Future mobile connectivity in Ireland

Final report

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Contents

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Figures and tables

Executive summary

Introduction and the Irish context

Ireland is characterised by high levels of smartphone and 4G penetration and rapidly rising consumption of mobile data, which has risen almost seven-fold since 2013 and is forecast to grow at an average of 32% per year up to 2022.[1]

While similar trends can be observed in other European countries, Ireland's distinctive characteristics (including population distribution) present significant challenges to meeting future mobile connectivity needs.

Specifically, the costs of achieving widespread mobile connectivity are particularly high in Ireland, owing to its highly distributed and rural populations. For example, Ireland's population density of 69.3 people per km^2 is considerably lower than the EU28 average of 117.5 people per km.[2] In addition, information from the Census of 2016 shows that:[3]

- Ireland's low population density of 70 people per km^2 falls to 27 people per km^2 in the rural areas[4]
- 37% of the population lives in rural areas;
- 3% of the population lives in 28% of the total land area;
- 70% of the population lives in 3% of the total land area; and
- 76% of the total landmass is forestry or farmland.

Within this context, and cognisant of the Irish Government's National Broadband Plan (NBP) which aims to bring high speed broadband to c540,000 (predominantly rural) premises in Ireland who would not obtain such connectivity absent a State intervention of public funds, ComReg commissioned Oxera, with Real Wireless as sub-contractor, to conduct a study on the future of mobile connectivity in Ireland. The objective was to provide insight and advice on three key areas:

1. the new or enhanced mobile services that are likely to emerge in Ireland over the foreseeable future, extending to at least 2025;
2. the likely costs associated with different deployment scenarios for future mobile connectivity services in Ireland;
3. the approaches that could be employed to incentivise the necessary investment for those deployment scenarios.

This study will inform, among other things, ComReg's award proposals for the future release of spectrum, which could include the release of spectrum from

[1] ComReg (2018), 'Mobile Data Traffic Forecast in Ireland (2018–2022)', 27 April.
[2] Eurostat, 'Population density', http://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=tps00003, accessed 23 July 2018.
[3] Census 2016 information is available from the Central Statistics Office, www.cso.ie, accessed 23 July 2018.
[4] Note, Ireland's population density based on Census 2016 information differs slightly to that based on Eurostat information. This may represent the use of given of different methodologies.

one or more of the 700MHz, 1.4GHz, 2.1GHz, 2.3GHz, and 2.6GHz bands.[5] These are referred to as the **Candidate Bands** in this report.

The remainder of this executive summary sets out the key observations gained from the three areas of work outlined above.

Mobile connectivity services likely to emerge in Ireland

Based on our assessment of the new or enhanced mobile connectivity services ('use cases') likely to emerge in Ireland for the foreseeable future, we find that:[6]

- **mobile broadband (MBB) will continue to be a key service** and the primary beneficiary of extending mobile capacity and coverage. In our view – and supported by operator statements - mobile network operators (MNOs) in Ireland will deploy infrastructure initially for MBB, with the intention to subsequently layer additional services onto that network in order to increase revenue;
- the Internet of Things (IoT) would not justify additional network build-out in its own right but, when combined with MBB, IoT improves the overall business case by increasing potential service revenue, differentiation from competitors, and customer loyalty;
- the two IoT use cases that have been shortlisted for modelling—**connected vehicle (CV)** (i.e. safety and driver assistance) and **Industrial Internet of Things (IIoT)**—can support a range of sectors on a common broad-coverage network, including manufacturing, logistics, agriculture, energy, etc.

These three use cases are not necessarily the only relevant use cases, but they have been selected to provide useful outputs from the modelling exercise based on their combined economic attractiveness and coverage deployment characteristics.

Specifically, we note that the focus of this report is on the MBB as the core use case, since this is what will likely drive key network investment decisions.

The mobile network cost model and simulation scenarios

To estimate the likely costs associated with different deployment scenarios for future mobile connectivity services, we developed a mobile network cost model for a synthetic mobile network that represents an 'average' mobile network in Ireland.[7] The synthetic network is based on Irish MNO data from 2017, which is the starting year of the model. For calibration purposes, the estimated coverage of the model in 2017 is evaluated against existing coverage estimates for Irish MNOs, to ensure that the model is well-aligned to reality.

The model emulates the network expansion decisions of a MNO in increasing the coverage of the targeted service by simulating both the deployment of new sites and the upgrading of existing sites using additional spectrum. This model

[5] ComReg (2018), 'Proposed Multi Band Spectrum Award: Preliminary consultation on which spectrum bands to award', Document 18/60, 29 June.
[6] Our findings are based on Ireland-specific extracts from existing research; interviews with Irish MNOs and stakeholders; secondary research; qualitative analysis of the mobile market; and our forecast model for MNO deployments.
[7] The synthetic MNO is based on the licensed site numbers, site locations, and licensed frequency bands of Vodafone and Meteor. The licensed site information from the Three network was not considered as it is currently going through a network consolidation, and its licensed site information is likely to change given this consolidation.

captures the trade-offs associated with different options, including by optimising the build-out based on costs and coverage.

Indoor population coverage was not modelled in this study since - among other things - the conditions for receiving a mobile signal indoors can vary significantly between buildings and even between rooms within a single building, thus making it impractical to estimate a loss that would accurately reflect indoor reception. This was highlighted in recent research from ComReg that indicated that the losses suffered by radio waves in penetrating modern building materials ranges from 20dB up to 60dB—which is a reduction in signal strength of at least 100 (and up to 1 million) times.[8] Further indoor connectivity to mobile and wireless devices can efficiently be addressed with the use of Wi-Fi and native Wi-Fi calling on a broadband connection, or the use of mobile repeaters which ComReg has recently made licence-exempt.

Seven main simulation scenarios are studied in this report, each relating to MBB (i.e. the core use case). The simulations vary in terms of mobile data throughput/speed (e.g. 3Mbit/s, 30Mbit/s) and whether the target is population coverage, geographic coverage, or in-vehicle coverage on motorways or primary roads.

Each scenario is run for all coverage levels up to 99.95%, which allows us to see how costs vary with coverage.

In addition to the seven main scenarios, we also considered a number of other scenarios. These relate to specific variants of the main simulation scenarios above, and to the CV and IIoT services.

The simulation results

Following the building of the mobile network costing model, we are able to observe how, for each scenario, the network costs would likely scale with coverage, for a typical Irish MNO.

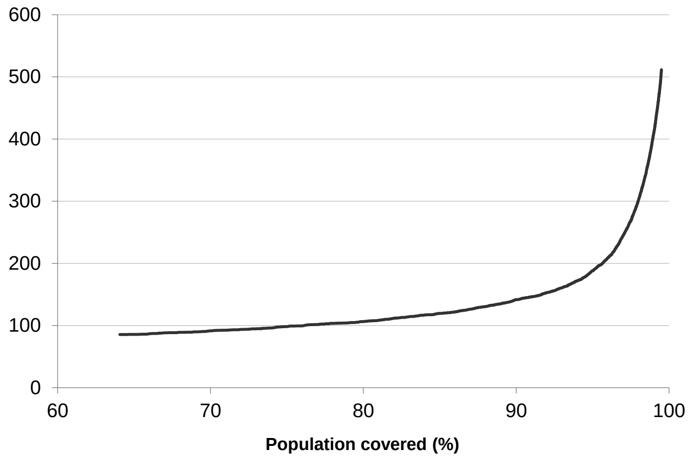
We find that, **while certain levels of coverage can be achieved with low levels of investment, the cost of coverage rises exponentially at high levels of coverage (across all scenarios)**. The figure below shows how the cost of providing 30Mbit/s population coverage rises exponentially after 95% coverage. For example, the estimated costs of increasing coverage from 99.0% to 99.5% is €102m.[9] This is over four times greater than the estimated cost of increasing coverage from 97.0% to 97.5%, which is €24m.

The network roll-out required to achieve 99.5% population coverage with 30Mbit/s would cost €511m and could be completed in 2027 with a rapid, but potentially unachievable, roll-out speed of 8.04% CAGR after mid-2020.[10]

It is important to note that the 30Mbit/s MBB service modelled in these studies is a mobile service and is not the same level of service outlined in the NBP service requirements which are notably higher.

[8] ComReg Document 18/73, “The Effect of Building Materials on Indoor Mobile Performance”, published 2 August 2018.
[9] On the basis of Ireland’s population being around 4.8m currently, this would equate to a cost of coverage per person of €4,250.
[10] The standard network roll-out used in this study is 2.5% CAGR and corresponds to a new site every week or an upgrade every two days, whereas a 8.04% CAGR corresponds to a new site every two days or three upgrades per day.

The cost of targeting 30Mbit/s population coverage, starting in mid-2020

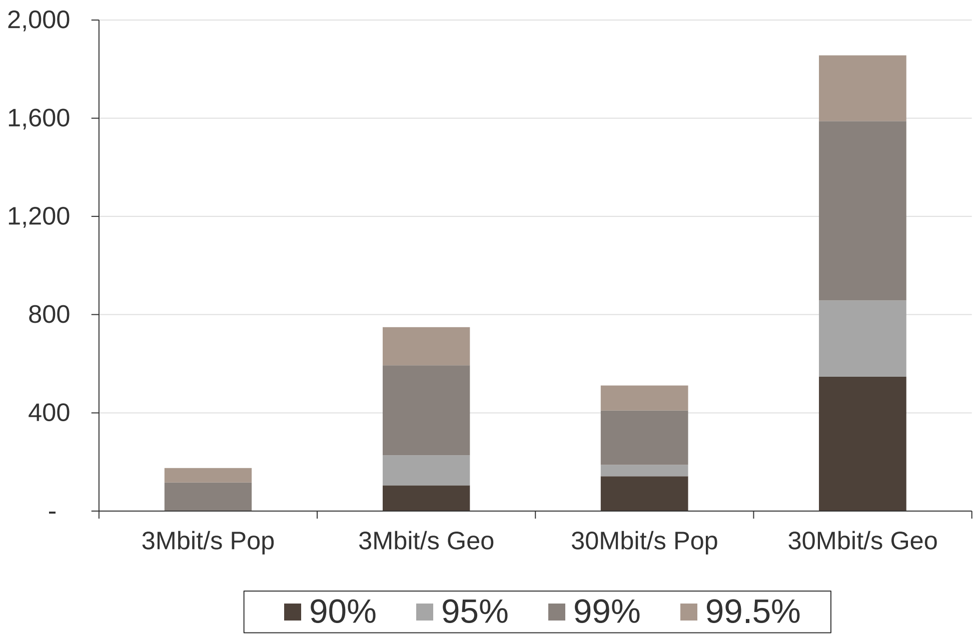


Source: Oxera/Real Wireless.

Furthermore, owing to Ireland's population characteristics, **mobile connectivity ambitions that target geographic coverage are likely to be much more costly than targeting population coverage**. For example, the network roll-out required to achieve 99.5% geographic coverage with 30Mbit/s would cost over €1,860m and would require a likely unachievable network roll-out speed of 19.96% CAGR after mid-2020 in order to achieve 99.5% coverage within 10 years.

The figure below shows that achieving 99% geographic coverage is around 3.8–5.1 times more costly than targeting population coverage (depending on whether one is targeting 3Mbit/s or 30Mbit/s speeds).[11]

Cost of achieving population or geographic coverage (€m, 2017 monies)



[11] 99.0% 3Mbit/s geographic coverage is 5.1 times more expensive than 99.0% 3Mbit/s population coverage. 99.0% 30Mbit/s geographic coverage is 3.8 times more expensive than 99.0% 30Mbit/s population coverage.

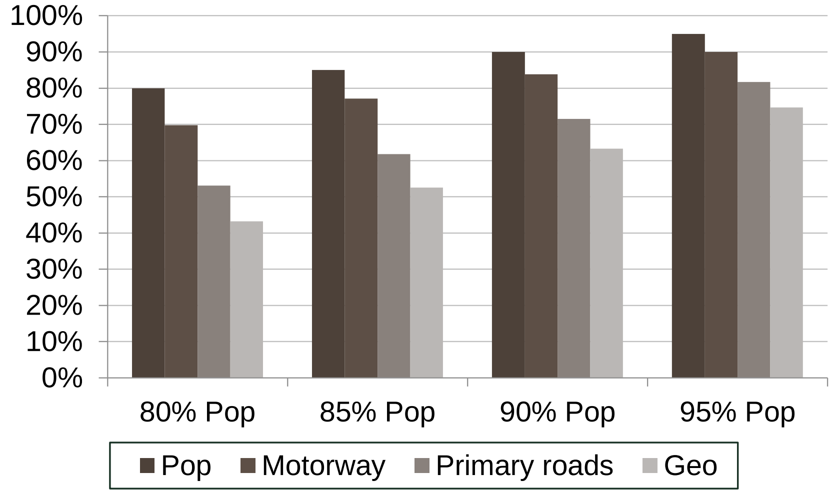
Note: With network roll-out speed to achieve 99.5% within 10 years (i.e. to complete the roll-out in 2027). High network roll-out speeds may not be feasible.

Source: Oxera/Real Wireless.

In addition to the higher cost, achieving high levels of geographic coverage takes longer than for the same level of population coverage. The base case assumption in the model is that the hypothetical MNO builds new sites at a 2.5% compound annual growth rate (CAGR) (which we consider feasible for an MNO to achieve). At this roll-out speed, while 99.5% population coverage for 30Mbit/s would only be achieved in the year 2043, in contrast 99.5% geographic coverage for 30Mbit/s would be achieved much later after 2070. While faster roll-out speeds have been modelled, they are associated with greater costs and less feasibility.

Finally, **targeting population coverage leads to incidental coverage of geography and roads**. For example, if an MNO rolls out a network to achieve 90% population coverage, it will (simply by virtue of where people live) incidentally achieve geographic coverage of around 60%. If the population coverage is increased to 95%, the incidental geographic coverage increases to over 70%. This is shown in the figure below.

Incidental 30Mbit/s coverage from 30Mbit/s population coverage



Source: Oxera/Real Wireless.

Further to the above, we set out below a number of other interesting findings from the mobile network costing analysis:

- higher speeds have a very material effect on costs, for example 99.5% population coverage would cost €181m or €511m depending on if the speed was 3Mbit/s or 30Mbit/s, respectively. 50Mbit/s speeds would be more costly again;
- the cost curve for in-vehicle road coverage is similar to population or geographic coverage in that it increases exponentially at high levels of coverage. Road coverage is less costly to achieve than population coverage, although covering primary roads in addition to motorways adds considerable cost. For example, 99.5% coverage of motorways with 30Mbit/s would cost €160m, while 99.5% coverage of motorways *and* primary roads with 30Mbit/s would cost €283m;

- a new entrant MNO, with less spectrum and no existing network, would face significantly greater network costs and a longer roll-out. For example, 98% population coverage with 30Mbit/s would cost €717m;
- site sharing is one way in which MNOs can reduce the network costs, although the magnitude cost saving depends on how many sites can be shared;
- expanding the mobile network to provide IIoT services would be costly, because it would require coverage in different areas to where the Irish population resides.

Observations on what the market would deliver commercially

Having undertaken an assessment of the costs of achieving different levels of mobile connectivity, and considered historic levels of investment, we then consider what levels of mobile connectivity Irish MNOs are likely to achieve through commercial incentives alone (i.e. in the absence of any governmental or regulatory intervention to promote investment in mobile connectivity).

We note that this study has not modelled the commercial incentives to rolling out coverage, however, by comparing the costs of different levels of coverage with some assumptions about how much Irish operators may be likely to invest in expanding network coverage over the coming years, we can produce some high-level views on possible coverage that may be delivered commercially. On the basis of this analysis, we find the following.

- It is **likely** that an Irish MNO will achieve (without intervention) 85–90% MBB population coverage[12] with 30Mbit/s. It is estimated that this would be achieved by 2024.[13]
- It is **possible** that an Irish MNO will achieve (without intervention) 90–95% MBB population coverage with 30Mbit/s. It is estimated that 95% would be achieved by 2027.[14]
- It is **unlikely** that an Irish MNO will achieve (without intervention) 95 – 99.5% MBB population coverage with 30 Mbit/s.

On this basis, if there is a policy objective to achieve greater (or faster) mobile coverage beyond that delivered by commercial operators, then an interventionist approach (be it regulatory or governmental) may well be required.

Approaches to incentivise investment in future mobile connectivity

If intervention is deemed necessary, then there are a number of possible approaches that could be adopted. Given this, ComReg asked us to:

- identify and consider the effectiveness of regulatory and/or governmental approaches taken (or proposed to be taken) within the EU and in other

[12] Targeting population coverage will also provide incidental coverage in other domains, such as to motorways and primary roads.
[13] This will generate the following incidental 30Mbit/s MBB coverage: 53–63% MBB geographic coverage; 77–84% MBB in-vehicle coverage of motorways; and 62–72% MBB in-vehicle coverage of national primary roads.
[14] This will generate the following incidental 30Mbit/s MBB coverage: 63–75% MBB geographic coverage; 84–90% MBB in-vehicle coverage of motorways; and 72–82% MBB in-vehicle coverage of national primary roads. It is also possible that a commercial operator will target additional motorway coverage of 30Mbit/s (without intervention), achieving 90–95% MBB in-vehicle motorway coverage with 30Mbit/s.

relevant jurisdictions to incentivise mobile connectivity investment beyond the level achieved by commercial incentives alone;

- provide observations on such approaches in relation to Ireland.

In doing so, we explored the effectiveness of coverage obligations, public subsidies, and mobile network sharing as approaches to improving mobile connectivity, noting in particular the experiences in five case study member states (Austria, Denmark, Finland, Sweden, and the UK). We focus on coverage obligations as the primary way in which ComReg can intervene to promote mobile connectivity.[15]

Our analysis indicates that coverage obligations can be an effective way of incentivising investment in mobile connectivity and could be appropriate for Ireland.[16] However, the specific details of coverage obligations need careful consideration and should be designed around each country's characteristics—there is no 'one size fits all'.

Conclusions and recommendations

In the light of our research into Irish use cases, our cost modelling, and our analysis into the effectiveness of approaches to incentivise future connectivity, we make a number of recommendations for ComReg. These policy recommendations will help ComReg in the design of any coverage obligations that it might apply to the Candidate Bands.

First, however, we note that the provision of indoor mobile connectivity can be promoted through complementary solutions other than mobile network roll-out, for example through Wi-Fi calling or mobile repeaters. Second, we note that there are also other regulatory or governmental approaches that could also be taken to address or promote mobile connectivity. For example, public subsidies could be considered, as could a variety of public-private partnerships. Such measures do not need to be decided prior to a spectrum award, as they could be applied at other times.

In short, the application of coverage obligations in the planned forthcoming spectrum award is not the only opportunity or mechanism to address or promote mobile connectivity in Ireland.

Notwithstanding the above, and as a result of the scope of work we have undertaken, we set out below 10 recommendations in relation to the consideration of potential coverage obligations for the Candidate Bands in Ireland.

Recommendations 1–4: understanding the Irish context and associated network costs (of greater mobile connectivity) is critically important to the success of any obligation

[15] For mobile network sharing, we observed that this is a commercial, operator-driven decision that is motivated particularly by the potential to save significant costs, and that the potential benefits need to be balanced against possible competition distortions that could arise. For public subsidies, we observed that there is an increasing number of public subsidy schemes that aim to promote mobile connectivity across the case study countries. These can be large or small schemes, depending on their scope, and can subsidise one (or more) MNOs or, indeed, infrastructure providers.

[16] In particular, we observed that coverage obligations on 800MHz spectrum licences acted effectively to promote roll-out of 4G, especially in rural areas, in the five case study member states—most MNOs achieve their coverage obligations (although they may also have achieved them in the absence of coverage obligations).

