided along roads (since MNOs will tend to follow population-driven coverage targets).

For these reasons, a different approach might be required to incentivise 5G roll-out to meet the requirements of connected cars. Hence, when establishing roll-out obligations for 5G licences, regulators may need to define specific road coverage roll-out targets, if they expect 5G networks to play a significant role in achieving government policies associated with delivery of services envisaged by the connected-cars market.

To bridge the gap between population-driven approaches to coverage roll-out, and the coverage that might be needed for reliable 5G automotive services, we have developed a range of targets that might help to focus network investment towards locations needed by the automotive sector (i.e.

along major roads): see Figure 6.14 below. The table also includes alternative demand-led targets, aimed at ensuring that there is a sufficient addressable market to persuade mobile operators to invest (i.e. that enough vehicles are equipped with 5G capability).

Further consideration by authorities of how these roll-out targets might be defined in practice will be needed. For example, our analysis suggests that there is a positive business case for investing in 5G coverage along roads, but only if the addressable market for this sector is captured by one single network. This suggests that any automotive-specific coverage targets should avoid leading to further fragmentation of the addressable market for automotive services, to a level where it is not viable for individual operators to make the necessary investment. The analysis also suggests that coordinated deployment of the 5G infrastructure and the V2I infrastructure is likely to generate synergies and improve the business cases of both 5G and V2I services.

Figure 6.14: Suggested 5G automotive targets [Source: Analysys Mason, 2016]

Category	Policy goal	Justification	Tool
Supply	V2I and 5G coverage targets along key roads	The investment required to deploy V2I infrastructure along roads is modest when compared to total investment in road infrastructure across Europe (i.e. less than 1% of current annual investment in roads). However, it is not modest compared to safety focused investment. There is a social benefit in rolling out 5G along roads, as it would contribute to ITS (V2N) and increase population connectivity. However, when compared to MNO investment in MBB, the funding needed to cover roads is relatively high (around 20% of the investment needed for MBB services), and the addressable market that is not clearly defined. This could represent a major risk for MNOs. Joint V2I and 5G infrastructure roll-out would reduce cost for each service and could also enable roll-out on a larger footprint.	Governments should proactively seek synergy and cooperation between road infrastructure and 5G operators. EU funds could be also put in place for such initiatives
Supply	In areas where 5G V2N is available but not V2I, V2N should support services offered by V2I	As above	As above + Requirement for 5G network to support V2N application – potentially dedicated Application Programming Interfaces (APIs)
Supply	Every road that is built/upgraded must include pre-installation for 5G network (fibre and	Most of the cost of 5G network deployment are linked to civil engineering work. Pre-installation would be extremely cost effective compared to later installation	Objective set at European level and included voluntarily by Member States in their national instruments

Category	Policy goal	Justification	Tool
	power along the road, and cabinets at appropriate locations)		
Demand	70% of vehicles placed on the EU market in 2025 to be 5G equipped (100% by 2030)	The cost of adding 5G connectivity to a car is relatively modest when compared to the total cost of a vehicle. This would create a sufficient addressable market to trigger development of innovative applications (e.g. smart parking)	Separate obligations could be imposed on car/bus manufacturers, and haulage companies, so that all vehicles on Europe's major transport routes would be connected using similar technology
Demand	All smart traffic/ parking/toll systems offered in European cities to be delivered over 5G infrastructure by 2030	The cost of running these services should decrease if there is further automation	Governments could be given responsibility for putting such a system in place. A potential incentive for MNOs to participate in putting such a system in place could be justified if payments could be delivered via mobile billing. Requirement for 5G network to support V2N application – potentially dedicated APIs
Demand	Insurance costs for 5G-equipped cars to be reduced by 5–10% under appropriate insurance schemes	Insurance would be able to better inform users on the risk they are taking. Pay-as-you-drive/pay-how-you-drive schemes would promote responsible driving	Developing the regulatory framework for such insurance policies

We note that a broader range of connected-car roll-out targets could be considered within the context of European policy for promotion of ITS, covering delivery of 'suitable coverage' for these services, irrespective of technology. The targets outlined in Figure 6.15 below could be applicable more broadly in the context of promoting ITS roll-outs using the harmonised 5.9GHz spectrum, possibly incentivising ITS providers to collaborate with MNOs to achieve service goals using a combination of ITS and 5G.

Figure 6.15: Suggested ITS targets [Source: Analysys Mason, 2016]

Category	Policy goal	Justification	Tool
Supply	Monitor/certify performance of artificial intelligence (AI) engines used in safety/security services for connected cars (i.e. autonomous driving)	Since autonomous driving is expected to become a reality, it might be justified to track developments in this area closely in the coming years, to provide input to policy direction and evidence of the possible societal benefits	A minimum QoS could be imposed for the communication between AI and the outside of the car, as the AI engine will perform better over a good connection
Supply	Every road that is built/renovated must include pre-installation for ITS equipment (fibre and power along the road, cabinet and antenna at appropriate locations)	Most of the cost of 5G network deployment are linked to civil engineering work. Pre-installation would be extremely cost effective compared to later installation	Objective set at European level and included voluntarily by Member states in their national instruments
Demand	Car manufacturers to include ITS equipment in new cars (50% in 2020 and 100% in 2025) (similar target to that for 5G above)	The cost for adding V2V technology to cars is relatively modest when compared to the total car cost, as indicated by our calculations in Section 6.6.1	An obligation could be imposed on car manufacturers, requiring V2V equipment for car certification
Demand	1–5% reduction in road casualties/injury thanks to V2X	A detailed analysis of the potential for V2I infrastructure to reduce accident should be conducted, once visibility on the technology market penetration is available	Analysis of the benefits of V2I can be conducted at European level. Deployment of V2I infrastructure has to be a policy-led action from national governments, potentially supported by EU funds
Demand	Lanes/parking spaces reserved for cars equipped with V2X	Environmental positive impact due to fuel reduction for cars equipped with V2X	Analysis of potential of such solution can be conducted at European level. Implementation through policy-led action from national governments, potentially supported by EU funds
Demand	Differentiated speed limits for cars equipped with V2X	Creating incentive for drivers to adopt V2X technology. This in turns helps car OEMs justify the more price increase due to V2X	As above
Demand	Public system for car platooning creation/platooning slot reservation	As above + promoting fuel efficiency.	As above + developing adequate regulation for car platooning

Category	Policy goal	Justification	Tool
Demand	Reduction in maximum driving time for self-drive truck drivers due to time spent in platooning	Ability of self-drive trucks to operate in tighter platoons on European highways could improve driving efficiency (e.g. reduce the space needed for platooning trucks and improve traffic flow) as well as reduce emissions, and cut costs. The further investment needed in the technology to deliver such solutions could be justified through efficiency savings (i.e. reconciling time spent in platooning with the maximum driving time for self-truck drivers)	Would require regulatory action to road haulage licences