1. Coverage obligations should take into account the multi-faceted nature of connectivity and be designed around Ireland's distinct characteristics and priorities.
2. Any proposed mobile licence coverage obligation needs to recognise the costs of achieving that coverage.
3. Observations on what a commercial operator would likely roll out in the absence of coverage obligations provides the basis for considering the incremental cost of a coverage obligation.
4. Commercial operators will likely focus on enhanced mobile broadband (MBB) services as the primary business case.

Recommendations 5–7: targeting population coverage is likely to be the most preferable approach in Ireland

5. Coverage obligations should not be designed with a focus on providing ubiquitous geographic coverage as this would be extremely costly.
6. Coverage obligations should be population-focused primarily where people live, but also consider where people work, transit and commute, and places of interest.
7. The costs for addressing black spots (i.e. the least populated 2–3% of the country) are likely to be substantial, and an MNO is unlikely to choose to cover these areas through commercial incentives alone.

Recommendations 8–10: a coverage obligation of 30Mbit/s to a high population level where people live would appear feasible, and this is where we would recommend ComReg should focus its attention

8. A coverage obligation with data speeds of 30Mbit/s[17] at cell edge to a high population level where people live (of, for example, 90–95% to be achieved by 2027, or somewhat earlier), would appear feasible given cost and network roll-out considerations.
9. The specified timeframe for achieving a coverage obligation needs to balance the speed of roll-out against costs and feasibility.
10. Coverage obligations should promote competition and, in doing so, not discourage new market entry.

[17] 30 Mbit/s represents the target data rate for 2020, as set out in Article 6 of the EU Radio Spectrum Policy Programme (RSPP) Decision.

1 Introduction

The Commission for Communications Regulation (‘ComReg’) commissioned Oxera, with Real Wireless as subcontractor, to investigate the future of mobile connectivity in Ireland. The key objectives were to provide advice on:

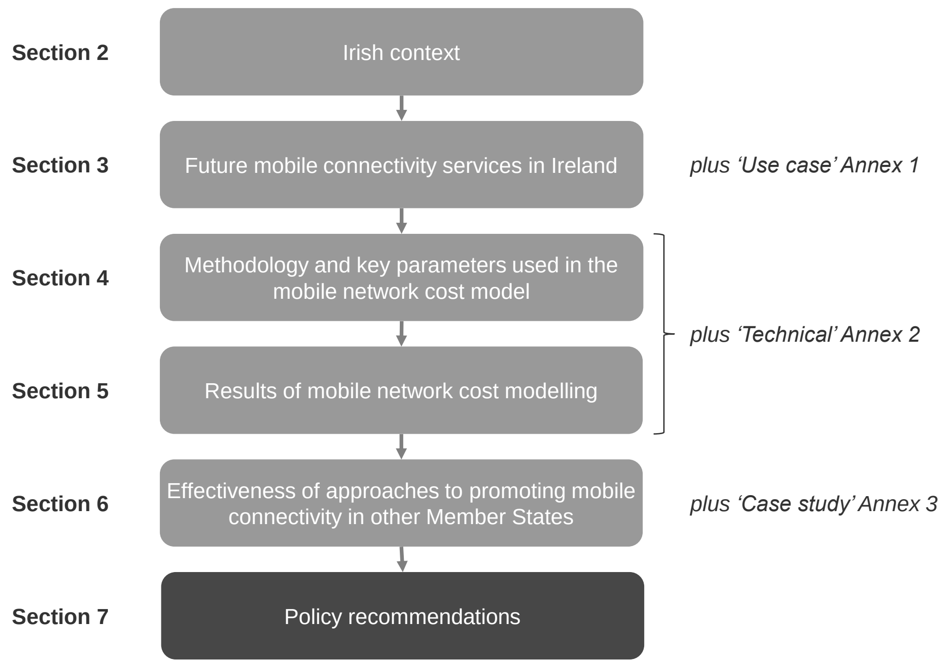
- the new or enhanced mobile services that are likely to emerge in Ireland over the foreseeable future, extending to at least 2025;
- the likely costs associated with different deployment scenarios for future mobile connectivity services in Ireland; and
- the approaches to incentivise such investment.

This advice is expected to inform ComReg’s award proposals for the future release of spectrum, which could include the release of spectrum from one or more of the 700MHz, 1.4GHz, 2.1GHz, 2.3GHz, and 2.6GHz bands.[18] In this report, we refer to these as the **Candidate Bands**.

Our approach in this study combines industry insight, network cost modelling, and international case studies and their relation to future mobile connectivity in Ireland.

The structure of this report is shown in Figure 1.1.

Figure 1.1 Report structure



Four annexes accompany the main report, intended to both supplement and further inform the latter. These annexes can be found on the ComReg website and consist of:

- Annex 1: Identification of the modelled use cases;
- Annex 2: Technical information and assumptions;

[18] ComReg (2018), ‘Proposed Multi Band Spectrum Award: Preliminary consultation on which spectrum bands to award’, Document 18/60, 29 June.

- Annex 3: Additional simulation results; and
- Annex 4: Evidence on the effectiveness of approaches to promoting mobile connectivity in other EU member states.

2 The Irish context

Ireland's mobile market has much in common with those in other European countries, but it also has some distinctive characteristics that shape the priorities for mobile coverage and capacity. Alongside other relevant considerations, these distinctive characteristics present significant challenges to the extension and provision of mobile data services (e.g. 30Mbit/s) to the entire population of Ireland. This section provides an overview of the main considerations in this regard.

2.1 Ireland's mobile market and the results of the consumer experience survey

Mobile communication services play an important role in Irish society and the Irish economy. ComReg's Mobile Consumer Experience Survey (Summer 2017) confirmed that consumers are using their mobile phones in more ways than ever before, and that consumers' expectations of their mobile phones have increased.[19] The survey's other key findings included the following.

- While voice and text are still the most popular services, three-quarters of people also use data. The most common online activities are browsing the Internet, using social media, streaming music, and using TV applications.
- Although most consumers are satisfied with their mobile phone service, a range of issues were identified, especially by those living in rural areas. The study found that a higher percentage of those living in rural areas experience more service issues (e.g. poor reception, inability to make calls, dropped calls, etc.) than those in more urbanised parts of the country.
- Mobile phone services can be affected by a range of issues, including the handset itself, in-building penetration[20] and the signal coverage of a particular mobile network operator.[21]

Ireland's mobile services are provided by three mobile network operators (MNOs) and a number of mobile virtual network operators (MVNOs). As of Quarter 2 2018, there were 6,120,535 mobile subscriptions (including dedicated MBB and machine-to-machine ('M2M') subscriptions) across a population of approximately 4.73 million.[22] The three MNOs are Vodafone, Three,[23] and Eir, which have market shares by subscribers of 38.8%, 35%, and 17.1% respectively. MVNOs account for 9.1% of subscribers.

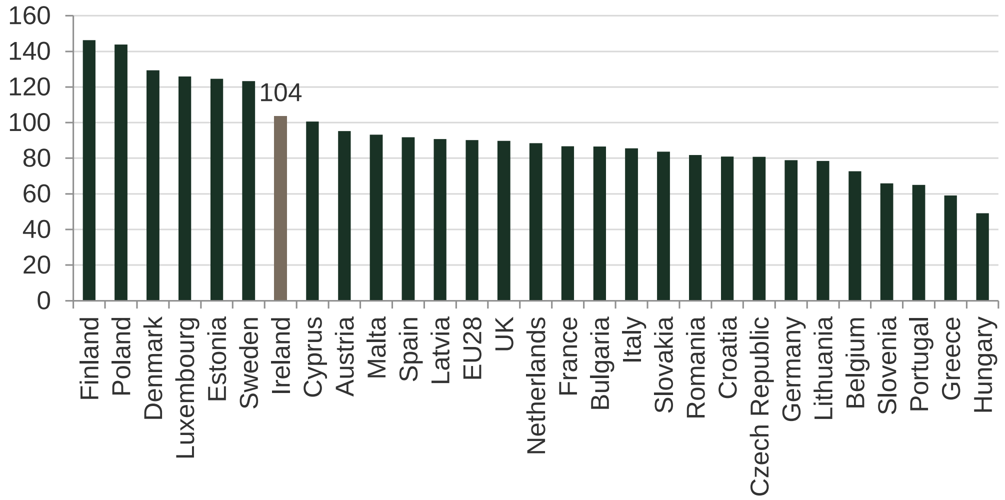
Ireland is characterised by high levels of smartphone and 4G penetration and rapidly rising consumption of mobile data, which has risen almost seven-fold since 2013 and is forecasted to grow at an average rate of 32% per year up to 2022.[24] A European Commission study on broadband coverage in Europe (June 2016) found that as of mid-2016, 96.7% of the homes in Ireland had LTE coverage compared to the EU28 average of 96.0%. Furthermore, 91.2% of

[19] ComReg (2017), 'ComReg publishes results of Irish mobile phone user experiences and perceptions national survey', 6 December; ComReg (2017), 'Mobile Consumer Experience Survey', 6 December.
[20] ComReg Document 18/73, "The Effect of Building Materials on Indoor Mobile Performance", published 2 August 2018.
[21] For more information on the performance of mobile handsets, see ComReg (2018), 'Mobile Handset Performance (Voice)', 6 February.
[22] ComReg (2018), 'Irish Communications Market: Quarterly Key Data Report: Data as of Q2 2018', Document 18/79, 13 September.
[23] Hutchison 3G UK Holdings Limited ('Three') acquired Telefonica Ireland Limited ('O2') as per the 2014 EC Merger Regulation Procedure, Case M.6692.
[24] ComReg (2018), 'Information Notice- Mobile Data Traffic Forecast in Ireland' ', 27 April.

rural households in Ireland had LTE coverage compared with the EU28 average of 79.7%, representing an increase of 18.2% in rural areas since 2015.[25]

In June 2017 Ireland had the seventh-highest mobile broadband penetration in the EU (see Figure 2.1).

Figure 2.1 Mobile broadband subscriptions per 100 people (June 2017)



Source: European Commission (2017), 'Digital Agenda Scoreboard key indicators', available at: https://digital-agenda-data.eu/datasets/digital_agenda_scoreboard_key_indicators/visualizations.

Other usage trends in the Irish mobile market include the following: [26]

- SMS volumes are declining substantially—down 9.7% year-on-year in Q2 2018;
- mobile voice volumes have been relatively static over the past 3 years;
- M2M subscriptions of 930,806 in Q2 2018 represent an increase of 24.6% on the same period last year and now accounts for 15.2% of total mobile subscriptions. However, most M2M services consume very little data (0.1% of all mobile data);
- in Q2 2018, smartphones accounted for approximately 93.8% of mobile subscriptions (excluding dedicated MBB and M2M);
- average monthly data usage per smartphone is increasing (5.8GB in Q2 2018)

2.2 Demographic characteristics of Ireland

According to a variety of measures, Ireland has one of the most widely distributed and rural populations in Europe. For example, Ireland's population

[25] European Commission (2017), 'Study on broadband coverage in Europe 2016', 21 September.
[26] ComReg (2018), 'Quarterly Key Data Report: Data as of Q2 2018', 14 December.

density of 69.3 people per km^2 is considerably lower than the EU28 average of 117.5 people per km^2 (Eurostat, 2016). [27, 28]

According to Eurostat, 72% of the Irish population live in NUTS 3 areas that are defined as predominantly rural areas. By contrast, across the EU as a whole only 22% of the population live in areas that are defined as rural regions.[29]

The Census of 2016 shows that:[30]

- Ireland's low population density of 70 people per km^2 falls to 27 people per km^2 in the rural areas[31];
- 37% of the population lives in rural areas;
- 3% of the population lives in 28% of the total land area (this is based on an analysis of the small areas);
- 70% of the population lives in 3% of the total land area (this is based on an analysis of the small areas); and
- 76% of the total landmass is forestry or farmland.

The above illustrates the challenges Ireland's demographic characteristics pose to the deployment of infrastructure for both fixed and mobile networks. Given such demographic features, there are certain parts of the country that are difficult to reach, and, if left to commercial incentives alone, the most sparsely populated regions in Ireland may not benefit from the availability of future mobile connectivity services.

2.3 The Irish government's actions to improve fixed and mobile coverage

Given Ireland's demographic characteristics, extending coverage of voice and data services to the most sparsely populated regions is commercially challenging. The Irish government is trying to address this challenge through the National Broadband Plan (NBP) and the Mobile Phone and Broadband Taskforce (MPBT).[32]

[27] Eurostat, 'Population density', http://ec.europa.eu/eurostat/tgm/table.do?tab=table&plugin=1&language=en&pcode=tps00003, accessed 23 July.

[28] For other measures see, for example: European Commission (2017), 'Broadband Coverage in Europe 2016'; Eurostat, 'Population structure by urban–rural typology, 1 January 2012', http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Population_structure,_by_urban%E2%80%93rural_typology,_1_January_2012_(%25_of_total_population).png#filelinks, accessed 23 July; Eurostat, 'Statistics on rural areas in the EU', http://ec.europa.eu/eurostat/statistics-explained/index.php/Statistics_on_rural_areas_in_the_EU, accessed 23 July; European Commission (2014), 'Regional Working Paper 2014: A harmonised definition of cities and rural areas: the new degree of urbanisation', January.

[29] There are 8 NUTS 3 regions in Ireland. Each NUTS-3 region is classified as predominantly rural, intermediate or predominantly urban based on certain thresholds of population size and density. These thresholds are applied to combinations of grid cells of 1 km square to get a proportion of rural areas within a given NUTS-3 unit. Units where less than 20% of the population is urban are predominantly rural, those with 20%-50% rural populations are intermediate areas and the rest are predominantly urban

[30] Census 2011 and 2016 are available from the Central Statistics Office, www.cso.ie, accessed 23 July.

[31] Note, Ireland's population density based on Census 2016 information differs slightly to that based on Eurostat information. This may represent the use of given of different methodologies.

[32] Department of Communications, Energy and Natural Resources (2012), 'Delivering a Connected Society: A National Broadband Plan for Ireland', August. Department of Communications, Climate Action & Environment and Department of Arts, Heritage, Regional, Rural and Gaeltacht Affairs (2016), 'Report of the Mobile Phone and Broadband Taskforce', December.

The NBP is a government initiative relating to fixed broadband services. The aim of the NBP is to extend high-speed broadband access (using fibre and other technologies) to the c540,000 premises in the NBP State Intervention area, thus providing government support where the market would not deliver this access. It aim is to achieve 100% coverage of premises across Ireland within three to five years of commencement of large-scale roll-out and it will thus address indoor connectivity for these premises. Further it provides the opportunity to efficiently extend this connectivity indoors to wireless and mobile devices by using complementary solutions such as Wi-Fi and native Wi-Fi calling.

The MPBT is a government initiative regarding broadband and mobile services whose aim is to identify immediate solutions to address deficits in mobile service and broadband coverage. 40 recommendations and actions were set out in its 2017 work programme[33], and 34 actions for 2018.[34] These actions focus on addressing specific issues that can have a significant impact on the roll-out of telecommunications infrastructure and are for delivery by departments, agencies, local authorities, ComReg, and industry providers.

Progress against these actions is set out in its implementation review of its 2017 work programme and the quarterly progress reports.[35] From this information we note that concrete progress has been made in areas such as:

- reducing the cost and streamlining planning processes for the deployment of telecommunications infrastructure. For example, legislation on Revised Exempted Developments have been signed into law;[36]

- installing ducting on motorways and primary roads. For example, the Transport Infrastructure Ireland (TII) has now completed the ducting on all original targeted gap sections of the network; and

- greater cooperation, including better information sharing between all stakeholders, to support better outcomes for consumers. For example, the Department of Rural and Community Development (DRCD), the Department of Communications, Climate Action and Environment (DCCAE), all 31 local authorities and MNOs are working together in pilot project on mobile coverage blackspots;

Further a focus group of the MPBT on mobile coverage has identified four broad categories that encapsulate the locations where people are most likely to wish to use their mobile phone.[37] These are:

- Areas where people live;

- Areas where people work;

- Transient and Commuting areas; and

- Areas where things happen.

[33] Ibid.https://www.dccae.gov.ie/documents/Taskforce Report.pdf
[34] https://www.dccae.gov.ie/documents/ImplementationReview2017.pdf
[35] These are available on the DCCAE website at the following link https://www.dccae.gov.ie/en-ie/communications/topics/Broadband/mobile-phone-and-broadband-taskforce/Pages/Mobile-Phone-and-Broadband-Taskforce.aspx
[36] The Planning and Development (Amendment) (No.3) Regulations 2018, 8 February 2018. Available at: http://opac.oireachtas.ie/AWData/Library3/HPLGdoclaid131217c_103054.pdf, accessed 23 July.
[37] https://www.dccae.gov.ie/documents/MPBT%20Report_ENG.pdf

In addition, this focus group has issued a ranked the list of categories of location and set out its view that the services available on a mobile phone at these categories of locations, should be; mobile voice telephone calls, text messaging and basic data activity such as web searches and browsing.

2.4 Spectrum availability in Ireland

One of the key inputs to provision of mobile services is the availability of suitable spectrum. Of the spectrum bands harmonised at EU/CEPT level for wireless broadband, Ireland has so far assigned 750MHz of spectrum for mobile usage, as shown in Table 2.1.

Table 2.1 Spectrum currently assigned for mobile services in Ireland

Frequency band	Amount of spectrum assigned	Current Technology usage in Ireland[1]	Year of first assignment to MNOs	Year of expiry
800MHz	60MHz	4G	2012	2030
900MHz	70MHz	2G/3G	Pre-2000	2030
1.8GHz	150MHz	2G/4G	Pre-2000	2030
2.1GHz	120MHz	3G	2002	2022 and 2027
3.6GHz	350MHz	FWA/4G	2017	2032

Note: FWA, fixed wireless access. FWA is not typically categorised as a mobile technology. [1]With the exception of the 2.1GHz spectrum band, which is for 3G usage, the spectrum assigned in the other spectrum bands is technology-neutral and service-neutral.

Source: Oxera/Real Wireless.

ComReg is currently progressing its plans to release spectrum from one or more of the Candidate Bands under consideration in this study, namely spectrum in the 700MHz, 1.4GHz, 2.1GHz, 2.3GHz, and 2.6GHz bands.

The Candidate Bands are all EU/CEPT harmonised bands for wireless broadband. However, there are some aspects of the availability and usage of these Bands in Ireland that are locally specific and may affect future policy and network deployment.

Of the Candidate Bands, the 700MHz band is likely to be of most interest in Ireland in terms of providing or improving coverage, given that its strong propagation qualities support more cost-effective approaches to the coverage of distributed and rural populations. In that regard, this band is subject to coverage-related obligations set out in the EU 700MHz Decision (see section 2.5). The 700MHz band is expected to be available for assignment by 4 March 2020, once Digital Terrestrial Television (DTT) services have been migrated from this band.[38]

The 2.6GHz band is likely to be a band of high interest in Ireland for providing capacity. This band has been released in most EU countries as part of the early stage 4G auctions and is widely deployed. In some cases, operators are aggregating such rights with spectrum rights in a lower-frequency spectrum band. This provides the operator with an improved balance between coverage (lower bands) and capacity (higher bands), resulting in better quality of service and higher overall spectrum efficiency. Ireland's timing for the release of this band may be propitious, as it would provide access to a strong band for

[38] DCCAE, '700MHz Migration', https://www.dccae.gov.ie/en-ie/communications/topics/spectrum/digital-dividend/Pages/700-MHz-Migration.aspx, accessed 23 July.

capacity with a significant device ecosystem at a time when urban capacity is becoming a significant challenge.

There are three other Candidate Bands considered for modelling purposes in this Study. The 1.4GHz band is currently unassigned in Ireland. The 2.3GHz band is largely unassigned in Ireland (within Asia, this is a band widely used for mobile services and has a strong device ecosystem). The 2.1GHz band is currently assigned and used for 3G in Ireland, but the current licences expire in 2022 and 2027 and the band has a strong device ecosystem.

2.5 The EU's decision on the use of 470–790MHz band

On 17 May 2017, the European Parliament and the Council adopted an EU Decision on the use of the 470–790MHz frequency band in the Union. Among other things, this EU Decision obliges that:[39]

> [...] by 30 June 2020, Member States shall allow the use of the 694–790 MHz frequency band (the '700 MHz band') for terrestrial systems capable of providing wireless broadband electronic communications services [Article 1] […]
>
> […] when Member States authorise the use of or amend existing rights to use the 700 MHz frequency band, they **shall take due account of the need to achieve the target speed and quality objectives** set out in Article 6(1) of Decision No 243/2012/EU[40], including **coverage in predetermined national priority areas where necessary, such as along major terrestrial transport paths**, for the purpose of allowing wireless applications and European leadership in new digital services to contribute effectively to Union economic growth [Article (2(1)), emphasis added] […]
>
> […] in applying Article (2(1)), 'Member States shall assess the need to attach conditions to the rights of use for frequencies within the 700 MHz frequency band and, where appropriate, shall consult relevant stakeholders in that regard.

The above obligations are relevant to Ireland's future release of the 700MHz band and have guided this study particularly when defining the future mobile connectivity deployment scenarios for modelling.

Next, we explore which mobile connectivity services are likely to evolve or emerge in Ireland.

[39] European Commission (2017), 'DECISION (EU) 2017/899 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2017', https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D0899&from=EN

[40] Article 6(1) states that 'Member States shall, in cooperation with the Commission, take all steps necessary to ensure that sufficient spectrum for coverage and capacity purposes is available within the Union, in order to enable the Union to have the fastest broadband speeds in the world, thereby making it possible for wireless applications and European leadership in new services to contribute effectively to economic growth, and to achieving the target for all citizens to have access to **broadband speeds of not less than 30Mbps by 2020**.' [Emphasis added]

3 Future mobile connectivity services in Ireland

3.1 Introduction and key findings

In this section we identify and describe the mobile connectivity services ('use cases') likely to evolve or emerge in Ireland, relevant to the Candidate Bands, over the foreseeable future (at least out to 2025).

Our analysis (see section 3.2) informs a list of possible use cases for the Candidate Bands that could be commercially attractive to Irish MNOs and other service providers, and that could deliver economic benefits to Ireland.

From that list of possible use cases, three are selected for modelling in the subsequent tasks of this project (see section 3.3). These three use cases are not necessarily the only relevant use cases, but they are selected to provide a valuable modelling exercise given their combined economic attractiveness and coverage deployment characteristics.

On the basis of the analysis conducted, we have found the following.

- From a longlist of possible use cases, **MBB will continue to be a core service** and the primary beneficiary of extending mobile capacity and coverage. In our view, operators will deploy infrastructure initially for MBB and then layer additional services onto that network in order to increase revenue.
- For the Internet of Things (IoT) use cases, Irish MNOs believe that these use cases would not justify additional network roll-out in their own right. However, when combined with MBB, these use cases improve the overall business case by increasing potential service revenue, differentiation from competitors, and customer loyalty.

The two IoT use cases shortlisted for modelling are the **connected vehicle (CV)** (i.e. safety and driver assistance) and **Industrial Internet of Things (IIoT)**, which can support a range of sectors on a common broad-coverage network, including manufacturing, logistics, agriculture, energy, etc.

3.2 Methodology

In terms of the analysis, our findings are based on Ireland-specific extracts from existing research; interviews with Irish MNOs and stakeholders; secondary research; qualitative analysis of the mobile market; and our forecast model for operator deployments.[41]

While the approach adopted did not include surveys of end-user demand, comparisons were made, where possible, with demand patterns in other countries (provided similar services have been launched). In this regard, service providers were asked about their assessment of likely demand, based on their market experience.

Data on European or global MNO intentions to deploy new use cases in the Candidate Bands was taken from a global survey of MNOs conducted by Rethink/Real Wireless in the Q4 2016. The response level was 86 Tier 1 and Tier 2 MNOs, 36 of which were based in the EU, and provides a representative

[41] Interviews were conducted in summer 2017 with Airspan Networks, Ericsson, Imagine Communications, Eir, Tesco Mobile, Three Ireland, Vodafone Ireland, and VT Networks.

view of the intentions of MNOs in terms of deploying networks that can support new use cases.[42]

Inputs from Irish MNOs and other service providers were analysed in the context of Real Wireless's knowledge of patterns of adoption by national and international MNOs, which it has tracked in detailed surveys since 2004.

3.3 Identifying the use cases to include in our modelling

Annex 1 provides a longlist of all possible use cases (summarised below) and then details three use cases selected for the modelling of mobile network costs.

3.3.1 Longlist of use cases for the Candidate Bands

As part of this study, detailed discussions were held with MNOs and other stakeholders (including MVNOs and Imagine, a fixed wireless operator), to establish a longlist of potential use cases for the Candidate Bands, and this information was then compared with European and global trends and patterns.

For MNOs across the world, there are two top-level objectives driving future investment.

1. To enhance the cost efficiency and user experience of existing services—such as MBB—by boosting data rates, device capacity, and coverage. This category also includes enhancing existing 2G-based M2M services in situations where they need additional data capability, or where the operator wishes to refarm spectrum from 2G.
2. To enable new services and revenue streams that centre on the IoT and may require far lower latency and/or higher levels of reliability than those that are delivered by LTE.

The MBB and machine-type communications (MTC) use cases were therefore examined in the context of potential to achieve the above top-level objectives in Ireland. Our analysis shows that most European MNOs, including all the Irish operators, will be initially focused on enhancing the business case for existing services (e.g. MBB), with new services beginning to be introduced post-2020/21.

The Irish MNOs that we interviewed stated that their first priority is to extend capacity and coverage for their core business model, MBB services, with LTE-Advanced and, later, 5G. They plan to achieve this by harnessing new capacity bands, such as 2.6GHz. It is clear that the more demanding the levels of latency and reliability, the longer the expected timescale to deploy.

In addition to MBB, MNOs are actively exploring many other use cases, such as those centred on IoT, which may generate additional revenues and improve the business case for LTE and future network build-out in the Candidate Bands, especially in rural and roadside areas. These would typically be layered onto MBB networks in order to diversify the revenue potential. According to interviews conducted for this study with Irish MNOs, the IoT use cases would not justify additional network build-out in their own right.

That view is held by many MNOs in other markets, and it is reflected in some analyst studies. For instance, a Rethink survey of EU operators in 2016 found that only 9% of MNOs believed that a new network build-out could be justified

[42] Rethink Technology Research RAN Forecast Q416: www.rethinkresearch.biz.

entirely by IoT services (except in the case of a software upgrade, such as NB-IoT), though 68% expected to deploy such services within three years of 5G roll-out.[43] In other words, although many operators do see commercial potential in IoT services, this is not enough to drive 5G deployment on its own. Nevertheless, IoT services will be incremental to the MBB case.

It would appear that many of the non-MBB use cases discussed with the Irish MNOs will initially be deployed using 4G networks and spectrum, sometimes using evolutions of LTE—such as Narrowband-IoT (NB-IoT) for low-power wide-area network (LPWAN) services. Then, when 5G is deployed, there will be the ability to enhance these services by adding, for instance, mission-critical or very low latency applications. It is very important to the business case in Ireland to be able to deploy new services without waiting for 5G, but rather as the market dictates.

Table 3.1 sets out the longlist of use cases for the Candidate Bands in Ireland and summarises their key advantages and disadvantages. This is based on the feedback we received from MNOs and other stakeholders, on comparisons with peer countries, and on our knowledge and experience.

[43] Rethink Technology Research RAN Forecast Q416; Rethink Technology Research (2018), 'MNOs choices in 5G: Slash costs or die, 6 February, https://rethinkresearch.biz/report/mnos-choices-in-5g-slash-costs-or-die/, accessed 23 July.

Table 3.1 Longlist of use cases for the Candidate Bands in Ireland

Use case	Pros	Cons
Enhanced MBB (esp. video)	Proven demand	The ARPU-to-cost ratio is worsening
Connected vehicles (In-Vehicle Infotainment, IVI, and safety)	Expected high growth in usage	Poor roadside coverage, sites issue
IIoT	Strong demand, identifiable revenues, identifiable social/economic benefits. May help justify rural coverage	Rural coverage currently poor
Fixed wireless/wireless multiplay	High demand among rural population, help mobile-only players move into multiplay. 3.6GHz good spectrum for this. Can layer other services like smart home	Local competitors already established in market.
Enhanced M2M (e.g. asset tracking)	Some services already established in GSM, lowering risk	Will require better road and sometimes rural coverage
Smart home	Added value to build on fixed or mobile subscribers. Can be marketed where there is coverage—doesn't have to be universal	Competition from other players, e.g. Google, utilities. ARPUs uncertain
Healthcare (health monitoring)	Some apps easy to support (e.g. fitness monitoring). High social impact in rural areas but depends on coverage	Competition from other players, e.g. Apple. More challenging healthcare use cases involve high reliability, potential liability etc. (e.g. critical care monitoring)
Smart city	Additional services to layer on existing infrastructure, relatively few sites needed, way to work with partners	There are few cities and it might not scale to towns

Note: ARPU refers to average revenue per user.

Source: Oxera/Real Wireless analysis based on MNO interviews (2017).

3.3.2 The three use cases selected for modelling

From our longlist of use cases, we identified three as being particularly relevant to Ireland. These use cases and the summary reasons for selecting them are set out in Table 3.2.

Each of the use cases identified in Table 3.2 was examined in detail by the project team and rated (based on stakeholder input, experience of other markets, and our own knowledge and experience) on its potential to:

- enhance the business case for network build-out in one or more Candidate Bands (often including existing spectrum bands such as 800MHz as well);
- drive demand for new services, which would enhance the business case for extending coverage in challenging areas, such as rural communities and roads;
- have importance to the Irish economy;
- address a broad base of demand in the short term and have potential future growth in terms of size and range of services that could be offered.

Table 3.2 The three use cases selected for modelling and summary reasons

Selected Use Case	Summary of reasons
MBB	• core business case for MNOs • significant addressable market with growth potential in rural areas—key justification for any network expansion • rising levels of demand—added value services enabled by MBB, especially video-based, may improve revenue model • drive usage of mid-band spectrum for capacity, as well as 700MHz for rural • social and economic benefits of greater rural broadband connectivity
Connected vehicle—safety and driver assistance	• high interest among all MNOs—significant addressable market with identifiable revenue opportunity • expected high level of uptake (based on other markets) • improve MNO business case for building out roadside coverage • drive usage of sub-1GHz spectrum (NB-IoT now, 700MHz later) • social benefits—improved safety • will provide insights into another longlisted use case (i.e. asset tracking
IIoT	• high interest among all MNOs—significant addressable market with identifiable revenue opportunity • identifiable economic impact for important Irish business sectors, such as manufacturing and agriculture • improve MNO business case for building out extended rural coverage, on which other services requiring very wide coverage could be layered • drive usage of sub-1GHz spectrum for remote and rural locations, such as factories—beginning in NB-IoT networks in existing 800MHz spectrum and will later also use 700MHz spectrum when it becomes available

Source: Oxera/Real Wireless analysis based on MNO interviews (2017).

Next, we describe the methodology behind the mobile network cost model.

4 Methodology and key parameters used in the mobile network cost model

This section sets out the methodology and key assumptions employed in developing the mobile network cost model, which estimates the additional mobile network infrastructure and costs required to increase the coverage of the targeted application service(s) as defined in the simulation scenarios.

In estimating the additional mobile network infrastructure and costs, the mobile network cost model uses the single user throughput (SUTP) at cell edge for the targeted service in a lightly loaded network as the basis for determining the coverage of a macrosite.[44] The model does not take into account the provision of additional infrastructure for increased capacity demands (e.g. from an increased number of users or increased usage), although the addition of new sites and the upgrading of existing sites would also provide additional capacity to the mobile network.

Indoor population coverage was not modelled in this study since - among other things - the conditions for receiving a mobile signal indoors can vary significantly by building and by room-to-room within a building thus making it impractical to estimate a loss that would accurately reflect indoor reception. This was highlighted in recent research from ComReg that indicated that the losses suffered by radio waves in penetrating modern building materials ranges from 20dB up to 60dB—which is a reduction in signal strength of at least 100 (and up to 1 million) times.[45] Further indoor connectivity to mobile and wireless devices can efficiently be addressed with the use of Wi-Fi and native Wi-Fi calling on a broadband connection, or the use of mobile repeaters which ComReg has recently made licence-exempt.

More detailed information on the mechanism, assumptions (including further information regarding coverage considerations), and parameters used in the mobile network cost model are set out in Annex 2.

Section structure

The structure of this section follows the steps of the methodology used to develop the model.

- **Step 1** sets out the assumptions and parameters to develop a synthetic mobile network. The aim of this step is to develop a hypothetical mobile network that represents an 'average' mobile network in Ireland.[46] The synthetic network is based on information from 2017, which is considered as the starting year of the network model.
- **Step 2** estimates the coverage for the synthetic network in 2017.
- **Step 3** sets out the methodology followed to validate the estimated coverage of the synthetic network in 2017 against other coverage estimates, in order to verify that the model is well-calibrated.

[44] SUTP is defined as the downlink bit rate that can be successfully delivered to a single active user per cell at a particular depth and consistency of coverage. This is the downlink bit rate or download speed that a user could experience when not contending with other users for service in that cell, so that the cell delivers the maximum possible data rate to a single user consistent with the signal quality experienced by that user.
[45] ComReg Document 18/73, "The Effect of Building Materials on Indoor Mobile Performance", published 2 August 2018.
[46] The synthetic network is based on the licensed site numbers, site locations, and licensed frequency bands of Vodafone and Meteor. The licensed site information from the Three network was not considered since it is currently going through a network consolidation, and its licensed site information is therefore likely to change.

- **Step 4** defines the assumptions made in relation to the network-expansion module of the model. The model aims to emulate the network expansion of an MNO by simulating the deployment of new sites and upgrading existing sites with additional spectrum to increase the coverage of the targeted service(s) defined in each of the simulation scenarios.
- **Step 5** defines the details of the simulation scenarios for modelling.
- **Step 6** is the running of the simulations and the presentation of the simulation results.

4.1 Step 1: Developing a synthetic mobile network

This section outlines the main assumptions and parameters used to develop the synthetic MNO, which represents an 'average' mobile network in Ireland in 2017. These main parameters are:

- availability of spectrum;
- number of macrosites, site location, and distribution of spectrum band carriers across the network;
- technology deployed per carrier;
- macrosite height per geotype area.

Details on other assumptions and parameters used in developing the synthetic model (e.g. radio frequency parameters in the link budget, etc.) are set out in Annex 2.

4.1.1 Availability of spectrum in 2017

We assume that in 2017, the synthetic MNO holds spectrum rights in four spectrum bands—namely:

- 2 x 10MHz in the 800MHz band;
- 2 x 10MHz in the 900MHz band;
- 2 x 25MHz in the 1.8GHz band;
- 2 x 20MHz in the 2.1GHz band.

4.1.2 Number of macrosites, site location, and distribution of spectrum band carriers in 2017

The number of macrosites, the location of the macrosites, and the distribution of spectrum bands carriers across the synthetic network in 2017 is based on licensing information supplied by ComReg for two of the three MNOs in Ireland.[47]

Table 4.1 sets out the number of macrosites and the distribution of spectrum bands carriers used in the synthetic network model.

[47] As the synthetic model is focused on providing coverage, we assume that it does not contain any microcells. The synthetic network is based on the licensed site numbers, site locations and licensed frequency bands of Vodafone and Meteor. The licensed site information from the Three network was not considered as it is currently going through a network consolidation, and its licensed site information is likely to change.

Table 4.1 Number of macrosites that support each spectrum band (2017)

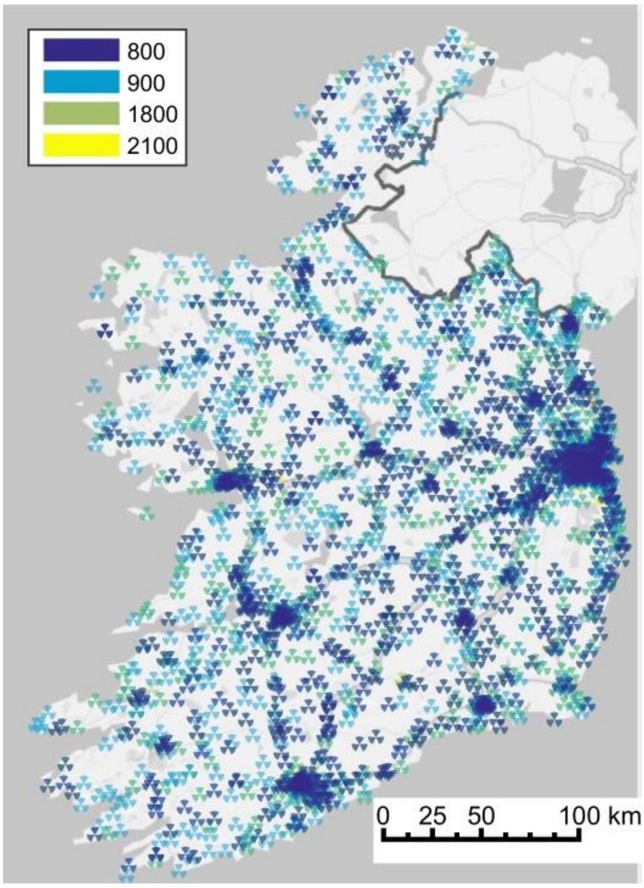
Band	Synthetic network	Vodafone	Meteor
800	870	1,110	693
900	1,890	1,931	1,876
1800	595	797	397
2100	1,500	1,469	1,583

Note: Macrosites can be multiband and co-sited.

Source: ComReg and Oxera/Real Wireless

Figure 4.1 illustrates the location of macrosites in the synthetic network in 2017.

Figure 4.1 Location of macrosites in the synthetic network in 2017



Source: ComReg and Oxera/Real Wireless.

Technology deployed per carrier in 2017

It is assumed that in 2017 there is no Carrier Aggregation (CA) and that for MBB the coverage of the synthetic network is based on a single LTE (3GPP Rel 8) carrier of 2 x 10MHz.[48]

[48] We are aware that some MNOs have already deployed two-band Carrier Aggregation, but the evidence available does not show that all MNOs have deployed Carrier Aggregation. However, the user handsets need to be compatible to exploit the full benefits of the Carrier Aggregation. With technological advances and handset churn, it is realistic to expect that there will be sufficient penetration into the handset population of the three-band Carrier Aggregation feature by 2020. For this reason, we did not consider Carrier Aggregation in our simulations until mid-2020.

4.1.3 Macrosite height per geotype area

Macrosite height is an important parameter in determining the coverage achieved. Given the lack of site height information from the real deployments in the licensed data, and noting that the aim of this study is to model coverage at a network level as opposed to providing precise coverage for each macrosite, we made assumptions about the height of existing and new macrosites. The table below summarises our assumptions for the macrosite heights per geotype area.[49]

Table 4.2 Macrosite heights per geotype area

Geotype area	Height (metres)
Urban	19
Suburban	16
Rural	18

Source: Oxera/Real Wireless.

4.2 Step 2: Estimating the coverage of the synthetic mobile network in 2017

The estimated coverage from the synthetic operator in 2017 is summarised in Table 4.3.