7 Connecting vertical sectors – smart cities

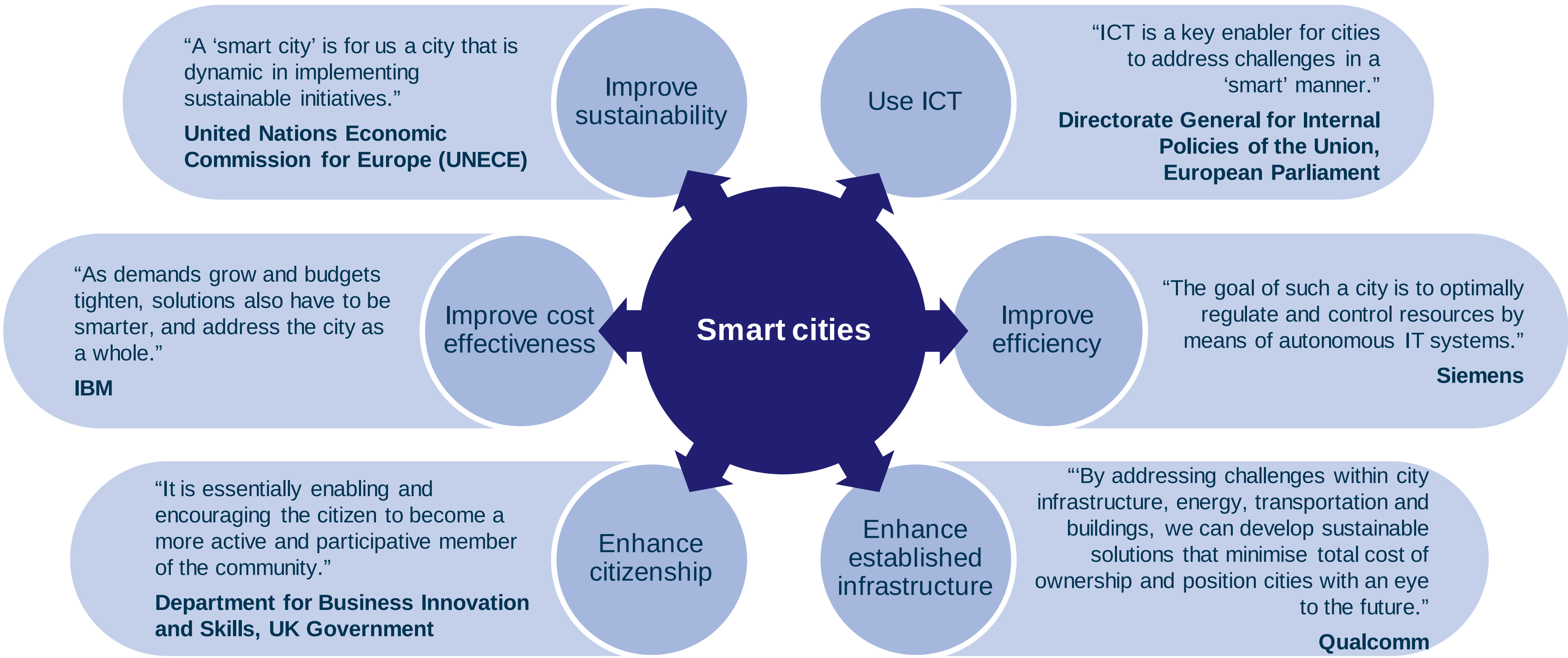
This section discusses qualitatively the potential for 5G networks to enhance wireless connectivity being provided within European smart cities. We firstly discuss the definition of 'smart city', including examples of the applications that such concepts offer. We then consider the role of 5G connectivity within future European smart cities (at a qualitative level, absent of detailed business modelling). We conclude with a summary of regulatory policy implications including possible targets aimed at encouraging investment in 5G infrastructure for smart city applications.

7.1 Connecting European cities

Connected cities are starting to transform the way that European citizens live and do business, just as 'connected services' more broadly are transforming the delivery of a wide range of public services both within and beyond cities. Within cities, 'smart' services include connectivity to monitor lighting, waste management, parking, water, public buildings and various roadside infrastructure (e.g. bus stops, traffic lights, etc.).

Definitions of smart cities vary, and although there is no single definition of a smart city, connectivity underpins many aspects of the smart-city concept. This connectivity can include both wired and wireless infrastructures, although many of the specific application areas within smart cities require some form of wireless connectivity (due to their location, mobility aspects and/or the need to use the flexibility that wireless connectivity can provide). Examples of smart-city definitions are shown in Figure 7.1 below, illustrating the range of characteristics that underpin the smart-city concept, from driving efficiencies in specific application areas to enhancing infrastructure and enabling smarter ways of operating.

Figure 7.1: Examples of smart-city definitions [Source: Analysys Mason, 2016]



In the European marketplace, today, smart cities connect various kinds of public amenity and infrastructure (spanning traffic management, bus routes, bus stops, parking, energy management, management of municipal buildings and spaces, etc.). They enable devices and infrastructure to be connected together, with a view to creating more efficient, cost-effective and safer cities. Typical services that a smart city can provide include:

- **Smart parking**, to gauge the state of parking and traffic in real time, and direct drivers to available parking spaces, via solutions such as sensors
- **Smart lighting**, to remotely control and monitor street lights, which can reduce electricity consumption as well as infrastructure maintenance costs
- **Smart metering**, triggered by an EU Directive in 2008, refers to a mandatory requirement for all homes in Europe to be fitted with smart meters by 2020
- **Municipal broadband services**, for example using Wi-Fi to provide publicly accessible broadband connectivity hotspots in city centres
- **Connected bus stops**, to deliver information to bus stops on bus routes (e.g. the time of the next bus) as well as a wider range of public information services (e.g. on nearby attractions, ticketing, local news, etc.)
- **Digital signage**, to provide near real-time information updates to road and traffic signs
- **Waste management**, to improve the efficiency of waste and recycling collections
- **Crowd-flow management**, to monitor the flow of visitors to large events or to measure footfall in city centres to predict and prevent over-crowding
- **Pollution monitoring**, for example using sensors to monitor air and water pollution; this information can also be cross-referenced against other analytics such as health data for the same city, in order to identify and protect 'at risk' citizens in a given area.

Most examples of smart cities are existing cities, where infrastructure has been upgraded to transform services and solutions, make efficiencies and achieve certain policy objectives (e.g. a reduction in traffic congestion, pollution control, cost savings and/or safety improvements). Smart cities in Europe include Berlin, Nice, Frankfurt, Munich and London. However, there are also 'greenfield' smart cities (i.e. new cities constructed with intelligent solutions for efficiency and sustainability), including PlanIT Valley in Portugal.

7.2 Enhancing smart cities using 5G

Various wireless technologies are currently used to provide connectivity within smart cities, including 2G-, 3G- and 4G-based networks as well as a variety of short-range wireless technologies such as Bluetooth and Wi-Fi. LTE machine-type communication (MTC), as described in Section 0 earlier, is part of 3GPP Release 13 and will provide improved capability for 4G LTE to be used in M2M applications, including in smart cities. Key benefits that MTC will bring include low power consumption/increased battery life and reduced device complexity (resulting in lower device costs). MTC-type systems can operate either within the same spectrum as that used by LTE MBB networks, or using dedicated channels (e.g. a ‘2×3MHz’ block in the 700MHz band, as described in Section 5.2).