Table 4.3 Estimated coverage of the synthetic network in 2017

Application data rate (Mbit/s) at cell edge	Population	Geographical	Rail in-carriage idealised-track[1]	Motorway in-vehicle	National primary roads in-vehicle	National secondary roads in-vehicle
3	96.7%	82.1%	99.4%	95.2%	89.7%	85.5%
30	62.4%	18.3%	61.7%	47.8%	31.3%	30.1%
50	43.6%	6.3%	30.3%	23.9%	12.3%	14.6%

[1] Signal propagation predictions can only be as accurate as the digital terrain map (DTM) database. For rail predictions, this argument is reinforced if narrow embankments and cuttings exist along the line. For a coverage assessment undertaken for the rail industry, it was considered necessary to work with 5m resolution; however, the DTM that Oxera was supplied with was 10x10m resolution—therefore, the cuttings will be missed.

Source: Oxera/Real Wireless.

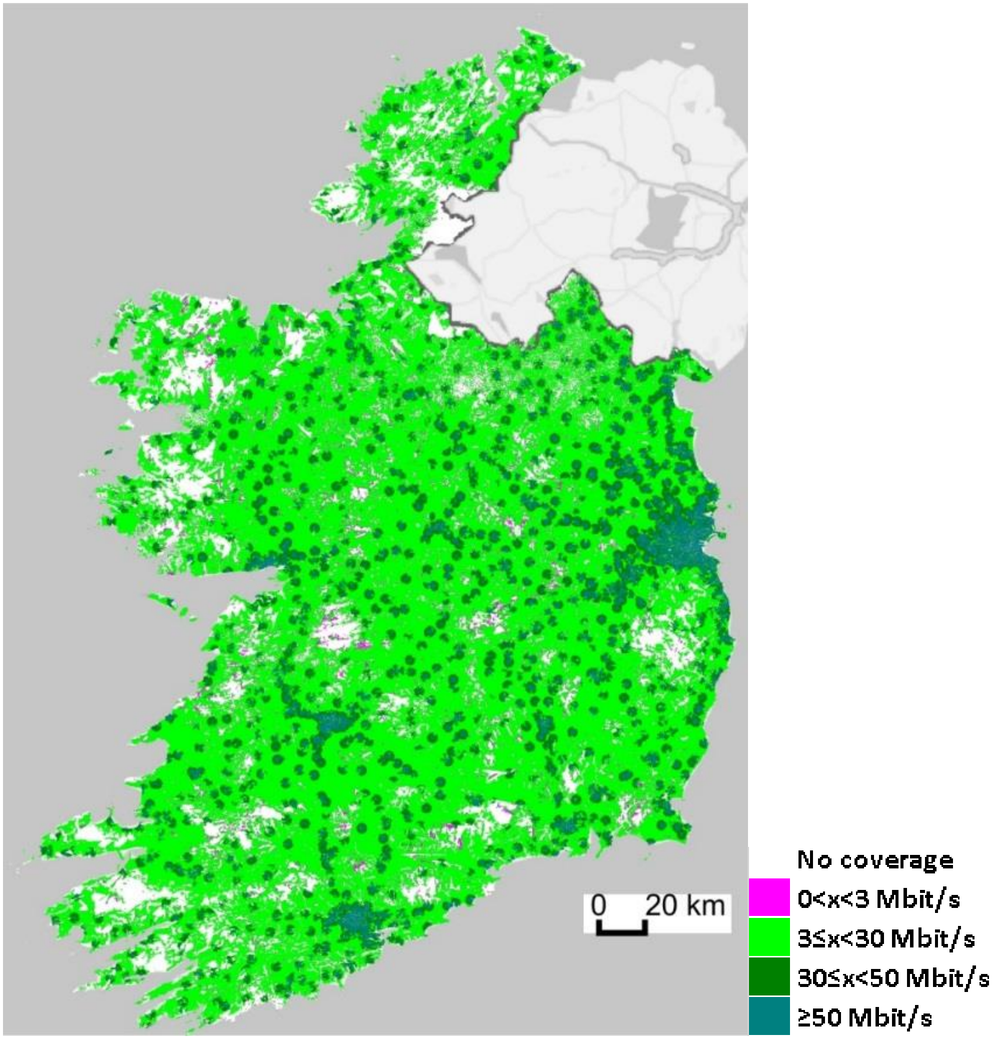
The application data rate (Mbit/s) at cell edge refers to the downlink bit rate that can be successfully delivered to a single active user per cell in a lightly loaded network—namely SUTP at cell edge.

In relation to the specific application data rates: 3Mbit/s represents a minimum mobile data rate, 30Mbit/s represents the target data rate for 2020 (as set out in Article 6 the EU Radio Spectrum Policy Programme (RSPP) Decision[50]), and 50Mbit/s represents a higher data rate.[51] For more detail see Annex 2.

Figure 4.2 shows the population coverage of the synthetic network in 2017.

[49] Various confidential industry sources; Ofcom (2017), '4G Coverage Obligation Notice of Compliance Verification Methodology', 24 November.
[50] European Commission (2012), 'DECISION No 243/2012/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 March 2012 establishing a multiannual radio spectrum policy programme', 14 March.
[51] We note that a 2Mbit/s indoor data rate was assumed as the minimum throughout requirement in the 800MHz coverage obligation study carried out by Ofcom in 2012. As technology advances, a slightly higher throughput value of 3Mbit/s (outdoors) as the minimum cell edge throughput appears reasonable.

Figure 4.2 Map of the estimated population coverage for the synthetic network in 2017



Source: Oxera/Real Wireless.

It should be noted that although the modelling provides a broadly representative picture of population coverage at a generic network level for the synthetic network, in reality, individual MNOs are likely to provide different coverage in practice. This is because individual MNOs may use different site locations and frequencies and optimise their network (e.g. varying antenna height, location, positioning, downtilt, power, etc.) for individual sites.

4.3 Step 3: Validating the estimated coverage of the synthetic mobile network

In order to validate the synthetic network model, we carried out a cross-checking exercise that compared the estimated coverage of the synthetic network in 2017 to other estimates of mobile coverage.

For this purpose, Table 4.4 summarises the estimated population and geographical coverage of a voice and 3Mbit/s data service for the synthetic network in 2017, the starting year of each of the simulated scenarios.

It should be noted that we did not explicitly model voice service, as the modelling of a voice service would have required significantly different modelling parameters and assumptions to those used for a data service. Instead, a 0.2Mbit/s data rate is used as a proxy for a voice service.[52]

Table 4.4 Estimated population and geographic coverage of a voice and 3Mbits/s data service in the synthetic network in 2017

	Estimated coverage using the synthetic operator's network of 1,890 macrosites	Estimated coverage using 870 macrosites (800MHz band), site density=10.3 sites per 1,000 km^2
Population coverage	Voice = 97.7% Data 3Mbit/s = 96.7%	Voice = 90.4% Data 3Mbit/s = 88.2%
Geographical coverage	Voice = 85.7% Data 3Mbit/s = 82.1%	Voice = 66.2% Data 3Mbit/s = 62.2%

Source: Oxera/Real Wireless.

The estimated coverage for the synthetic network in 2017 was first cross-checked against the input coverage being used in ComReg's Mobile Termination Rate (MTR) project modelling, where 98.7% population coverage and 84.7% geographical coverage by 2019 are used as modelling inputs.[53]

We understand that the ComReg MTR project uses different assumptions and approaches to those that we are using in this study. Nevertheless, we believe that these figures match sufficiently well with the estimated voice coverage as predicted by our model—namely 97.7% population and 85.7% geographic coverage.

Focusing on the 800MHz band, we also cross-checked our estimated coverage results for 2017 against Ofcom's 800MHz coverage study, focusing on Northern England.[54] Northern England was selected as it has similar terrain/clutter distribution to Ireland, although other characteristics (e.g. population density, distribution, etc.) are different.

In Ofcom's study, based on a site density of 14.9 sites per 1,000 km^2, the 800MHz population voice coverage for Northern England is estimated to be 93%. Using the lower site density of 10.3 sites per 1,000 km^2 for Ireland, the estimated 800MHz population voice coverage for 2017 in our study is 90.4%. This estimate is 3 percentage points lower than that of Northern England; among other things, this reflects the lower site density used in Ireland.

Taking the above into account, we consider that the synthetic network is well-calibrated.

4.4 Step 4: Modelling the expansion of the network

The aim of this step is to emulate the network expansion of an MNO (the synthetic operator is used as proxy). This is achieved by simulating the deployment of new sites and upgrading existing sites with additional spectrum to increase the coverage of the targeted service(s), as defined in each of the simulation scenarios in step 5.

The main parameters used in this step include:

[52] Jailani, E., Ibrahim, M. and ab Rahman, R. (2012), 'LEE speech traffic estimation for network dimensioning', conference paper, September.
[53] ComReg (2018), 'Price Consultation: Further Specification of Proposed Price Control Obligations for Fixed and Mobile Call Termination Rates', 13 March, Figure 14.
[54] Ofcom (2012), '4G Coverage Obligation: Notice of Compliance Verification Methodology: LTE', July.

- spectrum availability from 2017 onwards;
- technology deployed and carrier aggregation;
- the rate of network roll-out—sites and upgrades;
- network costings.

Detailed information on other aspects of the network expansion model are set out in Annex 2.

4.4.4 Spectrum availability from 2017 onwards

Two spectrum portfolios are assumed in the network expansion modelling.

Spectrum Portfolio 1, as shown in Table 4.5, sets out the spectrum that would be available to an incumbent MNO assuming that the spectrum in the Candidate Bands is assigned symmetrically among the three MNOs in mid-2020.

Table 4.5 Spectrum Portfolio 1 (quantity of spectrum, MHz)

	2017 to mid-2020	Mid-2020 onwards
FDD 700	-	10
FDD 800	10	10
FDD 900	10	10
SDL 1400[1]	-	10
FDD 1800	25	25
FDD 2100	20	20
TDD 2300	-	30
FDD 2600	-	20
TDD 2600	-	15
TDD 3600[55]	-	85

Note: 10MHz in a FDD band refers to 2 x 10MHz. [1] We did not model the 1.4GHz band because the additional cost to deploy new antennas would not justify its benefit. Furthermore, we consider the 1.4GHz carrier upgrade to be too costly an option for coverage, given that there are three sub-1GHz bands to utilise.

Source: Oxera/Real Wireless.

Spectrum Portfolio 2, as shown in Table 4.6, sets out the spectrum that would be available to a new entrant on the assumption that it was assigned 2 x 10MHz from the 700MHz band and 2 x 20MHz from the 2.6GHz band in mid-2020.

Table 4.6 Spectrum Portfolio 2 (quantity of spectrum, MHz) [56]

	2017 to mid-2020	Mid-2020 onwards
FDD 700	-	10
FDD 2600	-	20

Source: Oxera/Real Wireless.

[55] We do not include the 3.6GHz spectrum band in the modelling for the period 2017 to mid-2020 as we considered this band of negligible importance in providing coverage up to mid-2020 due to limited device support and the availability of lower frequency bands which are more suitable for coverage.
[56] In relation to Spectrum Portfolio 2, we note that a new entrant could also obtain spectrum from other Candidate Bands (SDL 1400, FDD 2100, TDD 2300, and TDD 2600, for example). While this is possible, we believe that such additional spectrum is unlikely to affect the simulation modelling results given the Carrier Aggregation assumptions used in the modelling. Furthermore, the lower frequency Candidate band (700

4.4.5 Technology and Carrier Aggregation

It is assumed that there is no Carrier Aggregation from 2017 to mid-2020 and that the coverage of the synthetic network is based on a single LTE carrier of 2 x 10MHz over the same period.

It is assumed that three-band Carrier Aggregation would be available from mid-2020 onwards. It would be deployed as follows.[57]

- Spectrum Portfolio 1—given the favourable propagation characteristics of sub-1GHz spectrum for coverage, we use Carrier Aggregation of 2 x 10MHz of 700MHz spectrum, 2 x 10MHz of 800MHz spectrum, and 2 x 10MHz of 900MHz spectrum.
- Spectrum Portfolio 2—we use Carrier Aggregation of 2 x 10MHz of 700MHz spectrum and 2 x 20MHz of 2.6GHz spectrum.

4.4.6 The network roll-out rate for new macrosites and upgrades

We assume that from 2017 until mid-2020, the synthetic MNO increases the number of macrosites in its network according to a 2.5% compound annual growth rate (CAGR). As explained in Annex 2, this 2.5% CAGR roll-out rate is based on historical site licensing data from Irish MNOs.

Other roll-out rates are also possible, depending on the development status of the network and the operator's expansion strategy. For example:

- a new entrant operator is likely to have a higher roll-out rate when it is building out its network to increase coverage;
- an incumbent operator with near-ubiquitous network coverage might have a lower roll-out rate, as it would presumably require far fewer new sites for coverage purposes.

From mid-2020 onwards, the following approach is used.

The standard 2.5% roll-out rate is maintained for the simulations scenarios. As set out in section 5, the standard 2.5% roll-out rate results in roll-out periods that:

- vary significantly between different simulations scenarios;
- are substantially in excess of 10 years for some scenarios.

There are difficulties in directly comparing the results of two or more simulation scenarios with substantially different roll-out rates, given factors such as the time value of money.

To address this issue and to facilitate a roll-out time period of up to 10 years (i.e. by 2027 for Spectrum Portfolio 1 and by 2030 for Spectrum Portfolio 2), an

MHz) will help the operators provide coverage of mobile connectivity, while the higher frequency Candidate bands (2.1 GHz 2.3 GHz, 2.6 GHz) will help the operators provide enough capacity to offer high quality mobile connectivity.

[57] During our discussions with Irish MNOs, we found that they would use the 700MHz band (possibly aggregated with other sub-1GHz bands) to enhance coverage. Therefore, we assume in our model that Irish MNOs will deploy three-band Carrier Aggregation after the 700MHz band is assigned. In the future, if Carrier Aggregation can help improve coverage (and if MNOs have the incentive to do so), it is reasonable to expect that MNOs will deploy this feature to enhance coverage. We note that coverage expansion could be achieved through other means, such as new site deployment. It is up to each MNO to carry out the cost-benefit analysis and decide on a strategy.

upward adjustment of the standard 2.5% CAGR rate was applied for certain simulation scenarios (as identified in section 5 of this report).

This upward adjustment allows the roll-out to be completed within 10 years. It also impacts the level of costs—for example, a quickly expanding network will generate more costs than if the expansion was slower.

Regarding network upgrades, we assumed that it takes five times longer to commission a new site than to perform a carrier upgrade or begin using a Shared Access site.[58] See Annex 2 for additional information in this regard.

4.4.7 Network cost

Estimates for the CAPEX and OPEX costs for a new macrosite, the upgrade of existing sites, and site refresh were provided by ComReg and align with those used in the ComReg MTR project[59] and by Ofcom.[60] These costs, as well as other parameters, such as the lifetime of the asset and the nominal cost trend, are set out in Annex 2.

4.5 Step 5: Defining the scenarios to be simulated

In light of the observations in section 3 and other relevant information,[61] a number of simulation scenarios were defined.

The main scenarios for this study are detailed in Table 4.7. These relate to the provision of the MBB service (i.e. the core use case), with data application rates of 3Mbit/s and 30Mbit/s. All of these scenarios use Spectrum Portfolio 1—the incumbent MNO spectrum portfolio.

[58] We also assessed the cost of a network roll-out for an MNO that would have access to the existing infrastructure provider, Shared Access, for site sharing.
[59] ‘Site refresh’ refers to the replacement cost for the radio equipment at the end of the radio equipment’s lifetime.
[60] See Ofcom (2018) ‘Improving mobile coverage: Proposals for coverage obligations in the award of the 700 MHz spectrum band’ [Link] paragraphs 330 - 335
[61] For example, the EU decision on the 470–790MHz band.

Table 4.7 Details of the main simulation scenarios

#	Target coverage type	Target service and application data rate (downlink)[1]	Target coverage to expand
1	Population	3Mbit/s (MBB)	Population coverage at domestic address locations
2	Population	30Mbit/s (MBB)	Population coverage at domestic address locations
3	Geography	3Mbit/s (MBB)	Geographic area coverage
4	Geography	30Mbit/s (MBB)	Geographic area coverage
5	Motorway and primary roads	3Mbit/s (MBB)	In-vehicle coverage on motorways and primary roads
6	Motorways	30Mbit/s (MBB)	In-vehicle coverage on motorways
7	Motorway and primary roads	30Mbit/s (MBB)	In-vehicle coverage on motorways & primary roads

Source: Oxera/Real Wireless.

Notes: [1] The target rates correspond to the service and data rate targeted after 2020, prior to 2020 we assume the base-case of a 3Maps targeted data rate.

For each of these scenarios, we use Spectrum Portfolio 1, see Section 4.4.4.

The other simulation scenarios for this study are detailed in Table 4.8. These relate to specific variants of the main simulation scenarios above, and to the CV and IIoT services.

Table 4.8 Details of the other simulation scenarios

#	Target coverage type	Target service and application data rate (downlink)[1]	Target coverage to expand
8[2]	Population by a new entrant	30Mbit/s (MBB)	Population coverage at domestic address locations
9	Population	50Mbit/s (MBB)	Population coverage at domestic address locations
10	Population with MNO site sharing	30Mbit/s (MBB)	Population coverage at domestic address locations
11	30Mbit/s population coverage to 95% in 2027, then IIoT coverage	MBB: 30Mbit/s until 95% population reached IIoT: 384kbit/s from when MBB population coverage > 95%	MBB: population coverage at domestic address locations IIoT: Coverage of IIoT pixels
12	30Mbit/s population coverage to 95% in 2027, then CV coverage	MBB: 30Mbit/s until 95% population reached CV: 512kbit/s from when MBB population coverage > 95%	MBB: population coverage at domestic address locations CV: Coverage to vehicles at road locations

Source: Oxera/Real Wireless.

Notes: [1] The target rates correspond to the service and data rate targeted after 2020, prior to 2020 we assume the base-case of a 3Maps targeted data rate. [2] Scenario 8 utilises the Spectrum Portfolio 2 (since Spectrum Portfolio 1 would be used by the incumbent), all other scenarios in the table use Spectrum Portfolio 1.

The tables above show that these scenarios differ in terms of specific modelling parameters, as they have:

- different target services (MBB, CV, or IIoT);
- different downlink application data rate levels (384kbits/s, 512kbit/s, 3Mbit/s, 30Mbit/s, or 50Mbit/s);
- different target coverage to expand (population, geographic area, road coverage, coverage of IIoT pixels, etc.).

4.6 Step 6: Run the simulations and present the results

The final step in the simulation modelling is the running of the simulation scenarios and the presentation of the results.

The model estimates the number of additional sites and upgrades and the network costs for the different simulation scenarios on the basis that the synthetic network coverage is expanded at minimum cost.

5 Results of mobile network cost modelling

Section 5 presents the results of the simulation scenarios defined in section 4, in terms of the additional mobile network infrastructure and costs required to achieve certain levels of mobile connectivity. In addition, it provides observations on specific black spot areas and observations on what the market would be likely to deliver commercially (e.g. without intervention).

As a starting point, the network cost modelling takes a hypothetical synthetic MNO, which is based on a blend of sites from existing Irish MNOs.[62] On this basis, the synthetic MNO's network represents the modelled network 'today', and from there we expand the network to achieve higher levels of coverage, and in doing so assess the cost implications.

The model computes the costs of increasing the network coverage/capacity, both from adding new mobile sites and from upgrading existing sites. Due to the focus of this study being on mobile coverage, the model does not explicitly account for increased capacity demands (e.g. from increased number of users or increased usage) when estimating the additional infrastructure that would be required to increase coverage.

The structure of this section is as follows.

- **Key features of the cost modelling analysis (section 5.1)**: a brief introduction to incidental coverage, switching of the coverage target in 2020, and the challenges involved in achieving faster roll-outs.
- **Summary results (section 5.2)**: the summary results for the main scenarios, which relate to the MBB service (the core use case) with speeds of 3Mbit/s and 30Mbit/s, and also for the other scenarios (which are either specific variants of the main scenarios, or related to non-MBB use cases).
- **Detailed results for the main scenarios (section 5.3)**: more detailed results for each of the main scenarios, including the relationship between coverage, the number of sites, and costs. Further information on the simulation results is contained in Annex 3.
- **Observations on increasing mobile connectivity in black spot areas (section 5.4).**
- **Observations on what the market would deliver commercially (section 5.5)**: observations on the level of coverage that would be provided on a commercial basis (i.e. without intervention).

5.1 Key features of the cost modelling analysis

Before showing and discussing the results of the analysis (in sections 5.2 and 5.3) we set out in this sub-section some key features of the analysis which are important foundations for understanding the scenario results.

5.1.1 Targeting a particular speed results in 'incidental coverage'

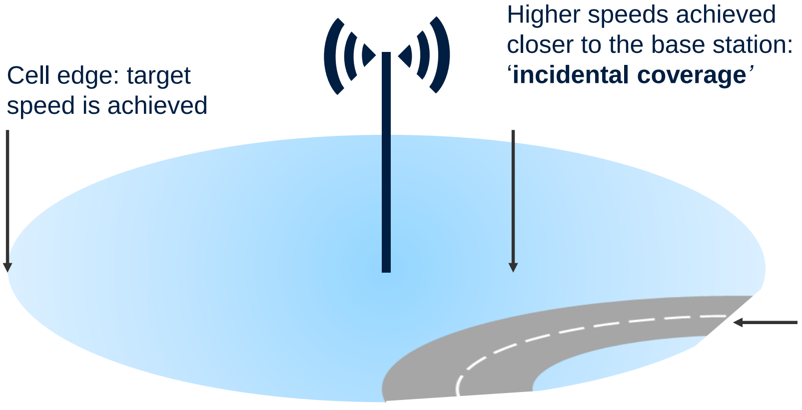
As explained in section 4, for each of the simulation scenarios there is a target service (e.g. mobile broadband, IoT), a target application data rate (i.e. Mbit/s

[62] While this provides a representative picture of coverage at a generic level, individual MNOs are likely to have different coverage to that generated from the simulations. This is because individual MNOs may use, for example, different site locations and frequencies, and they optimise their network (e.g. antenna height, location, positioning, downtilt, power, etc.) on an individual site level.

of data throughput), and a target coverage type (e.g. population vs geographic coverage).

An important reality of mobile connectivity is that those areas close to a base station receive higher speeds than areas further away from the base station. Also, when targeting a certain form of coverage (e.g. population) there will inevitably by coverage of other dimensions (such as geographic or road). We present this in Figure 5.1 (below).

Figure 5.1 Incidental coverage (stylised example)



Source: Oxera/Real Wireless.

As an example, suppose that the hypothetical MNO targeted (and subsequently achieved) 90% Irish population coverage of 30Mbit/s. As a result of this, and on the basis of the network modelling completed during this study, we estimate that:

- 99% of Ireland's population would get speeds of at least 3Mbit/s;
- 74% of Ireland's population would get (faster) speeds of 50Mbit/s;
- 63% of Ireland's land-area would be covered with 30Mbit/s;[63] and
- 84% of Ireland's motorways would be covered with 30Mbit/s.

Such additional (i.e. non-targeted) coverage is referred to throughout this document as 'incidental coverage'.

5.1.2 The coverage target switches in mid-2020

As outlined in section 4, each scenario is based on the hypothetical MNO targeting 3Mbit/s population coverage until mid-2020, at which point the target switches to the specified scenario (e.g. targeting 30Mbit/s population coverage).

This approach is driven by the assumption that 700MHz spectrum is expected to become available in mid-2020. The availability of the 700MHz band is assumed to coincide with the availability of Carrier Aggregation. Both the 700MHz band and Carrier Aggregation reduces the cost of providing coverage (as site upgrades cost less than building new sites). Therefore, the incremental cost of providing coverage is reduced in the immediate years following mid-

[63] This is because the population of Ireland is clustered into urban areas (if the population were distributed evenly across the landmass, then the geographic coverage would be equal to the population coverage).

2020 (mid-2020 appears as a ‘kink’ in many of the charts in section 5). However, as we will see in section 5.2, the incremental cost of coverage rises again when coverage reaches very high levels.

5.1.3 Faster network roll-out is more challenging to achieve

In general, we expect that faster network roll-out would be more costly for an MNO to achieve. This is because we expect that the unit costs would rise if an MNO had to deploy additional sites/upgrades more rapidly. For example, the network roll-out may require more engineering staff, vehicles, and equipment.

This requirement would result in the MNO incurring higher costs (than for a slower network roll-out). The network costing model does not fully capture these extra costs of faster roll-out; therefore, the model provides a lower bound estimate of the network costs where the speed of roll-out is significantly faster than the base case (2.5% CAGR).

We also expect that faster network roll-outs may be less feasible for an MNO to achieve. For example, even if the MNO was able to invest in more engineering staff, vehicles, and equipment, the process of doing so would take time and may not be commercially viable. Therefore, network roll-outs that require speeds significantly greater than the base case (2.5% CAGR) should be viewed with caution.

For context, a network roll-out with 2.5% CAGR in 2020 corresponds to a new site every week, or a carrier-upgrade every two days.

5.2 Summary results

We set out in this sub-section a brief summary of the results of the modelled scenarios, before going on to discuss them in more detail in section 5.3.

For each of the main scenarios, Table 5.1 presents the simulation results in terms of the estimated network infrastructure required, and associated network costs, by the hypothetical MNO to expand the targeted coverage to a 99.5% level within a 10-year timeframe (i.e. by the end of 2027).

Table 5.1 Overview of results for the main scenarios

#	Scenario	Start coverage	End coverage	Network infrastructure: additional new sites & upgrades	Network cost (8–10 year roll-out, 20-year PV)
1	3Mbit/s population	96.7% population	99.5% population	420 new sites & 377 upgrades	€181m
2	30Mbit/s population	62.4% population	99.5% population	1,466 new sites & 1,606 upgrades	€511m
3	3Mbit/s geographic	83.3% geographic	99.5% geographic	2,240 new sites (with considerable investment in greenfield sites) & 964 upgrades	€749m
4	30Mbit/s geographic	18.3% geographic	99.5% geographic	5,910 new sites (out of which 313 in challenging terrain) & 1,252 upgrades	Over €1,860m
5	3Mbit/s motorway & primary roads	95.6% motorway 90.4% primary roads	99.996% motorway 99.5% primary roads	327 new sites & 50 upgrades	€149m
6	30Mbit/s motorway & primary roads	47.8% motorway 31.4% primary roads	99.98% motorway 99.5% primary roads	754 new sites & 392 upgrades	€283m
7	30Mbit/s motorway	47.8% motorway	99.5% motorway	369 new sites & 141 upgrades	€160m

Note: '20-year PV' (Present Value) refers to the length of time over which OPEX and CAPEX are incurred.

Source: Oxera/Real Wireless.

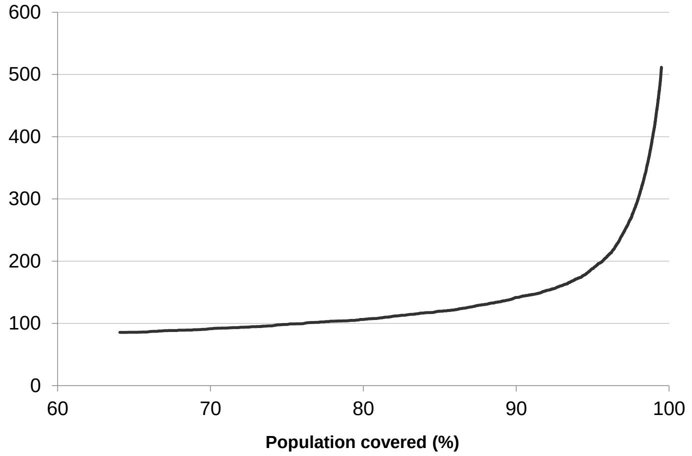
There are five key observations based on the summary results of the main scenarios, outlined below.

First, the cost of coverage rises exponentially at high levels of coverage (across all scenarios). As explained in section 4, the hypothetical MNO expands coverage to those areas with the lowest cost per target coverage achieved—for example, the lowest cost per population covered, or the lowest cost per km of motorways covered. This means that the less costly coverage is provided first (typically urban areas). This also means that the cost of each additional percentage of coverage increases as the roll-out continues (whatever the coverage target might be).

As an example, suppose that the hypothetical MNO targeted population coverage of 30Mbit/s. As shown in Figure 5.2, the cost of providing coverage increases exponentially for the last 5% of population. While the last 5% will (by definition) be the most costly 5% of coverage, the exponential increase in cost is significant when targeting 30Mbit/s population coverage.

The steep increase in cost is because the last 5% of the population reside in more remote places, which tend to be topographically challenging, and the cost of expanding the network to those areas is greater. It is also because the population density decreases in remote areas, meaning that more base stations are needed to cover the same number of residences (and therefore the cost per population increases).

Figure 5.2 The cost of targeting 30Mbit/s population coverage, starting in mid-2020 (€m, 2017 monies)

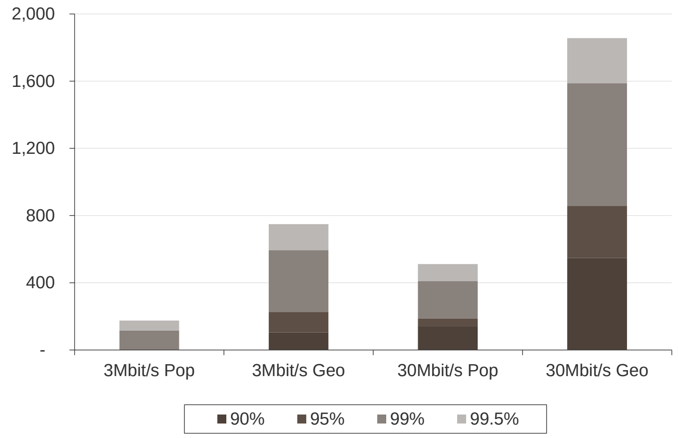


Source: Oxera/Real Wireless.

Second, targeting high levels of geographic coverage is more costly than targeting population coverage (or road coverage). Targeting geographic coverage (e.g. landmass in terms of km^2) necessarily involves covering a larger area than targeting population coverage (e.g. only those areas where the population resides).[64] Therefore, geographic coverage involves more base stations (especially in rural areas, where building the network costs more). Therefore, the cost of targeting geographic coverage is greater than targeting population coverage.

Figure 5.3 shows how targeting geographic coverage is significantly more costly than targeting population coverage, for both 3Mbit/s and 30Mbit/s target speeds.

Figure 5.3 Cost of achieving population or geographic coverage (€m, 2017 monies)



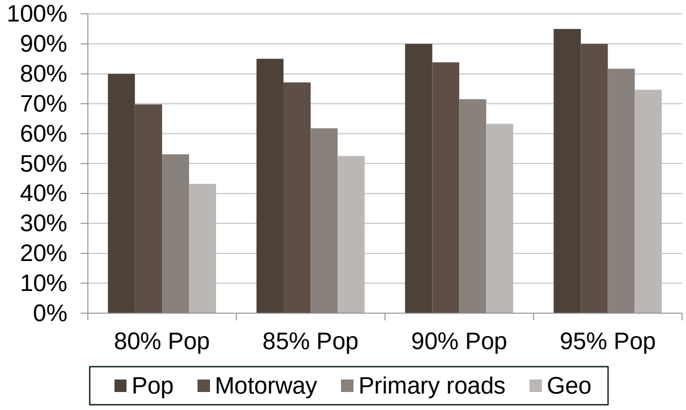
Note: With network roll-out speed to achieve 99.5% within 10 years.

Source: Oxera/Real Wireless.

[64] If the population were distributed evenly across the landmass, then the geographic coverage would be equal to the population coverage. However, as the population is clustered into major cities, the geographic coverage is less than the population coverage (when population coverage is targeted).

Third, targeting population coverage leads to reasonable incidental coverage of geography and roads. As explained in section 5.1.1, achieving a coverage target results in incidental coverage. Targeting population coverage leads to reasonable levels of coverage over geography and roads, as shown in Figure 5.4.

Figure 5.4 Incidental 30Mbit/s coverage from achieving population coverage with 30Mbit/s



Source: Oxera/Real Wireless.

Fourth, targeting road coverage is less costly than population coverage. Achieving 30Mbit/s coverage of 99.5% of the population would cost €511m and be completed in 2027 (with 8.04% CAGR from mid-2020), whereas achieving 30Mbit/s coverage of 99.5% of motorways and national primary roads would cost €283m and be completed in 2027 (3.78% CAGR from mid-2020).

Fifth, targeting primary roads in addition to motorways adds considerable cost. Achieving 30Mbit/s coverage of 99.5% of motorways would cost €160m and be completed in 2024 (with 2.5% CAGR throughout), whereas achieving 30Mbit/s coverage of 99.5% of motorways and national primary roads would cost €283m and be completed in 2027 (3.78% CAGR from mid-2020).

The table below summarises the results from the other scenarios.

Table 5.2 Summary results for the other scenarios

#	Scenario	Start coverage	End coverage	Network infrastructure: additional new sites and upgrades	Roll-out time period (with 2.5% roll-out CAGR)	Network cost (20-year PV)
8	30Mbit/s population–new entrant	0% population	98% population	3,372 new sites	2020–2056 (39 years)	€717m
9	50Mbit/s population	43.6% population	80.9% population	288 new sites & 1,088 upgrades	2017–2025 (eight years)	€144m
10	30Mbit/s population–site sharing	62.4% population	99.5% population	1,569 new sites (out of which 165 are shared) & 1,660 upgrades	2017–2041 (24 years)	€362m
11	30Mbit/s population coverage to 95% in 2027, then IIoT coverage	27% IIoT (2027)	99.5% IIoT	**Significantly more than*** 1,255 new sites & more than 1,540 upgrades	2027 to well beyond 2039	€929m
12	30Mbit/s population coverage to 95% in 2027, then CV coverage	31% CV motorway (2027)	99.5% CV motorway	**More than*** 2,238 new sites & more than 1,758 upgrades	2027 to beyond 2049	€422m

Note: '20-year PV' (Present Value) refers to the length of time over which OPEX and CAPEX are incurred.

* The simulation analysis was run out until

Source: Oxera/Real Wireless.

There are four key observations based on the summary results of the other scenarios, outlined below.

First, new entrants face significantly higher costs and longer roll-outs (comparing Scenario 2 with Scenario 8). This is because the new entrant has to build over double the number of new sites.

Second, increasing the target speed from 30Mbit/s to 50Mbit/s increases costs (comparing Scenario 2 with Scenario 9). This is because the higher target speed requires more network infrastructure.

Third, site sharing (as defined in the model) somewhat reduces costs (comparing Scenario 2 with Scenario 10). This is because sharing 165 sites reduces costs.

Fourth, targeting non-MBB services (IIoT and CV) once the 30Mbit/s population coverage has reached 95% significantly increases the time it takes to roll out the coverage and involves significant extra costs. For example, with the IIoT case, this is mainly due to the fact that many IIoT locations do not coincide with population based coverage locations.

Detailed results for the other scenarios can be found in Annex 3.

5.3 Detailed results for the main scenarios

This section presents detailed results for each of the main simulation scenarios in terms of: the network sites/upgrades and costs associated with increasing coverage; the incidental coverage delivered; and the roll-out speeds required to achieve coverage targets within 10 years.

The detailed results are presented in the following order.

First, population and geographic MBB coverage:

- Scenario 1: 3Mbit/s population (section 5.3.1)
- Scenario 2: 30Mbit/s population (section 5.3.2)
- Scenario 3: 3Mbit/s geographic (section 5.3.3)
- Scenario 4: 30Mbit/s geographic (section 5.3.4)

Second, in-vehicle road MBB coverage:

- Scenario 5: 3Mbit/s Motorway & Primary roads (section 5.3.5)
- Scenario 6: 30Mbit/s Motorway & Primary roads (section 5.3.6)
- Scenario 7: 30Mbit/s Motorway (section 5.3.7)

5.3.1 Scenario 1: 3Mbit/s MBB population coverage

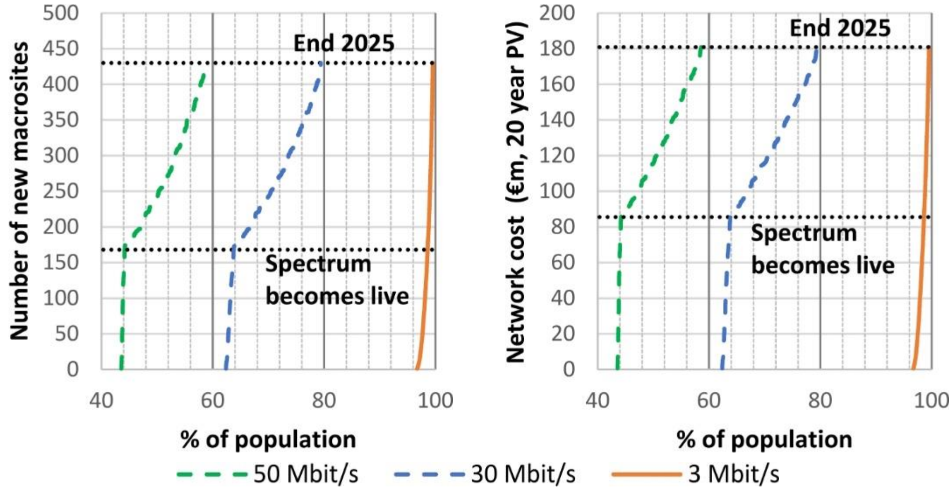
In Scenario 1, the targeted coverage is 3Mbit/s MBB population coverage. When calculating results for expanding the network to meet this targeted coverage, the incidental MBB population coverage for 30Mbit/s and 50Mbit/s services is also presented.

- Figure 5.5(a) shows the number of new sites required to provide the coverage.
- Figure 5.5(b) shows the costs required to provide the coverage.
- Figure 5.5(c) shows how the network costs increase over time.

The results show that expanding 3Mbit/s population coverage from 96.7% to 99.5% requires 420 new three-sector sites and 377 carrier upgrades to existing sites. This expansion would cost €181m and take 8.5 years to complete, from May 2017 to November 2025 (with 2.5% CAGR).

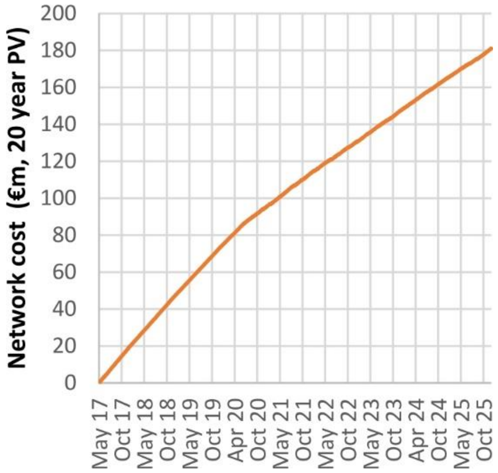
As discussed in section 5.1.2, the incremental cost of coverage decreases in mid-2020 when the 700MHz band becomes available and Carrier Aggregation is deployed. This is the cause of the ‘kink’ in Figure 5.5(a) and Figure 5.5(b).