Enhancements to the LTE specification which are being developed as part of 3GPP will also enable new forms of connectivity, applicable to IoT-type requirements (e.g. device-to-device communication, multi-hop and broadcast-type one-to-many connections). Wi-Fi and Bluetooth solutions are also expanding, such that LTE, Bluetooth and Wi-Fi can be used together to provide sufficient wireless connectivity to support smart cities for the foreseeable future. Hence it is likely that many smart-city services will continue using existing wireless technologies for some years to come, with 5G complementing and eventually replacing existing technologies in later phases of deployment, based on market demand. This phased introduction of 5G into smart cities is in line with the phasing of wireless connectivity within the automotive sector alongside ITS, as described in Section 6 above.

Once fully available, 5G networks can be expected to enhance today’s smart-city solutions, offering faster wireless connectivity speeds, lower latency and, potentially, greater coverage.

The potential benefits of providing 5G mobile broadband connectivity within a smart-city environment are likely to include:

- the potential to seamlessly connect both people and things
- improved network availability and responsiveness, enabling real-time monitoring, data collection and analytics
- increased capacity, reducing the likelihood of congestion arising from different IoT applications and consumer uses of mobile broadband services
- higher data speeds, providing capacity to support many more users with higher-speed services (including ultra-high-definition video)
- the potential to use combinations of technologies seamlessly (e.g. 4G, Wi-Fi and 5G) to make better use of data between different sources, coordinate and target services more efficiently.

Possible ‘killer applications’ of 5G in smart cities might be similar to those for 5G MBB (e.g. the ability to provide connections within very densely populated urban areas or to areas where very large numbers of users will congregate, with a requirement for multimedia services). As with 5G MBB, specific 5G services that may become relevant for smart cities include large-bandwidth content sharing and ultra-high-definition video.

Overall, the benefits that 5G is expected to bring should make it possible for more devices and things to be connected, which in turn should create further opportunities for smart cities to add value to the way we live and work in cities. As with LTE, economies of scale will be important for 5G, so that IoT-type smart-city applications can be delivered efficiently and cost effectively. Achieving these economies of scale involves both a technology and a spectrum dimension (i.e. ensuring the EU-wide availability of spectrum for 5G, including spectrum suitable for IoT-type applications).

7.3 Possible regulatory goals and targets for 5G

As described earlier in this report, there may be a need to re-consider how European policy and targets for 5G roll-out are defined, to specifically promote the uptake of 5G solutions by the range of vertical industries that are most relevant to the future connected society in Europe. Such policies and targets aimed at encouraging provision of 5G services for smart cities might be based on specific measures to deliver increased connectivity speed or quality within urban centres in Europe, for example (possibly including possible requirements for indoor coverage). We note that the Commission has recently proposed such measures in the 5G Action Plan, which includes a target of all urban areas and major terrestrial transport paths having 'uninterrupted 5G coverage' by 2025.

Figure 7.2 below summarises other possible targets that could be proposed, to promote the use of 5G connectivity within European smart-city initiatives. As noted previously, further study into the tools and approaches to implement such targets is recommended.

Figure 7.2: Suggested 5G smart-city targets [Source: Analysys Mason, 2016]

Category	Policy goal	Justification	Tool
Demand	Monitoring of specified infrastructure services in European cities (e.g. traffic lights, bus stops, bus lanes, dustbins, connected signs, etc. to use 5G connectivity	The justification for this type of target being defined would have to be nationally defined (e.g. based on political agenda in different countries), requiring analysis by public authorities responsible for particular smart cities to justify the societal and/or economic benefit achieved	Public authorities responsible for implementing smart city projects would procure solutions from operators through the usual public funded procurement processes, subject to the relevant European legislation (e.g. State aid)
Demand	All new homes within designated smart cities to be intelligent buildings with 5G connectivity (e.g. small cells)	Has the potential to save lives (e.g. via wireless delivery of floor plans firefighters) but justification for investment would be needed at a national level, given the potential scale of investment needed	As above
Supply	All government buildings to deploy 5G coverage	The cost is likely to be limited for Government buildings within city centres, as 5G should cover all government buildings at reasonable cost. However, there might be additional costs if specific levels of speed and quality for indoor coverage were mandated	As above
Supply	5G connectivity to be provided to customers on all forms of public transport	The additional cost would be limited if 5G road coverage is delivered (e.g. to address connected car use cases) It is noted there could be positive impact on the environment (e.g. CO_2 reduction), due to increased use of public transportation arising from this investment	As above.

8 5G as an enabler for broadcasting services

This section discusses the role that 5G might play in the AV broadcast sector. In Section 8.1 we discuss the evolution of AV media services and distribution. We consider the evolving patterns of television (TV) viewing in Europe, from traditional broadcast platforms towards use of complementary platforms (including Internet based-video streaming services) and the increasing use of mobile and portable devices. We also consider the question of whether Internet-based services will continue to complement broadcast networks in future (or will increasingly become substitutes), and look at the role of 5G as an infrastructure for delivering AV services.

In Section 8.2 we briefly discuss the regulatory implications associated with the increasing importance of the Internet (and 5G) for TV viewing.[31]

8.1 Evolution of infrastructure for audiovisual media distribution

Evolution of infrastructures for AV media distribution

AV media services form an essential part of European culture and society.[32] Most AV video services in Europe are delivered to television sets located within homes and businesses at present. However, these services can also be streamed within the home, over the Internet, to multiple devices (e.g. to a personal computer), typically using Wi-Fi (within homes or businesses) or over 4G networks (whilst outside or on the move). There is therefore a growing use of portable and mobile devices – particularly smartphones and tablets – for TV viewing of various types, including both live programmes and on-demand video.

At present, broadcasters mostly reach their TV audiences in Europe using a range of fixed infrastructures. Digital terrestrial TV (DTT) is the name given to digital terrestrial infrastructures that have been designed specifically to deliver TV services, using spectrum in the UHF band (currently 470–694MHz). These primarily use digital video broadcasting (DVB) technology. DVB technology can take various forms, depending on the main transmission network which is used: UHF TV networks use DVB-T, generically referred to as DTT; cable services use DVB-C; satellite services use DVB-S (distributed via satellites that use designated satellite spectrum internationally). Wireline networks used to deliver TV services over fixed broadband networks are referred to as IPTV.

Broadcasters are increasingly using the open Internet (i.e. broadband networks) to reach their target TV audiences – exploiting the increasing availability of super-fast fixed broadband network capability across homes in Europe (whether over cable, copper, fibre or, to a lesser extent, satellite).

31 It is noted that there are several forms of dedicated broadcast network, including satellite, IPTV, cable as well as terrestrial (DTT) – in the section we primarily discuss dedicated broadcast networks in the specific context of DTT.

32 Whilst AV services can be very wide reaching, we focus here on the main TV channels and similar video services, such as video on demand (VOD), typically available in Europe.