Figure 5.5 Scenario 1 results: 3Mbit/s MBB population coverage



(a) New sites vs population coverage

(b) Network cost vs population coverage

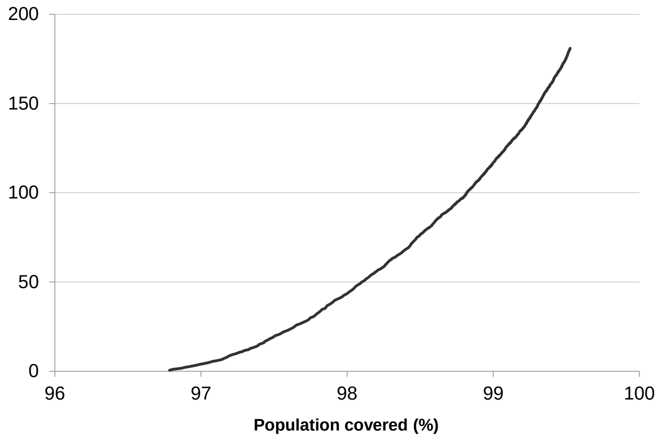


(c) Network cost vs time

Source: Oxera/Real Wireless.

The results reveal that the incremental costs of providing coverage increase as the coverage rate approaches 99.5%. This is shown in Figure 5.6. For example, the cost of increasing coverage from 97% to 97.5% is €17m, while the estimated network cost of increasing coverage from 99% to 99.5% is €70m.

Figure 5.6 Scenario 1: The costs to cover the last few percentages of the population with 3Mbit/s (€m, 2017 monies)



Source: Oxera/Real Wireless.

As described in Annex 1, Section 1.5, Irish MNOs stated that they are targeting 98% population coverage by 2020. For 3Mbit/s MBB population coverage, the results for Scenario 1 show that this would cost approximately €45m (from the starting population coverage of 96.7%).

Further results for Scenario 1 can be found in Annex 3.

5.3.2 Scenario 2: 30Mbit/s MBB population coverage

In Scenario 2, the targeted coverage is 30Mbit/s MBB population coverage. When calculating results for expanding the network to meet this targeted coverage, the incidental MBB population coverage for 3Mbit/s and 50Mbit/s services is also presented.

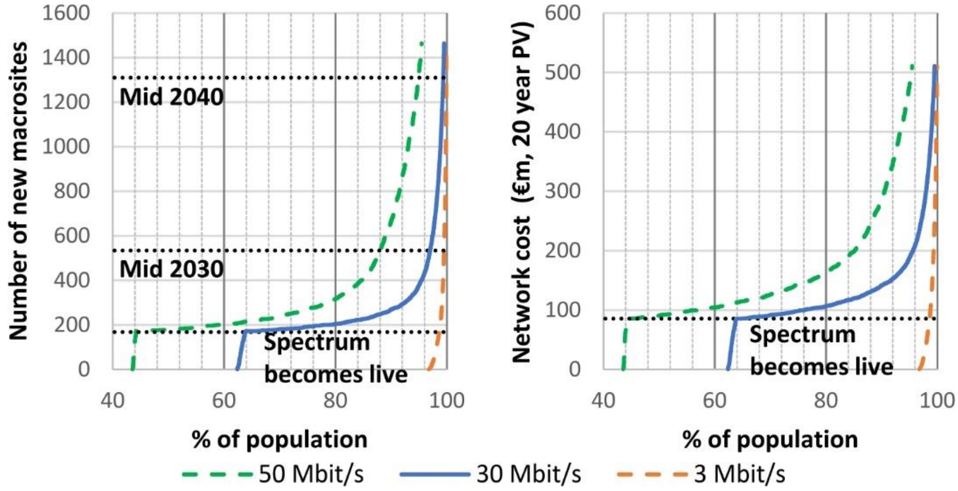
As explained in section 5.1.2, the hypothetical MNO targets 3Mbit/s population coverage until mid-2020, when the 700MHz band becomes available and Carrier Aggregation is deployed. From mid-2020, the hypothetical MNO targets 30Mbit/s population coverage. This is the cause of the ‘kink’ in Figure 5.7(a) and Figure 5.7(b) below.

- Figure 5.7(a) shows the number of new sites required to provide the coverage.
- Figure 5.7(b) shows the costs required to provide the coverage.
- Figure 5.7(c) shows how the completion date depends on the roll-out speed.

Overall, these simulation results indicate that to expand 30Mbit/s MBB population coverage from 62.4% to 99.5% would require 1,466 new three-sector sites and 1,606 carrier upgrades to existing sites. This expansion would cost approximately €511m and take 10 years to complete, with a network roll-out CAGR of 8.04% from mid-2020 onwards.

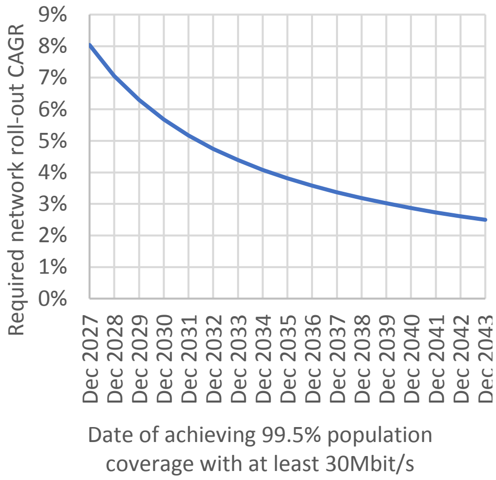
If the hypothetical MNO continued to build the network at a rate of 2.5% (the base case) then 99.5% 30Mbit/s population coverage would be achieved in 2043. This is shown in Figure 5.7(c) below. As discussed in section 5.1.3, faster roll-out speeds may be less feasible.

Figure 5.7 Scenario 2 results: 30Mbit/s MBB population coverage



(a) New sites vs population coverage at different throughput levels

(b) Cost vs population coverage at different throughput levels

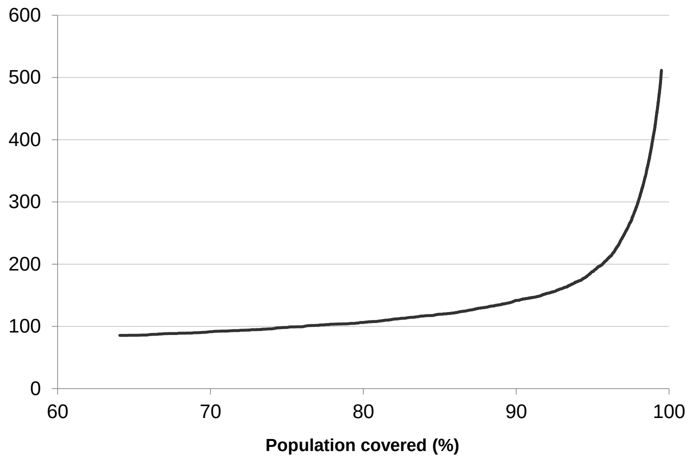


(c) Date of achieving 99.5% population coverage with at least 30Mbit/s, with implied network roll-out speed

Source: Oxera/Real Wireless.

The results reveal that the incremental costs of providing coverage increase as the coverage rate approaches 99.5%. This is shown in Figure 5.8. For example, the cost of increasing coverage from 97% to 97.5% is €24m, while the estimated network cost of increasing coverage from 99% to 99.5% is €102m.

Figure 5.8 The cost of targeting 30Mbit/s population coverage, starting in mid-2020 (€m, 2017 monies)



Source: Oxera/Real Wireless

Providing population coverage of 30Mbit/s also generates high levels of incidental coverage of 3Mbit/s population coverage and reasonable levels of geographic coverage. For example, 95% geographic coverage with 3Mbit/s generates incidental population coverage of 99.4% with 3Mbit/s. This is shown in Table 5.3.

Table 5.3 Incidental coverage arising from 30/Mbit/s population coverage

Type of incidental 3Mbit/s coverage	95.0% population coverage with 30Mbit/s	99.5% population coverage with 30Mbit/s
Population (3Mbit/s)	99.3%	99.9%
Geographic	74.7%	90.5%
Motorway	90.4%	97.0%
National primary roads	81.7%	94.6%
Rail	93.0%	98.0%

Source: Oxera/Real Wireless.

Further results for Scenario 2 can be found in Annex 3.

5.3.3 Scenario 3: 3Mbit/s MBB geographic coverage

In Scenario 3, the targeted coverage is 3Mbit/s MBB geographic coverage. When calculating results for expanding the network to meet this targeted coverage, the incidental MBB coverage is also presented.

As explained in section 5.1.2, the hypothetical MNO targets 3Mbit/s population coverage until mid-2020, when the 700MHz band becomes available and Carrier Aggregation is deployed. From mid-2020, the hypothetical MNO targets 3Mbit/s geographic coverage. This is the cause of the ‘kink’ in Figure 5.9(a) and Figure 5.9(b).

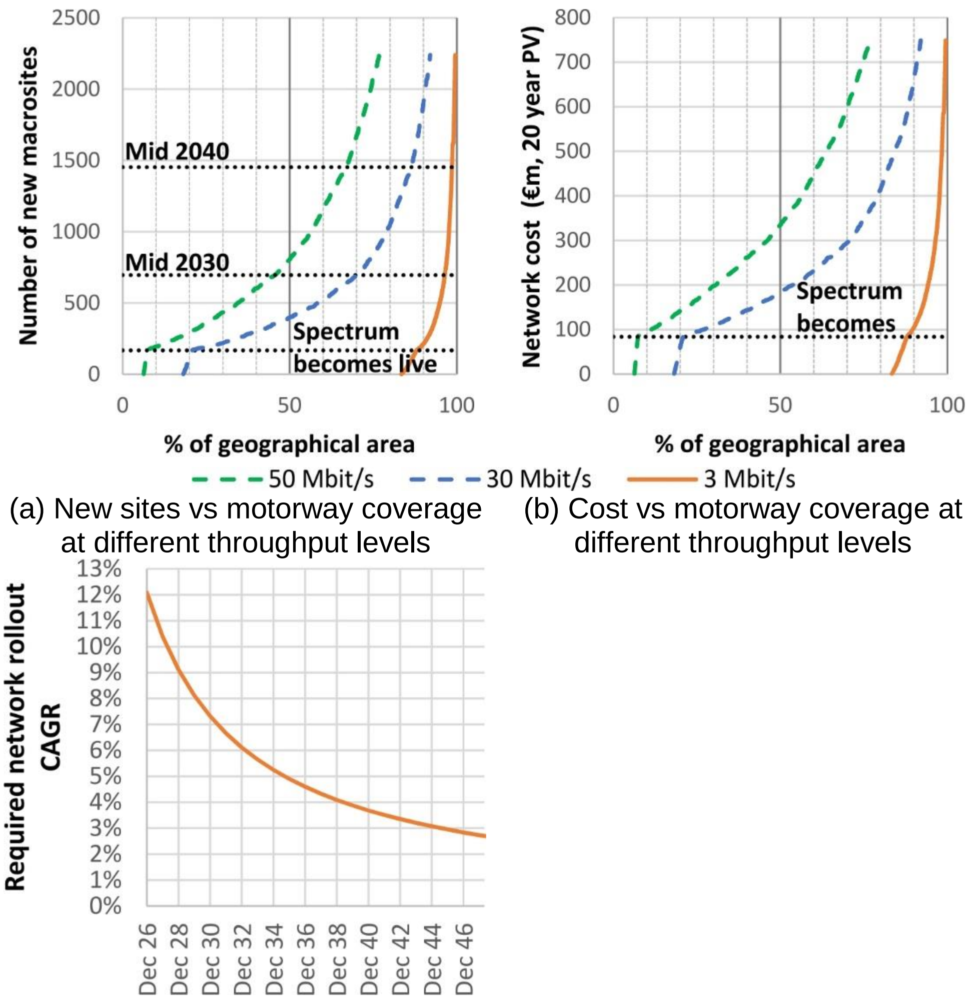
- Figure 5.9(a) shows the number of new sites required to provide the coverage.
- Figure 5.9(b) shows the costs required to provide the coverage.

- Figure 5.9(c) shows how the completion date depends on the roll-out speed.

Overall, these simulation results indicate that to expand coverage to 99.5% geographic coverage with speeds of 3Mbit/s would require 2,240 new three-sector sites and 964 carrier upgrades to existing sites.[65]

This expansion would cost approximately €749m and take 10 years to complete, with a network roll-out CAGR of 10.4% from mid-2020 onwards. If the hypothetical MNO continued to build the network at a rate of 2.5% (the base case), then 99.5% 3Mbit/s geographic coverage would be achieved in 2048. This is shown in Figure 5.9(c). As discussed in section 5.1.3, faster roll-out speeds may be less feasible.

Figure 5.9 Scenario 3 results: 3Mbit/s MBB geographic coverage



(a) New sites vs motorway coverage at different throughput levels

(b) Cost vs motorway coverage at different throughput levels

(c) Date of achieving 99.5% geographical coverage with at least 3Mbit/s

Source: Oxera/Real Wireless.

Providing geographic coverage of 3Mbit/s also generates high levels of incidental coverage of 3Mbit/s. For example, 95% geographic coverage with

[65] Alternatively, expanding coverage to 95.0% geographic coverage with speeds of 3Mbit/s would require 551 new three-sector sites and 433 carrier upgrades to existing sites.

3Mbit/s generates incidental population coverage of 99.4% with 3Mbit/s. This is shown in Table 5.4.

Table 5.4 Incidental coverage arising from 3Mbit/s geographic coverage

Type of incidental 3Mbit/s coverage	95.0% geographic coverage with 3Mbit/s	99.5% geographic coverage with 3Mbit/s
Population	99.4%	99.9%
Motorway	98.7%	99.7%
National primary roads	97%	99.6%
Rail	99.6%	99.9%

Source: Oxera/Real Wireless.

Further results for Scenario 3 can be found in Annex 3.

5.3.4 Scenario 4: 30Mbit/s MBB geographic coverage

In Scenario 4, the targeted coverage is 30Mbit/s MBB geographic coverage. When calculating results for expanding the network to meet this targeted coverage, the incidental MBB geographic coverage for 3Mbit/s and 50Mbit/s services is also presented.

As explained in section 5.1.2, the hypothetical MNO targets 3Mbit/s population coverage until mid-2020, when the 700MHz band becomes available and Carrier Aggregation is deployed. From mid-2020, the hypothetical MNO targets 30Mbit/s geographic coverage. This is the cause of the ‘kink’ in Figure 5.10(a) and Figure 5.10(b).

- Figure 5.10(a) shows the number of new sites required to provide the coverage.
- Figure 5.10(b) shows the costs required to provide the coverage.
- Figure 5.10(c) shows how the completion date depends on the roll-out speed.

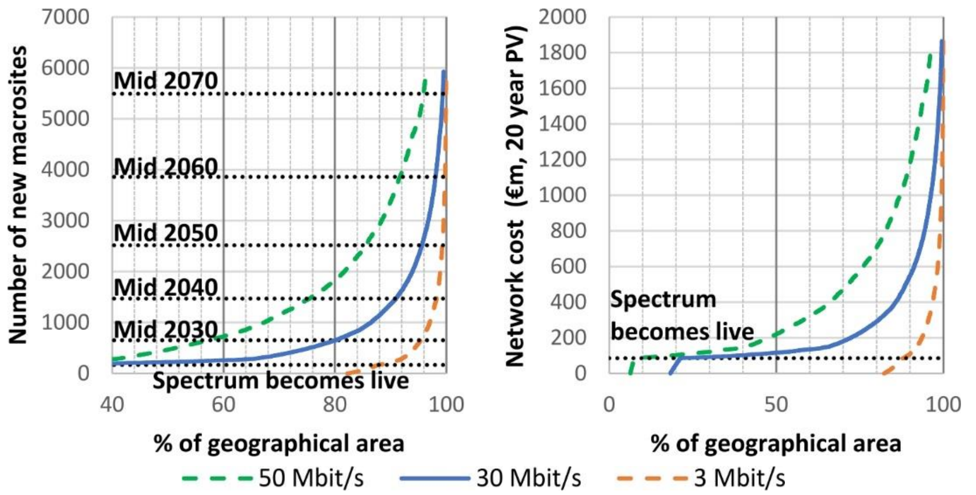
Overall, these simulation results indicate that to expand 30Mbit/s geographic coverage from 18.3% to 99.5% coverage would require 5,910 new three-sector sites (of which 313 are in challenging terrain) and 1,252 carrier upgrades to existing sites. This expansion would cost over €1,860m to complete in 10 years, based on a network roll-out CAGR of 19.96% (from mid-2020).[66]

If the hypothetical MNO continued to build the network at a rate of 2.5% (the base case), then 99.5% 30Mbit/s geographic coverage would be achieved after 2070. This is shown in Figure 5.10(c). As discussed in section 5.1.3, faster roll-out speeds may be less feasible.

It is worth noting that the hypothetical MNO deploys a larger number of new sites compared to the other scenarios because the existing infrastructure is not well-suited for geographical coverage.

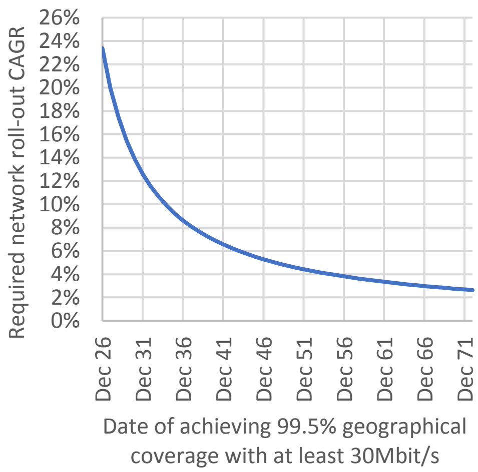
[66] Alternatively, providing 98% coverage would require 3,802 new three-sector sites and 806 carrier upgrades to existing sites.

Figure 5.10 Scenario 4 results: 30Mbit/s MBB geographic coverage



(a) New sites vs geographical coverage at different throughput levels

(b) Cost vs geographical coverage at different throughput levels



Source: Oxera/Real Wireless.

Further results for Scenario 4 can be found in Annex 3.

5.3.5 Scenario 5: 3Mbit/s MBB Motorway & Primary roads coverage

In Scenario 5, the targeted coverage is 3Mbit/s MBB in-vehicle coverage of motorways and national primary roads. When calculating results for expanding the network to meet this targeted coverage, the incidental MBB coverage for 30Mbit/s and 50Mbit/s services is also presented.

As explained in section 5.1.2, the hypothetical MNO targets 3Mbit/s population coverage until mid-2020, when the 700MHz band becomes available and Carrier Aggregation is deployed. From mid-2020, the hypothetical MNO targets 3Mbit/s coverage of motorways and national primary roads.

- Figure 5.11(a) shows the number of new sites required to provide motorway coverage.
- Figure 5.11(b) shows the costs required to provide motorway coverage.

- Figure 5.11(c) shows the number of new sites required to provide primary road coverage.
- Figure 5.11(d) shows the costs required to provide primary road coverage.

The results show that achieving 3Mbit/s coverage of 99.5% of motorways would require 204 new three-sector sites and eight carrier upgrades of existing sites. This would also deliver 95% coverage of national primary roads with 3Mbit/s. This is shown in Table 5.5.