In this context, MBB and Wi-Fi networks currently complement this fixed broadband network capability – for example to stream services within the home on secondary screens (laptops, tablets and smartphones), as noted above.

A summary of the current composition of AV media services in Europe (by technology type) for main screen TV viewing is shown in Figure 8.1and Figure 8.2 below. It is noted that the proportion of homes in which the 'first TV set' connection is provided using DTT is still most relevant although it has declined in recent years, while the use of IPTV and satellite has been increasing.

Figure 8.1: First TV set connections by technology in Western Europe [Source: Analysys Mason, 2016]

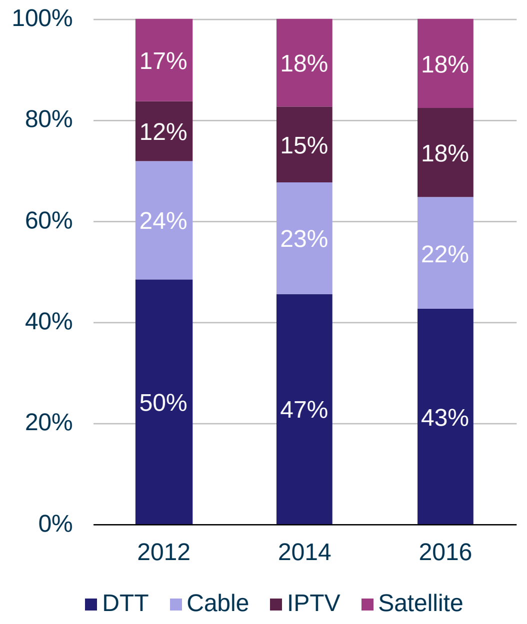
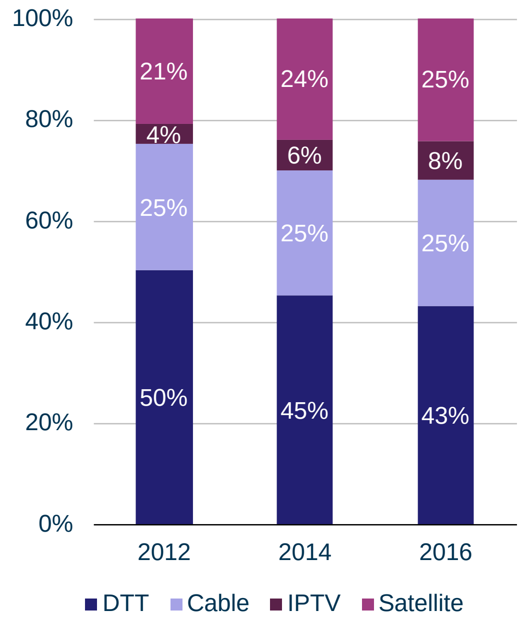


Figure 8.2: First TV set connections by technology in Central & Eastern Europe [Source: Analysys Mason, 2016]



Hybrid services, whereby broadcast TV such as DTT distribution is combined with additional video services delivered over the Internet, have become popular in some markets. These can either be delivered to homes via 'connected TV sets' or through dedicated viewing boxes (e.g. 'You View' and 'Freeview Player' in the UK). Two distinct forms of Internet-based video service are now emerging, namely subscription-based services such as IPTV (which typically provide both linear TV and VOD services), and OTT VOD, provided for general access over the Internet. The increasing use of VOD services within the home is a key trend that is evident across Western Europe, as shown below.

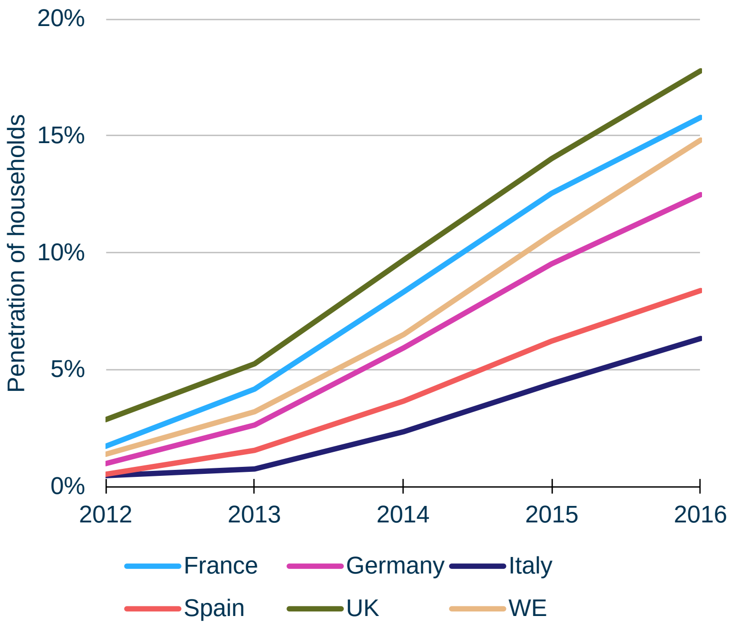


Figure 8.3: Evolution of VOD penetration in selected Western European countries [Source: Analysys Mason, 2016]

Despite rapid growth in the use of VOD services, viewing of content from traditional linear broadcasters over broadcast networks still the most popular way to consume TV content, when considered across the entire population, based on published research.[33] However, research also highlights significant differences in the viewing patterns between different generations of TV viewer – with the youth market generally watching less traditional TV, with additional time being shifted towards live streaming and VOD services. This same drop-off in traditional TV viewing is not so apparent when considering other age groups, however. Hence, it remains unclear whether (and when) the relative importance of different viewing patterns will signify a change in how terrestrial TV broadcasters deliver their services. Given the cultural importance of traditional linear TV content, it is likely that this form of TV content and broadcast network viewing will be required in some form in Europe for some years hence. However, there is no doubt that IP networks are increasingly being used in addition to dedicated broadcast networks like DTT, for new content but also for traditional TV content. Hence, IP delivery mechanisms for TV viewing (i.e. broadband networks and the Internet) are becoming increasingly relevant both for linear and non-linear TV services, and this trend will most likely result in DTT being less relevant to TV viewers in the future.

Greater use of mobile devices to access TV services whilst on the move is also likely to become increasingly relevant, and viewing patterns are already shifting towards increasing consumption of content on mobile and portable devices. 5G can also potentially offer significant performance benefits for higher-resolution video compared to current mobile networks as well as creating new AV service possibilities for broadcasters (such as virtual reality gaming and interactive streaming services, through allowing simultaneous transmission on the uplink and the downlink, for example).

33 Source: Ofcom, *The Communications Market Report*, August 2016.

Broadcasting regulation in Europe

The current regulatory and distribution model for AV media, TV channels and VOD services includes 'public service broadcast' (PSB) channels, as well as a wide range of commercial channels relevant to the national or other specific territory. These TV channels are usually delivered as a live or scheduled, broadcast or streamed service (also known as linear) but also increasingly as time-shifted programmes (typically using personal video recorders (PVRs) and digital video recorders (DVRs)), or on-demand programmes (catch-up channels on players, free-to-air video on demand (FTA VOD), subscription VOD (SVOD) and so forth). As well as 'public broadcasters' in Europe (i.e. broadcasters providing PSB content), there are also a range of pay TV providers, some of whom gain access to premium content (such as football/sport, TV series, premium live events). Consumers access these pay TV services, as they do OTT services, through some form of subscription. DTT, as described in the previous section, has in most cases been promoted in Europe to extend the number of available channels which are delivered as 'free to air', which means that consumers receive these free to view channels on their TV set without paying a subscription (other than annual payment of a TV licence in some markets). Under current broadcast regulations, DTT platforms are a way for public broadcasters to provide free-to-air access to either regional or national channels on a common platform. In exchange, the public broadcasters receive preferential treatment relating to access to sufficient capacity on the DTT platform, as well as revenue (e.g. a proportionate share of the revenue from licence fees) to fund national content creation. Private broadcasters, on the other hand, receive revenue primarily from advertising.

Although national circumstances vary between different European countries, the broadcasting regulations at a European level (i.e. as contained in the EC directive on television[34]) are linked to delivery of PSB channels, delivered free-to-air as described above. In some EU member states, there are specific requirements for PSB services to be 'universally available'. In turn, these regulations are linked to the regulation and use of DTT platforms in many European countries, including access to spectrum for terrestrial TV broadcasting.

However, as broadband infrastructures take on a more central role in TV distribution, and with the potential for DTT's role as the main transmission network for PSB channels to be supplanted by other networks, there seems to be a growing requirement to re-assess specific and related PSB regulations and their association to DTT, to make them appropriate to the evolution of the telecoms market and its associated regulatory framework, including 5G.

Potential role of LTE and 5G

The 3GPP Multimedia Broadcast Multicast Service (MBMS), or LTE Broadcast can be used for the transmission of mobile television services, and provides support for the transmission of multimedia content such as pictures, audio and video. MBMS was originally developed for 3G networks, supporting both multicast and broadcast transmission. LTE broadcast was designed from the start to deliver broadcast video content (linear or non-linear). It benefits from inherent SFN support and

34 See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:l24101

widespread support in mobile devices (most LTE device chipsets support LTE broadcast, with a firmware configuration needed to unlock the capability). However, LTE broadcast has gained limited market adoption to date to deliver linear TV. A key issue has been the lack of support for free-to-air and subscription-free viewing (since all users authenticate onto an LTE network to use a mobile service).

These shortcomings have been identified by the 3GPP community, which is currently working on a work item named 'enTV' to update the standard. The European Broadcasting Union (EBU) has been closely involved in this work item, among other initiatives, relating to the definition of the service requirements. 3GPP and the EBU have also commenced discussion on the distribution of AV services in the context of 5G.[35]

The requirements identified for enTV include the possibility to support:

- different deployment models – including deployment of a fully independent, broadcast only network (i.e. separate transmission network from 4G/5G MBB)
- support for receive-only terminals and free-to-air viewing
- Use of SFN and cell sizes applicable to a nationwide (or equivalent) network

enTV is part of 3GPP release 14, with completion expected towards the end of 2016.

3GPP has also adopted broadcast specific requirements for the definition of 5G-NR. The requirements are based on those defined for enTV, as described above, although it is expected that 5G will support a wider range of cell size and deployment options.

Hence, there will be potential that 5G infrastructure can either provide an additional or alternative means of distributing AV video content, depending on the regulatory framework. Irrespective of the role that 5G might play, it seems clear that increasing integration of AV broadcasting with broadband networks (including mobile) raises certain issues that will require a re-thinking of current telecoms and broadcast regulation. The main considerations are briefly summarised below.

8.2 Regulatory considerations for the convergence of broadcasting with telecoms and 5G

As noted in the previous section, broadcasting regulations in Europe are premised on PSB broadcasting, with PSB channels delivered free-to-air, often using a nationally deployed DTT network. By contrast, the principle of regulation in the telecoms market, including the mobile sector, is to encourage infrastructure competition, as discussed throughout this report, as a tool to achieve better infrastructure and more rapid innovation. The regulatory frameworks currently applying in the broadcast and telecoms sector are such that market structure and competition in the respective sectors is different, as are the incentives to optimise delivery of different video applications. This

35 See http://www.3gpp.org/news-events/conferences/1683-ebu

limits the opportunities for parties on both sides (i.e. broadcasters, telecoms and mobile operators) to adapt their roles to address a convergent market.

The requirements currently being discussed in 3GPP for 5G aim to make 5G infrastructure suitable to support the requirement of broadcast content providers, in particular PSBs. However, although 5G infrastructure could be designed to address the technical issues needed to deliver national TV services, a suitable regulatory framework to enable this convergence to take place still needs to be identified.

There is therefore a need to study in detail the regulatory framework that would be the most appropriate to support future national broadcasting policies (including the associated obligations such as reach and free-to-air viewing). This is needed both to facilitate the convergence already taking place in the market between broadcasting and telecoms and to ensure that PSBs can leverage the best technology and provide the best services to meet TV consumer's requirements. A broad review of this type would also ensure the best use of UHF frequencies can be determined. Considerations of such a review would need to span various issues from the support of national broadcast policies through to assignment and use of UHF spectrum and net neutrality.

9 Conclusions and recommendations

Whilst the development of 4G networks was broadly linked to the rapid increase in data traffic being carried by mobile networks, and a need to meet increasing consumer demand for MBB services, drivers for the development of 5G are more diverse.

In particular, the internationally agreed vision for 5G includes a diverse range of services and devices and delivery of this mix of services over mobile networks brings new business opportunities for mobile operators. Use cases for 5G range from MBB services to consumer mobile devices (with these being considerably enhanced compared to today's 4G services to enable provision of highly immersive MBB services such as VR and AR services), as well as a wide variety of IoT-type use cases. The IoT use cases include a wide range of device to device and device to network applications such as in automated vehicles, robotics, smart homes and buildings, e-health and smart grid. In some of these use cases, very high available and reliable wireless infrastructures are essential (e.g. emergency services). Delivering these new business opportunities will rely on significant investment being made in 5G infrastructures. The business models of MNOs in Europe to support such investments are underpinned today by revenue from MBB use, which are derived from the ARPU that operators obtain from individual subscribers. With the regulatory framework for mobile communications in Europe based on encouraging infrastructure competition, a downwards trend in ARPU has occurred since 4G networks were launched in Europe, as competition has intensified.

This report has therefore aimed to assess the investments needed for 5G, in the context of the business models of European mobile operators. A summary of our conclusions is provided below.

► *Deployment of mobile broadband will dominate the early roll-out of 5G*

Improving broadband connectivity was one of the key polices that the Commission has supported in achieving the DAE. Mobile connectivity is playing an increasing role in this as mobile data usage becomes ever more intensive. It is widely anticipated that 5G networks will further enhance the availability of fast and even superfast mobile broadband services, enhancing today's 4G network capabilities to bring higher throughput, better capacity and availability, and lower latency.