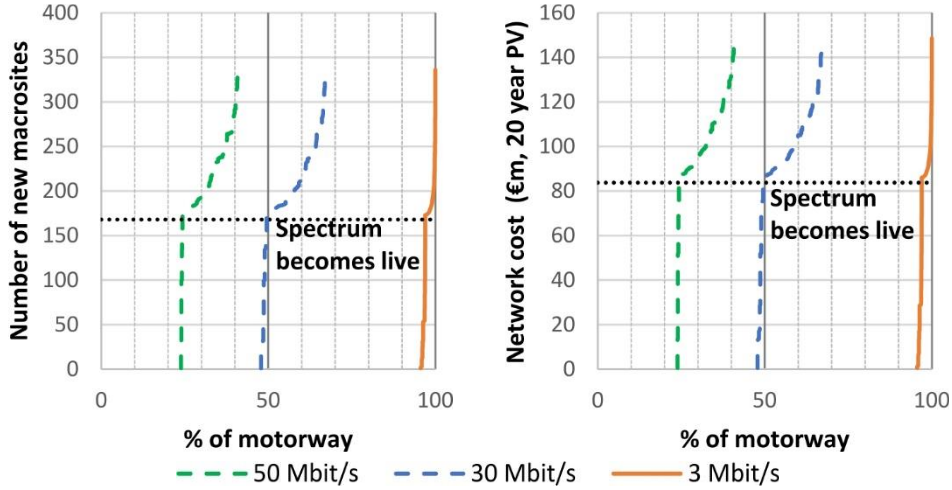
Alternatively, achieving 3Mbit/s coverage of 99.5% coverage of national primary roads would require 327 new three-sector sites and 50 carrier upgrades of existing sites. This would also deliver 99.996% coverage of motorways with 3Mbit/s. A network roll-out speed of 2.5% CAGR would achieve 99.5% coverage of primary roads with 3Mbit/s in mid-2023.

Table 5.5 Incidental coverage arising from 99.5% coverage with 3Mbit/s of motorways and primary roads

	99.5% motorway coverage with 3Mbit/s	99.5% primary road coverage with 3Mbit/s
Motorway	**99.5%**	99.996%
National primary	95%	**99.5%**
National secondary	92%	92%
Regional roads	92%	93%
National tertiary	97%	97%
Rail	99.5%	99.5%

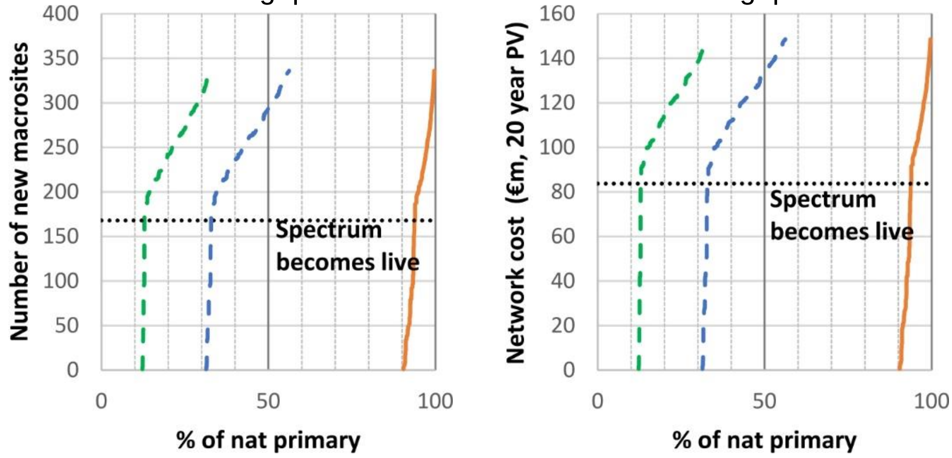
Source: Oxera/Real Wireless.

Figure 5.11 Scenario 5 results: 3Mbit/s MBB coverage of motorways and national primary roads



(a) New sites vs motorway coverage at different throughput levels

(b) Cost vs motorway coverage at different throughput levels



(c) New sites vs national primary road coverage at different throughput levels

(d) Cost vs national primary road coverage at different throughput levels

50 Mbit/s 30 Mbit/s 3 Mbit/s

Source: Oxera/Real Wireless.

Further results for Scenario 5 can be found in Annex 3.

5.3.6 Scenario 6: 30Mbit/s MBB Motorway & Primary roads coverage

In Scenario 6, the targeted coverage is 30Mbit/s MBB in-vehicle coverage of motorways and national primary roads. When calculating results for expanding the network to meet this targeted coverage, the incidental MBB coverage for 3Mbit/s and 50Mbit/s services is also presented.

As explained in section 5.1.2, the hypothetical MNO targets 3Mbit/s population coverage until mid-2020, when the 700MHz band becomes available and Carrier Aggregation is deployed. From mid-2020, the hypothetical MNO targets 30Mbit/s coverage of motorways and national primary roads. The hypothetical

MNO first targets motorways (with approximately 100 sites), then primary roads.[67]

- Figure 5.12(a) shows the number of new sites required to provide motorway coverage.
- Figure 5.12(b) shows the costs required to provide motorway coverage.
- Figure 5.12(c) shows the number of new sites required to provide primary road coverage.
- Figure 5.12(d) shows the costs required to provide primary road coverage.
- Figure 5.12(e) shows how the completion date depends on the roll-out speed.

The results show that achieving 30Mbit/s coverage of 99.5% of motorways would require 521 new three-sector sites and 368 carrier upgrades of existing sites. This would also deliver 94% coverage of national primary roads with speeds of 30Mbit/s. This is shown in Table 5.Table 5.6 below.

Alternatively, achieving 30Mbit/s coverage of 99.5% coverage of national primary roads would require 754 new three-sector sites and 392 carrier upgrades of existing sites. This would also deliver 99.98% coverage of motorways with speeds of 30Mbit/s.

Table 5.6 Incidental coverage arising from 99.5% coverage with 30Mbit/s of motorways and primary roads

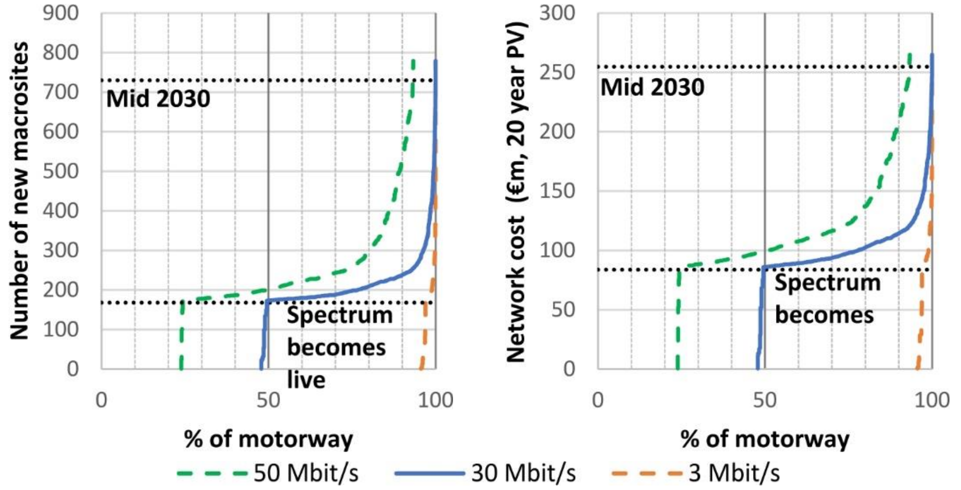
	99.5% motorway coverage with 30Mbit/s	99.5% primary road coverage with 30Mbit/s
Motorway	**99.5%**	99.98%
National primary	94%	**99.5%**
National secondary	55%	57%
Regional roads	56%	59%
National tertiary	76%	77%
Rail	70%	72%

Source: Oxera/Real Wireless.

If the hypothetical MNO continued to build the network at an annual rate of 2.5% (the base case) then 99.5% 30Mbit/s motorway and primary road coverage would be achieved after 2030. This is shown in Figure 5.12(e). With the network
roll-out of 3.78% CAGR, 30Mbit/s MBB is provided to 99.5% of motorway and national primary roads by the end of 2027. As discussed in section 5.1.3, faster roll-out speeds may be less feasible.

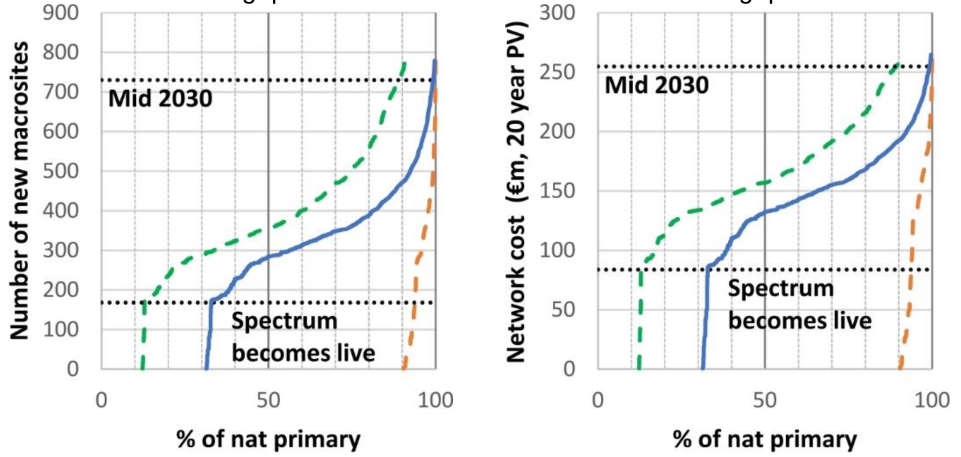
[67] To prioritise motorway coverage, a soft transition from motorway to national primary roads was implemented, achieved by weighting the benefit of a new (or upgraded) site. The benefit from deploying a new site was equal to the road lengths covered that otherwise would not get coverage at the target throughput: *benefit = Motorway + 0.1*National_primary_roads* where 'Motorway' is the length of motorway type within the coverage area that otherwise would not get coverage at the target throughput, and National_primary_roads is the length of national primary roads thoroughfare type within the coverage area that otherwise would not get coverage at the target throughput.

Figure 5.12 Scenario 6 results: 30Mbit/s MBB coverage of motorways and national primary roads



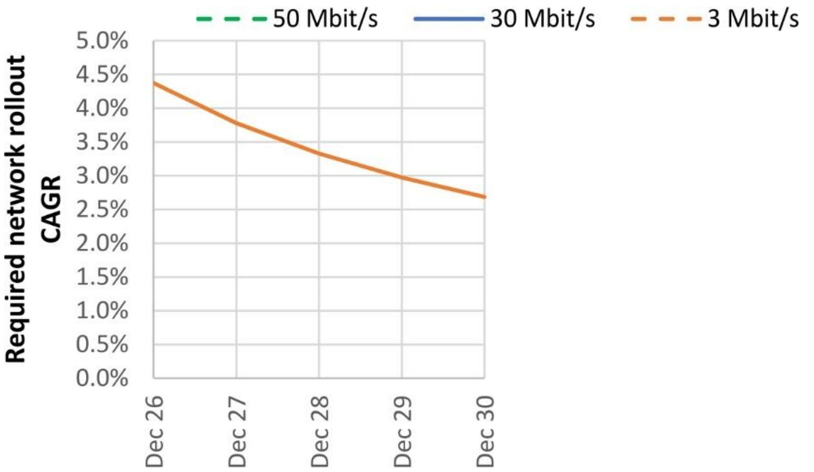
(a) New sites vs motorway coverage at different throughput levels

(b) Cost vs motorway coverage at different throughput levels



(c) New sites vs national primary road coverage at different throughput levels

(d) Cost vs national primary road coverage at different throughput levels



(e) Date of achieving 99.5% motorway and national primary road coverage with at least 30Mbit/s

Source: Oxera/Real Wireless.

Further results for Scenario 6 can be found in Annex 3.

5.3.7 Scenario 7: 30Mbit/s MBB Motorway coverage

In Scenario 7, the targeted coverage is 30Mbit/s MBB in-vehicle coverage of motorways. When calculating results for expanding the network to meet this targeted coverage, the incidental MBB coverage for 3Mbit/s and 50Mbit/s services is also presented.

As explained in section 5.1.2, the hypothetical MNO targets 3Mbit/s population coverage until mid-2020, when the 700MHz band becomes available and Carrier Aggregation is deployed. From mid-2020, the hypothetical MNO targets 30Mbit/s coverage of motorways.

- Figure 5.13(a) shows the number of new sites required to provide motorway coverage.
- Figure 5.13(b) shows the costs required to provide motorway coverage.

The results show that achieving 30Mbit/s coverage of 99.5% of motorways would require 369 new three-sector sites and 141 carrier upgrades of existing sites. This is shown in Table 5.7 below. A network roll-out speed of 2.5% CAGR would achieve 99.5% coverage of primary roads with speeds of 30Mbit/s by mid-2024.

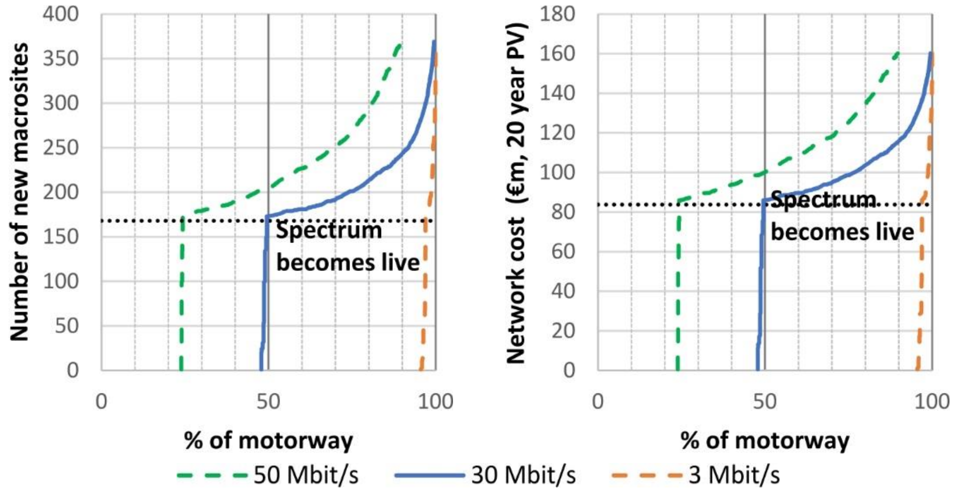
As shown in Table 5.7, the incidental coverage arising from achieving 99.5% coverage of motorways with speeds of 30Mbit/s is less than that achieved under Scenario 6 (where primary roads are also targeted with speeds of 30Mbit/s).

Table 5.7 Incidental 30Mbit/s coverage arising from 99.5% coverage with 30Mbit/s of motorways

	Incidental coverage of 30Mbit/s from 99.5% Motorway coverage
National primary	39%
National secondary	42%
Regional roads	39%
National tertiary	65%
Rail	65%

Source: Oxera/Real Wireless.

Figure 5.13 Scenario 7 results: 30Mbit/s MBB coverage of motorways



(a) New sites vs motorway coverage at different throughput levels

(b) Cost vs motorway coverage at different throughput levels

Source: Oxera/Real Wireless.

Further results for Scenario 7 can be found in Annex 3.

5.4 Observations on increasing mobile connectivity in black spot areas

Black spots areas refer to geographic areas in which there is no current mobile network coverage. For existing mobile network operators, these areas generally relate to the pockets of 'no coverage' zones, and are predominantly in rural (sparsely populated) areas.

It is very challenging to provide coverage to black spot areas, as there can be a lack of local site infrastructure (e.g. power, backhaul connectivity, physical access, etc.). Furthermore, the commercial business case to deploy a site to provide coverage in a black spot area can be weak, given the higher site costs and lower revenues generally associated with these sparsely populated areas.[68]

The issue of improving mobile phone coverage (including in black spot areas) is being considered by the MPBT. A black spot pilot project was included in the MPBT's 2017 work programme, and its Implementation Review 2017 classified this work as a significant step in identifying problem areas and any infrastructure that could potentially be used to improve mobile coverage.[69] This pilot project has now been expanded to encompass all 31 local authority areas (see 2018 Action 12[70]), and all local authorities are now being asked to map local black spots and identify infrastructure that could potentially be used to provide additional coverage on an economic basis. The next steps in this

[68] For example, the results of Scenario 4 indicate that to achieve 99.5% geographic coverage for the 30Mbit/s MBB service, 313 sites are required to be deployed in challenging areas. This refers to the deployment of sites in areas where the modelling restrictions for the deployment of new sites (see Annex 3) have been relaxed in order to achieve high geographical coverage. As noted in the Annex 3, the estimated costs when targeting high geographical coverage is likely to be conservative.

[69] In 2017, the Department of Rural and Community Development (DRCD) and the Department of Communications, Climate Action and Environment (DCCAE) worked with a pilot group of local authorities to identify the issues associated with mapping local black spots. DRCD and DCCAE (2018), 'The Mobile Phone and Broadband Taskforce Implementation Review 2017', 21 February, https://www.dccae.gov.ie/documents/ImplementationReview2017.pdf, accessed 20 July 2018.

[70] 2018 Action 12: "Expand the mobile coverage blackspots pilot project to encompass all 31 local authority areas".

process is for the revised blackspot data to be collected from the mobile telecommunication companies, and for this to be merged with that from the local authorities to identify priority locations.[71] From the simulation results presented above, we note that the costs of addressing black spots (i.e. the least populated 2–3% of the country) depends on the level and quality of the required coverage (e.g. 3Mbit/s, 30Mbit/s).[72] These costs can be substantial, as the marginal cost of coverage becomes non-linear and increases exponentially beyond specific levels.

- Regarding 3Mbit/s MBB population coverage (Scenario 1), the estimated cost of increasing coverage from 99.0% to 99.5% is €70m. This is over four times greater than the estimated cost of increasing coverage from 97.0% to 97.5%, which is €17m.
- Regarding 30Mbit/s MBB population coverage (Scenario 2), the estimated cost of increasing coverage from 99.0% to 99.5% is €102m. This is over four times greater than the estimated cost of increasing coverage from 97.0% to 97.5%, which is €24m.

5.5 Observations on what the market would deliver commercially

In this report we use the term ‘expected commercial roll-out’ to refer to what we consider an Irish MNO would be likely to achieve in terms of mobile coverage in the absence of any regulatory or governmental intervention (such as a spectrum licence coverage obligation). This assessment, among other things, may be helpful in determining whether any future coverage obligations are likely to be categorised as 'Precautionary’ or ‘Interventionist’ as set out in the DotEcon Report (Document 18/103d). As defined by DotEcon:

- Precautionary obligations are those that are expected to be surpassed by the natural deployment level of licensees operating in a competitive market (´Precautionary Obligations´).
- Interventionist obligations are those that are aimed at actively extending coverage beyond the limits that competition alone might deliver (´Interventionist Obligations´).

Below, we also provide a high level assessment of what coverage range each type of obligation is likely to fall into.

The assessment in this section is based on: interviews with stakeholders; the results from the mobile network modelling analysis; and historic investment trends of Irish MNOs. We have not conducted a full-demand modelling exercise. Ultimately, the assessment of what Irish MNOs will achieve (without coverage obligations) depends on many factors, including the impact of competition between the operators.

5.5.1 Population coverage

On the basis of commercial incentives, it is likely that an MNO will choose to primarily target population coverage, as this provides the best opportunity to earn a return on investment (i.e. the demand for mobile connectivity is likely to be greatest in residential areas and where people work and congregate).

[71] https://www.dccae.gov.ie/documents/Mobile%20Phone%20and%20Broadband%20Taskforce%20Q2%20Progress%20Report.pdf
[72] It should be noted that in these simulations, it is assumed that the hypothetical MNO can always deploy site infrastructure to address black spots.

It may not be commercially viable to pursue the last few percentage points of population coverage, given that the marginal cost of coverage rises substantially (as only the areas which are most difficult to cover are left). The speed of roll-out under commercial incentives will also be set to maximise the returns on investment (quicker roll-out up to commercial viability is more costly, but enables the benefits of connectivity to be felt sooner).