The initial focus of 5G is expected to be on MBB-type services, before expanding to other vertical sectors (including IoT and mission-critical services). It is quite clear that MBB will be the initial/main service, as it provides the necessary economy of scale to enable the rapid deployment of MBB services building on the investments made in 4G infrastructure. This then provides the basis to expand these services into other vertical sectors. Most of the 5G trials undertaken by major vendors and operators have been focusing on MBB data rates and peak speed, which further supports the view that MBB is main 5G opportunity that mobile operators see at present.

The Commission's 5G action plan for Europe, however, envisages a richer set of 5G services appearing over time, with infrastructure delivering support for a range of applications from MBB through to IoT, ultra-reliable communications and AV broadcasting. A key goal of our study has been to investigate how a MBB business model can be adapted to deliver a more diverse range of services and applications, and the best regulatory structure to achieve this.

Noting the expectation that that 5G MBB will be the services initially deployed in Europe, and based on using spectrum in the 3.4–3.6GHz band, we have found from the business modelling conducted for this study that there is a positive case for operators to invest in 3.5GHz to provide 5G MBB services in Europe. Infrastructure sharing makes a positive difference to the business case and importantly, this can expand the coverage (for a given level of investment) by up to 20%. Deeper levels of sharing (e.g. the sharing of spectrum) might improve this situation further. Given the significant advantages that this additional coverage will provide for European citizens, the regulatory environment for 5G should therefore promote sharing where it is commercially and technically advantageous, in order to bring increased benefits to European citizens from having better 5G availability and reach.

Taking into account the current level of investments achieved by European operators, 5G coverage using the 3.5GHz band could reach up to 70% of the population in some countries (and could be as much as 99% in a scenario involving infrastructure sharing among MNOs). Increasing the level of investment by just 10% would allow to exceed 80% of population coverage (and could rise to more than 99% of the population under an infrastructure-sharing scenario).

► *Using 5G networks to deliver IoT services can bring benefits but the addressable market for such services needs to be more clearly defined to stimulate investment*

Certain aspects of IoT services are different from what MNOs will design for delivery on standard mobile networks (i.e. those driven by voice and MBB services). In some cases, these require bespoke connectivity solutions, different device types and/or other network changes, which might increase costs for MNOs. Added to the uncertainty of whether there is an adequate addressable market in some IoT vertical sectors to justify the offering of tailored 5G solutions, there are therefore risks to MNOs from investing in 5G infrastructure in order to deliver IoT services, if they do not have a clear picture of the demand for services or a clearer picture of the addressable market for such services in different European countries. These risks need to be considered carefully in the context of business cases for mobile networks which are today premised on delivering MBB services to European citizens and consumers.

We have identified certain key characteristics of IoT services that might be better supported using a dedicated spectrum for IoT (rather than using spectrum shared with MBB) while reusing the MBB infrastructure, which include:

- Applications requiring **resilient, highly available connections** (i.e. they are QoS sensitive); if MNOs delivered those services, they would need to prioritise this traffic over other traffic
- Applications requiring **a high level of security** for connections, or where **privacy of data** (e.g. personal data) must be guaranteed (it is noted that many healthcare applications fall into this category if information involving patient records is being transferred between a mix of people,

devices and systems without the patient's authorisation of each individual transfer of information)

- Applications requiring **connectivity in ultra-remote areas**; it might not be commercially viable for MNOs to provide coverage to very remote areas (e.g. to serve utility applications such as gas or water control stations)
- Applications where **data-usage patterns** are different from those of handset/MBB traffic (e.g. utility, smart-city or health applications with high data upload requirements would require MNOs to dimension capacity in the uplink, instead of their normal practice of dimensioning MBB for the downlink).

Based on our modelling, we found that the business case of a scenario where an MNO uses 2×3MHz of separately assigned spectrum in the 700MHz band[36] to provide health services over an LTE-based dedicated IoT infrastructure is more profitable than a scenario in which health applications are provided by an MNO over a common infrastructure with MBB. This is on the basis that health applications provided on the top of MBB in the 700MHz band, could lead to lower investments in health-specific services, due to higher revenue of the mobile operator being driven by MBB. In our modelling, the assumption that an operator would deploy a dedicated infrastructure using separate spectrum (although sharing certain aspects of the network where feasible, such as sites and backhaul) improved the MNO's NPV by between 6% and 13%. Our modelling assumed one operator deploying a dedicated IoT infrastructure in separately assigned 700MHz spectrum in a European country although we note that different models are possible depending on national circumstances.

The use of MBB networks to deliver services to other vertical sectors (such as the provision of automotive V2N services) needs to be assessed carefully. In our analysis, we modelled the feasibility of providing 5G coverage along roads, as part of a deployment of 5G in the 3.5GHz band. It should be noted that, in practice, other bands (e.g. 700MHz) are likely to be used in combination with 3.5GHz, which should improve the business case. However, use of higher frequency bands is needed to deliver full 5G capability. The extent of full 5G capability needed is highlighted in the Commission's recent report on socio-economic data for the strategic planning of 5G introduction in Europe, which suggests three key capabilities for 5G (50Mbit/s speed, scalable solutions, and ultra-tactile internet). The provision of 50Mbit/s speeds will not be achieved in bands below 1GHz.[37]

However, based on our modelling, the business case for an average MNO to deploy 5G coverage along roads using the 3.5GHz band is almost always negative. This is the case whatever assumptions are made regarding levels of coverage and take-up, under a scenario which reflects current mobile market structure (i.e. multiple competing infrastructures providing services along roads). However, in a situation where multiple MNOs collaborate to deploy 5G along roads using a single shared infrastructure, the results change meaningfully, with many of the scenarios having a positive NPV

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36 It is assumed that the MNO is awarded the 2×3MHz spectrum through a competitive award, and pays an upfront fee for spectrum similar to prices for the 2×30MHz of 700MHz that is being assigned for MBB use on a per MHz per pop basis.

37 For example, a typical assignment of 2×10MHz per operator in the 700MHz band (e.g. with the available 700MHz spectrum shared among three or four operators) might achieve around 10Mbit/s per network.

in the French and UK cases. We therefore conclude that encouraging infrastructure sharing would improve operators' business case and the viability of the 5G services along roads.

It should be noted that in our analysis we have assumed a small uplift in mobile ARPU is implemented in the business model in order to capture the additional usage/revenue that MNOs will obtain from providing an automotive service. Although we have not specifically considered price trends, our view is that a higher level of ARPU than that assumed in our model might not be feasible in European countries, given the downwards trends in MBB ARPU in recent years. However, we note that more optimistic assumptions on ARPU would improve the profitability of the business cases presented (i.e. if subscribers are willing to pay a higher premium to receive 5G automotive services).

- ► *There is a risk that the investment required by MNOs to deliver widespread IoT services might exceed the operator's share of revenue, unless additional spectrum is made available (e.g. 2×3 at 700MHz) and widespread network sharing between operators is implemented*

Total investments over 20 years (2020–40) of an average operator with 700MHz spectrum which is used to provide MBB and IoT services would reach circa EUR11 billion in France, EUR18 billion in Germany and EUR12 billion in UK.

Based on our modelling, the business case of a scenario where an MNO uses 2×3MHz of dedicated spectrum in the 700MHz band[38] to provide health services over an LTE-based IoT network (e.g. NB-IoT) is more profitable than a scenario in which IoT applications are provided by an MNO over a common infrastructure with MBB (i.e. if health applications are provided on the top of MBB in the 700MHz band this can lead to lower investments in the IoT-specific services, due to higher revenue driven by MBB). In our modelling, the use of a dedicated band for an IoT network improved the MNO's NPV by between 6% and 14%. This improved business case might enable operators to accelerate the network roll-out for IoT, for example.

- ► *5G coverage of main transport routes – with true 5G capacity and data rates - will be critical to the future of connected and automated cars, but is extremely challenging from the economic perspective. Allowing network sharing and pre-installing 5G (i.e. making cabinet, power and fibre available) are likely to be required to ensure coverage of main transport routes is achieved.*

The use of MBB networks to deliver services to other vertical sectors (such as the provision of connected car services) needs to be assessed carefully. In our analysis, we modelled the feasibility of providing 5G coverage along roads, as part of a deployment of 5G in the 3.5GHz band.

For automotive applications, it is noted that 5G networks are likely to supplement planned ITS in Europe and so there is a possibility that applications in this sector will be split between networks, with safety-related applications carried over ITS networks. In this scenario, 5G networks would

38 It is assumed that the MNO is awarded the 2×3MHz spectrum through a competitive award, and pays an upfront fee for spectrum similar to prices for the 2×30MHz of 700MHz that is being assigned for MBB use on a per MHz per pop basis.

provide MBB services tailored to the automotive sector (e.g. in-car entertainment, traffic, travel and parking information and e-booking etc.).

The cost of rolling out ITS infrastructure along highways and motorways, mainly for safety reasons, is not excessive in our modelling, primarily as we assume that only around 35% of highways and motorways need to be covered in accordance with European policy requirements (e.g. it is assumed coverage is only needed at particular locations, such as at fatality hotspots and major junctions). This investment represents less than 1% of total road investment that national governments in Europe typically make to upgrading road infrastructure in a country and would have social benefits in the form of a reduction in road fatalities and injuries.

Extending the coverage of a 5G MBB network to provide 100% road coverage along highways and motorways does not generate positive NPV for operators if we assume that competing operators will do this (and hence the market share of one operator is limited compared to the network costs), based on our modelling. However, if we assume that competing operators collaborate to deploy a single shared infrastructure along major road routes, the business case improves.

In the case of all operators deploy 5G covering all motorways and highways, an average French operator would need to invest circa EUR2 billion, while in the case of Germany it would reach circa EUR4 billion due to the great extension of German highways. In the UK, as the length of road networks are significantly reduced as a result of the smaller geography of the country, investments would be around EUR1 billion.

Our modelling suggests that a collaborative ITS/5G model between MNOs and the operator which manages the ITS network (whereby an MNO would be able to reuse ITS infrastructure for 5G) should be beneficial, as it could improve an MNO’s incremental NPV from road coverage by between 15% and 20%.

It should be noted that, in practice, other bands (e.g. 700MHz) could be used in combination with 3.5GHz, which should improve the business case for coverage – although we assume the use of higher frequency bands (with greater bandwidth available) is needed to deliver full 5G capability. As evidence of the capabilities envisaged for 5G networks, the Commission’s recent report on socio-economic data for the strategic planning of 5G introduction in Europe suggests three key capabilities of 50Mbit/s speed, scalable solutions, and ultra-tactile internet. Irrespective of the network performance requirements for ultra-tactile internet, the provision of 50Mbit/s speeds alone will not be achieved in bands below 1GHz[39] based on the bandwidth available. Hence our 5G MBB business modelling has focussed on initial deployment in the 3.5GHz band (although even that this band in isolation will not deliver the key capabilities indicated in the Commission’s report).

Based on our modelling, the business case for an average MNO to deploy 5G MBB coverage along roads using the 3.5GHz band is almost always negative, if we assume that revenue is split among three or four competing operators. This is the case whatever assumptions are made regarding levels

39 For example, a typical assignment of 2×10MHz per operator in the 700MHz band (e.g. with the available 700MHz spectrum shared among three or four operators) might achieve around 10Mbit/s per network.

of coverage and take-up, under a scenario which reflects current mobile market structure (i.e. multiple competing infrastructures providing services along roads). This suggests that, under the current regulatory model of competing infrastructure, widespread 5G coverage along roads will not materialise within the necessary timescales to stimulate early take-up of these services in Europe, as the cost to operators is too high. However, in a situation where multiple MNOs collaborate to deploy 5G along roads using a single shared infrastructure (i.e. the operator pays 25% or 33% of network costs to capture 25% or 33% of market share, compared to 100% of network costs to capture 25% or 33% of market share in the base case) the results improve. We can therefore conclude that the business case for a shared infrastructure in each country to cover roads with 5G is the most likely one. This is likely to be highly beneficial for achieving widespread benefits from 5G roll-out across Europe, since a shared infrastructure model, reducing the investment costs for individual operators, could enable coverage to be rolled out sooner and hence for services to be more quickly available.

It should be noted that in our analysis we have assumed a small uplift in mobile ARPU is implemented in the business model for providing a tailored service to the automotive sector, in order to capture the additional usage/revenue that MNOs will obtain from improving coverage along main transport routes. As noted previously, it is far from certain that European consumers will be willing to pay a premium for 5G services, noting current European ARPU trends. However, consumers might be willing to pay more to receive 5G automotive services. Keeping in mind that network competition is expected to lead to service and quality improvements and also deliver increased innovation, we note that more optimistic assumptions on ARPU would improve the profitability of the business cases presented (i.e. if subscribers are willing to pay a higher premium to receive 5G automotive services).

► *Stimulating 5G take-up and penetration will promote more rapid and extensive deployments of 5G networks*

It seems clear that further policy action might be needed to incentivise 5G roll-out if the aim (as indicated in the Commission’s 5G Action Plan) is to bring more available, reliable, seamless and secure connectivity across both consumer and industrial uses of MBB. Specifically, the broad range of use cases being envisaged for 5G includes IoT services with widely differing network requirements (e.g. in terms of guaranteed levels of coverage, reliability and latency) to those of MBB. Current 4G roll-out targets (such as the roll-out obligations included in 4G spectrum licences by NRAs) are typically focused on using the available spectrum to deliver specified services to a specific proportion of population. These targets by nature encourage deployment to be prioritised towards the most populated areas of countries. Hence, further policy action might be needed to target different forms of coverage, such as along roads, or to specific geographic locations. Further action to address the demand side of the mobile network roll-out (e.g. promoting measures aimed at stimulating take-up and use of services either by consumers or by specific vertical sectors) might also be relevant. This is because of the uncertainty existing in the business model to extend 5G services to meet the needs of specific vertical sectors, which demand-side goals would help to address. Finally, there might be a need for base stations to be installed on publicly-owned infrastructures in order to fulfil specific coverage targets, and hence collaboration between operators and relevant local authorities and public bodies should be encouraged.

Figure 9.1 below summarises possible targets to encourage investment in 5G networks and to accelerate the take-up of 5G. Further study on the implementation of such goals and targets is recommended.

Figure 9.1: Suggested 5G targets [Source: Analysys Mason, 2016]

5G vertical	Category of target (supply/demand)	Policy goal (examples)
MBB	Supply	EUR3 billion annual 5G investment across the EU
MBB	Supply	Coverage of the EU's business districts by 2025
MBB	Supply	All urban zones in the EU to have 5G connectivity by 2025
MBB	Supply	Sustained 100Mbit/s in when on the move for 95% of covered population
MBB	Demand	50% of the EU population to be using 5G by 2025
MBB	Demand	50% of MBB connections to be 5G by 2025
Healthcare	Supply	5G MBB coverage (from at least one mobile network) to include specific geographical locations where hospital buildings are located within urban centres
Healthcare	Supply	All hospitals and public buildings to have 100% 5G indoor coverage within five to ten years respectively (in line with population coverage)
Healthcare	Supply	All ambulances and other emergency vehicles (e.g. police cars/fire engines) to have a 5G base station embedded for ad-hoc 5G coverage during interventions within the next five to ten years
Healthcare	Demand	All ambulance dispatch services to use 5G technology within five to ten years (in line with population coverage)
Healthcare	Demand	Possibility for 5G phone users to undertake healthcare-related financial transactions (paying doctors, ordering medicines, etc.) within five years
Healthcare	Demand	Availability of health applications (e.g. drug reminders, activity trackers, emergency calls) for 5G phone users within five years, sponsored by governments
Healthcare	Demand	Year-on-year reduction in hospital nights as a result of 5G-driven e-health
Healthcare	Demand	Specified medical devices (e.g. pacemakers, diabetes trackers, medical alarms) to have 5G connectivity embedded within five to ten years
Automotive	Supply	V2I and 5G coverage targets along key roads
Automotive	Supply	In areas where 5G V2N is available but not V2I, V2N should support services offered by V2I
Automotive	Supply	Every road that is built/upgraded must include pre-installation for 5G network (fibre and power along the road, and cabinets at appropriate locations)
Automotive	Demand	70% of vehicles placed on the EU market in 2025 to be 5G equipped (100% by 2030)
Automotive	Demand	All smart traffic/ parking/toll systems offered in European cities to be delivered over 5G infrastructure by 2030

5G vertical	Category of target (supply/demand)	Policy goal (examples)
Automotive	Demand	Insurance costs for 5G-equipped cars to be reduced by 5–10% under appropriate insurance schemes.
ITS	Supply	Monitor/certify performance of artificial intelligence (AI) engines used in safety/security services for connected cars (i.e. autonomous driving)
ITS	Supply	Every road that is built/renovated must include pre-installation for ITS equipment (fibre and power along the road, cabinet and antenna at appropriate locations)
ITS	Demand	Car manufacturers to include ITS equipment in new cars (50% in 2020 and 100% in 2025) (similar target to that for 5G above)
ITS	Demand	1–5% reduction in road casualties/injury thanks to V2X
ITS	Demand	Lanes/parking spaces reserved for cars equipped with V2X
ITS	Demand	Differentiated speed limits for cars equipped with V2X
ITS	Demand	Public system for car platooning creation/platooning slot reservation
ITS	Demand	Reduction in maximum driving time for self-drive truck drivers due to time spent in platooning
Smart city	Demand	Monitoring of specified infrastructure services in European cities (e.g. traffic lights, bus stops, bus lanes, dustbins, connected signs, etc. to use 5G connectivity
Smart city	Demand	All new homes within designated smart cities to be intelligent buildings with 5G connectivity (e.g. small cells)
Smart city	Supply	All government buildings to deploy 5G coverage
Smart city	Supply	5G connectivity to be provided to customers on all forms of public transport

Annex A Glossary

2G	2nd generation of mobile technologies
3D	3-dimension (TV context)
3G	3rd generation of mobile technologies
3GPP	3rd Generation Partnership Project (3GPP)
4G	4th generation of mobile technologies
5G	5th generation of mobile technologies
5G-NR	5G new radio technology
AI	Artificial intelligence
API	Application programming interface
ARPC	Average revenue per connection
ARPU	Average revenue per user
AV	Audiovisual
BT	British Telecom
CARE	Community road accident database
CDMA	Come-division multiple-access
DA	Digital Agenda (European Commission)
DAE	Digital Agenda for Europe
DSM	Digital Single Market
DSRC	dedicated short-range communications
DTT	digital terrestrial television
DVB	digital video broadcasting
EBITDA	earnings before interest, taxes, depreciation and amortisation
EC	European Commission
ECC	European Electronics Committee
EPFL	Electronic Communications Committee
ETP	Refers to ETP Networld 2020 – European Technology Platform for Communications Networks and Services
EU	European Union
EUR	Euro currency
FDD	Frequency division duplication
FIFA	Fédération International de Football Association
FTA	Free-to-air

GDP	Gross domestic product
HSPA	High-speed packet access
HSPA+	Evolved high-speed packet access
IEEE	Institute of Electrical and Electronics Engineers
IMT	International mobile telecommunications
IoT	Internet of things
IP	Internet protocol
IPTV	Internet protocol television
ITS	Intelligent transport systems
ITU	International Telecommunication Union
LAA	Licence-assisted access
LSA	Licensed shared access
LTE	Long-term evolution (4G mobile technology standard)
M2M	Machine-to-machine
MBB	Mobile broadband
MBMS	Multimedia broadcast multicast service
MNO	Mobile network operator
MUX	Multiplex
NB-IoT	Narrowband-IoT
NPV	Net present value
NRA	National regulatory authority
OTT	Over the top (in broadcasting context)
PC	Personal computer
PERS	Personal emergency response systems
(5G) PPP	(5G) public–private partnership
PSB	Public service broadcasters
QAM	Quadrature amplitude modulation
RAN	Radio access network
ROI	Return on investment
RPM	Remote patient monitoring
RSPG	Radio Spectrum Policy Group
RSPP	Radio Spectrum Policy Programme
SK	South Korea Telekom
SVOD	Subscription video-on-demand
TDD	Time division duplex

TDF	TéléDiffusion de France (French company)
TIM	Telecom Italia Mobile
TV	Television
UHD	Ultra-high definition
UHDTV	Ultra-high definition television
UHF	Ultra-high frequency
UK	United Kingdom
USA	United States of America
V2I	Vehicle to infrastructure
V2N	Vehicle to network
V2V	Vehicle to vehicle
V2X	Vehicle to everything
VHF	Very high frequency (radio waves)
VOD	Video on demand
VR	Virtual reality
WAVE	Wireless access in vehicular environments
WRC	World Radiocommunication Conference