We consider that between 2017 and 2020, the extension of the mobile network is likely to be focused on expanding basic connectivity (i.e. 3Mbit/s population coverage).[73] This is partly due to existing levels of coverage, and partly due to the availability of spectrum and carrier aggregation of the three sub-1GHz bands —the 700MHz band will become available mid-2020, and the 900MHz band is unlikely to be refarmed just yet given existing usage for 2G and 3G services.

We consider that from mid-2020, the commercial extension of the mobile network is likely to switch to a focus on extending higher-speed connectivity (e.g. minimum 30Mbit/s population coverage).[74] This is partly because more spectrum will become available, which will also more readily enable three-band Carrier Aggregation (a key technology that will reduce the cost of high-speed connectivity).

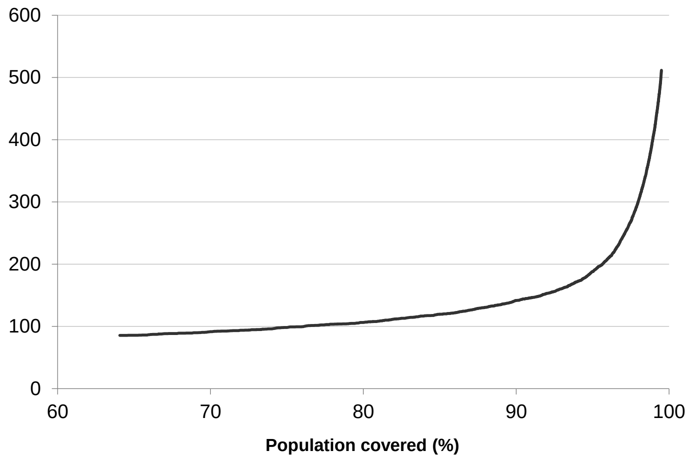
The anticipated switch to 30Mbit/s connectivity is also a product of the fact that providing 3Mbit/s coverage for the last few percentage points of population rises exponentially—the MNO would be able to cover a significant proportion of the population with 30Mbit/s for the same cost as expanding 3Mbit/s. Furthermore, given that existing coverage levels at 3Mbit/s are relatively high, the returns on serving the remainder of population is declining as the population served per base station falls for each additional percent of population served.

After 2020, an MNO targeting 30Mbit/s could more cost effectively target a significantly larger proportion of the population with improved quality of service, compared to extending 3Mbit/s coverage to <1% more of the population. Such an approach would likely be a more preferable commercial strategy and provide a greater return on investment, particularly where 98.6% of the population (and those travelling to those areas) had at least a basic level of connectivity of 3Mbit/s. Improving 30Mbit/s will, in any case, improve 3Mbit/s coverage (through incidental coverage).

The level of coverage achieved will depend in large part on the relationship between coverage and costs. Figure 5.14 shows the costs of expanding 30Mbit/s in the period after 2020; we can see that there is an exponential relationship between coverage and costs. The ability to improve 30Mbit/s population coverage through upgrading sites and additional available spectrum (rather than having to build new sites) means that the initial incremental cost of improving coverage from its starting position of 62.4% is low. However, the incremental cost rises as the coverage rises (especially above 90%), as more investments (particularly in new sites) are required to achieve incremental increases in coverage.

[73] This refers to connectivity at cell edge; other parts of the cell that area closer to the base station will likely have a higher throughput rate.
[74] The European Union’s Digital agenda for Europe distinguishes between basic broadband (between 256 Kbps and 30 Mbps), fast broadband (above 30 Mbps and up to 100 Mbps) and ultra-fast broadband (above 100 Mbps). In targeting “fast broadband” commercial operators are likely to aim for a minimum of 30 Mbps.

Figure 5.14 The cost of targeting 30Mbit/s population coverage, starting in mid-2020 (€m, 2017 monies)



Source: Oxera/Real Wireless.

5.5.2 Road coverage

As with population coverage, MNOs have an incentive to cover roads as their customers make use of mobile coverage on the road. However, achieving widespread coverage of roads requires additional investment (on top of the cost of providing population coverage), and commercial roll-out is unlikely to provide ubiquitous road coverage for high speed connectivity.

The level of mobile coverage provided over roads can vary in terms of the type of road (motorways, primary roads, secondary roads, third roads), the level of coverage (km), and the target speed (Mbit/s). In general, we expect that the commercial roll-out would target motorways in the first instance, due to the quantity of traffic carried.[75] There are three key observations to make regarding the commercial roll-out over roads.

First, targeting population coverage results in reasonable incidental road coverage. A certain level of road coverage will be provided without the MNO needing to target it specifically. For example, targeting 90% Irish population coverage of 30Mbit/s results in:

- 97% 3Mbit/s motorway coverage;
- 95% 3Mbit/s primary road coverage;
- 84% 30Mbit/s motorway coverage;
- 72% 30Mbit/s primary road coverage.

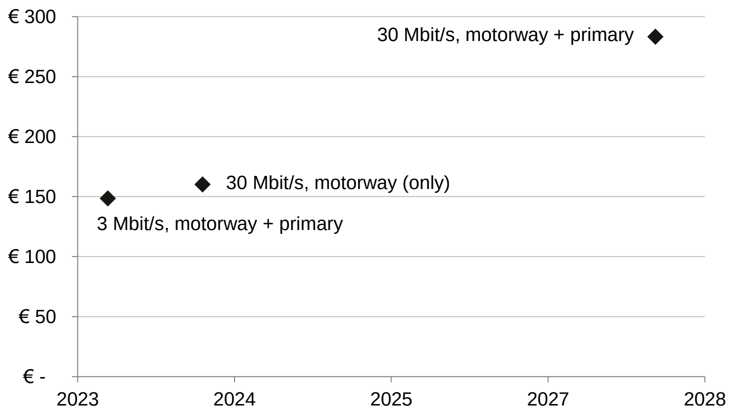
Given that we expect the commercial MNO to target 30Mbit/s population coverage, reasonable levels of road coverage are likely to be achieved.

Second, providing 30Mbit/s coverage of motorways is significantly less costly than providing 30Mbit/s coverage for motorways and primary roads; this can be seen in Figure 5.15. Therefore, commercial 30Mbit/s coverage of motorways is more likely than commercial 30Mbit/s coverage of primary roads.

[75] For example, the M50 (Dublin) carries 145,000 vehicles per day, and motorway traffic is growing at a faster rate than the rest of the road network. See Transport Infrastructure Ireland (2018), ‘National Roads Network Indicators 2017’, April,.

Third, providing 3Mbit/s coverage for motorways and primary roads is significantly less costly than providing 30Mbit/s coverage for motorways and primary roads. This can also be seen in Figure 5.15. Therefore, commercial 3Mbit/s coverage of primary roads is more likely than commercial 30Mbit/s coverage of primary roads. However, high levels of primary road 3Mbit/s coverage are achieved through incidental coverage (see above), and the commercial MNO may not invest in further expansion of primary road 3Mbit/s coverage (as the costs grow exponentially – see the results of scenario 5).

Figure 5.15 Cost and time to reach 99.5% coverage of the specified target, at 2.5% CAGR (PV, millions)



Source: Oxera/Real Wireless.

5.5.3 Interviews with stakeholders

During our discussions with the Irish MNOs (see section 3), we noted the following information related to their observations on coverage expansion in Ireland.

- For MBB, MNOs claimed to be currently achieving close to 90% geographical coverage, compared to population coverage in the 'high 90s' for 4G data and 98% for outdoor voice.
- With 700MHz LTE—possibly aggregated with other sub-1GHz bands—MNOs believe that they could reach 97% geographic coverage around 2022 by harnessing the efficiencies of the 5G radio in certain areas, especially by improving cell edge performance.
- For roads, coverage levels are below 90%—all three MNOs would aim to boost that to the high 90s, but only if they can get roadside sites, which they see as a government/highways agency issue.

In relation to bullet 1, Table 4.3 and Table 4.4 shows that population coverage for the synthetic mobile network is 96.7% (3 Mbps) and 97.7% (voice). Therefore, Irish MNO observations in relation to 'high-90s' 4G data and 98% for outdoor voice appear reasonable. In relation to the observation that MNOs are currently achieving close to 90% geographical coverage, the synthetic mobile network estimates coverage of 82.1% for 3Mbit/s and 85.7% for voice. Therefore, these observations for basic 4G connectivity appear reasonable although somewhat overstated, and it is more likely that 90% geographic coverage (3 Mbps) will be achieved by mid- 2020 for 3 Mbps and voice.

In relation to bullet 2, some MNOs mentioned that they would expand the networks to provide coverage to 97% of the geographic area by 2022.

However, given the costs and roll-out time associated with geographic coverage, (for example, scenario 3 indicates that 97% geographic coverage of 3Mbit/s at a roll-out rate of 2.5% CAGR would only be achieved in January 2032 and would cost €270m), we are of the view that achieving approximately 98% population coverage (with basic connectivity of 3Mbit/s) in Ireland is more plausible in the period up to mid-2020. Should certain MNOs target more aggressive roll-out, the population coverage achieved is likely to be beyond 98%.

Providing coverage to geographical areas is more costly than providing similar levels of coverage to the population. This is because of the dispersed nature of the populated areas in the country. The greater network roll-out required for geographic area coverage also takes longer to be built.

In relation to bullet 3, motorway coverage for the synthetic mobile network is estimated at 95.2%, while national primary and national secondary road coverage is 89.7% and 85.5% for 3Mbits/s. Therefore, Irish MNO observations that existing coverage levels for roads are below 90% appears reasonable. In relation to gaining access to roadside sites, we note that such issues are likely to have been raised and considered in the MPBT

5.5.4 Historic levels of investment

While past behaviour is not necessarily a good predictor of future behaviour, by looking into historical investments by Irish MNOs, we are able to contrast the orders of magnitude of such previous investment with the investment levels required going forward to meet certain connectivity levels. This will allow us to see the existence and magnitude of any potential commercial funding gap.

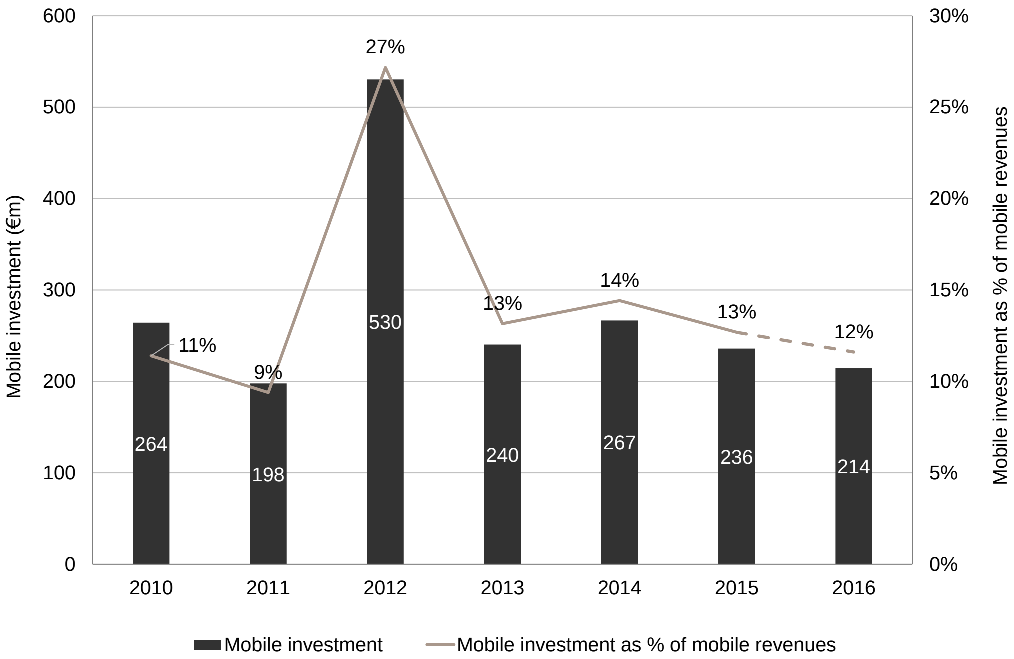
Two Irish MNOs (Eir and Vodafone) have claimed that they will (collectively) spend over €800m on their 4G networks (although it is unclear what proportion of this will go into expanding network coverage). Eir has stated that it plans to invest approximately €330m,[76] while Vodafone has reportedly invested €550m.[77]

The overall level of historical network investment by (all) Irish MNOs (which in addition to the above would include Three), appears to be significant—€289m per annum in the period 2010–16—on the basis of data from the European Commission. The annual average from 2014–16 is slightly lower at €239m. This is shown in Figure 5.16.[78]

The network investment shown in the figure includes investments other than improving the coverage of connectivity (for example, replacing existing assets at the end of their lifespan might not increase connectivity, while upgrading assets to new technologies might increase connectivity). These figures, therefore, represent an upper-bound estimate of the historical level of capital investment in improving mobile coverage.

[76] Eir (2013), 'eircom Group First to Launch 4G Mobile in Ireland', press release, 26 September, https://www.eir.ie/opencms/export/sites/default/.content/pdf/IR/news/eircom_launches_irelands_first_4g_service.pdf, accessed 24 July.
[77] TeleGeography (2016), 'Vodafone Ireland completes national network upgrade; 4G coverage reaches 90%', 12 April, https://www.telegeography.com/products/commsupdate/articles/2016/04/12/vodafone-ireland-completes-national-network-upgrade-4g-coverage-reaches-90/, accessed 24 July. It is unclear how much Three invested in 4G, due to the merger with O2's 4G network.
[78] The greater investment in 2012 was likely preparation for the spectrum that was auctioned in 2012 and became available for use in 2013.

Figure 5.16 Mobile network investment in Ireland across all MNO (2010–16)



Note: Adjusted to 2016 prices using CPI. Excluding licence fees. Mobile revenues in 2016 estimated as the average of mobile revenues in 2013–15.

Source: Oxera/Real Wireless, ComReg, European Commission 'Telecommunications data files', Central Statistics Office.

If we take the average annual total investment across the whole period (€289m) as an upper bound, and the average from 2014–2016 (€239m) as a lower bound, and split equally between the three Irish MNOs (Vodafone, Eir, Three), we get €80m–€96m per annum.[79]

As noted above, it is unlikely that this full amount is spent on improving mobile coverage. Under a conservative estimate of only 10–20% of network investment being spent on improving mobile coverage, this would yield an annual investment to improve mobile coverage of €8m–€19m, for each MNO.[80]

5.5.5 Concluding observations on what the market would deliver commercially

Different Irish MNOs may adopt different strategies depending on if they face different costs or revenues, or if they target different segments of the market. Importantly, different MNOs will have different starting coverage levels and network topologies as well, meaning that the optimal strategy may vary significantly; for example, one MNO may target greater coverage of 3Mbit/s than another.

On this basis, it should be noted that given differences between MNOs, we would expect there to be differences in future investment strategies. It is not possible to definitively say which Irish MNOs will achieve which level of coverage; however, we can take a view on the likelihood that **some** Irish MNOs will achieve certain coverage levels. As noted above, this may provide

[79] It should be noted that while dividing by three is appropriate for the purposes of the synthetic MNO, in reality, the levels of investment are proportioned differently and vary between MNOs.
[80] The 2014–16 average is €80m, and the 2010–16 average is €96m. 10% of either is €8m and €9.6m, respectively. 20% of either is €16m and €19.2m, respectively.

useful information in determining whether any future coverage obligations can be categorised as precautionary or interventionist

Below, we summarise our observations from comparing the model results with the historic mobile network investment. We also set out the number of sites and upgrades required for each particular coverage level. While the cost of additional sites will be an important determining factor in roll-out, the availability of sites will also be a particularly important factor.

The period 2017–20

For 2017–20, we assume that a MNO would focus on population coverage, and that the base case would occur (2.5% network growth targeting 3Mbit/s coverage)—the modelling of other scenarios alters the roll-out after mid-2020 only after the Candidate Bands become available. With a network growth rate of 2.5%, the base case would accomplish 98.6% 3Mbit/s population coverage by mid-2020. This would also result in 63.9% levels of incidental 30Mbit/s population coverage and 88.7% incidental geographic coverage.

Based on historic network investment levels, investing €8m–€19m per annum from mid-2017 to mid-2020 would result in total present value of investment of €21m–€51m.[81] If the historic network investment refers to CAPEX investment (only), then this may be enough to deliver the required investment in 3Mbit/s coverage to 2020: the CAPEX-only PV cost of the base case to mid-2020 is €45m.

It is possible that some MNOs may stop increasing 3Mbit/s coverage before reaching 98.6% population coverage, but the base case cannot by definition reflect multiple roll-out strategies, and, as we see from the historical investment, 98.6% should be an achievable level of population coverage.

The period 2020 onwards

The analysis for what a MNO might do commercially from mid-2020 starts from the level of coverage achieved in the period to mid-2020 (i.e. 98.6% 3Mbit/s coverage and 63.9% 30Mbit/s coverage).

It is unlikely that an MNO would have the commercial incentive to target increasing 3Mbit/s coverage beyond 98.6% (to, say 99.5%) in the years after 2020, as the cost of reaching the last few percentage points of population increases exponentially. It would be more likely that an MNO would wish to invest in improving 30Mbit/s population coverage, given the higher potential returns to investment in 30Mbit/s (see section 5.5.1).

Table 5.8 sets out the estimates for the costs required to achieve higher levels of 30Mbit/s population coverage (i.e. at least 80% and up to 99.5%). During this assessment, we provide a view on the likelihood of different levels of coverage, according to the following:

- Future coverage obligations in the “*Very Likely*” and “*Likely*” categories should broadly correspond to any 'Precautionary Obligations’ as such obligations are expected to be surpassed by commercial rollout in a competitive market
- Future coverage obligations in the “*Possible*” category could be considered ‘Precautionary Obligations’ given the investment required is likely to be

[81] The future investment is discounted at 8.63% and is in 2017 monies. For example, if an MNO invested €4m in 2017, followed by €8m in 2018 and 2019, and then €4m in 2020, the present value would be the 2017 investment plus discounted investment in 2018–20, equalling a total of €21.3m.

within that which was invested by the Irish MNOs 2010–16. However, this would depend on individual operator's circumstances and commercial strategy, and caution should be exercised within this range.

- Future coverage obligations in the "*Unlikely*" category would broadly correspond to an 'Interventionist Obligation' given that the cost of serving those areas is expected to go beyond what operators would be willing to do commercially.

The data in the table assumes that in 2020, MNOs have achieved 64% population coverage of 30Mbit/s. It therefore shows the incremental cost of increasing this coverage. For example, to increase 30Mbit/s population coverage from 64% to 80%, it would cost about €16m CAPEX (not including the OPEX costs of running the network) and require the building of 204 new sites and 363 site upgrades. Given the historical levels of investment observed, we consider it very likely that MNOs in Ireland would achieve this level of coverage by 2023.

Table 5.8 Increasing 30Mbit/s population coverage levels from 2020

30Mbit/s population coverage	Date achieved	Total CAPEX from 2020* (nominal €m)	New sites built from 2020*	Site upgrades built from 2020*	Assessment of likelihood (i.e. that an operator would achieve this on their own)
80%–85%	2022 (80%)–2023 (85%)	16–27	204–227	363–568	**Very likely** The incremental cost of expanding coverage is low (compared to the incremental cost at higher levels of coverage) and it is likely that the commercial case for expanding 30Mbit/s coverage will exceed the costs of doing so. Also, the investment required is likely to be well within that which was invested by the Irish MNOs 2010–16, implying that the level of investment is not unprecedented.
85%–90%	2023 (85%)–2024 (90%)	27–44	227–270	568–825	**Likely** As above, the incremental cost of expanding coverage is low (compared to the incremental cost at higher levels of coverage) and it is likely that the commercial case for expanding 30Mbit/s coverage will exceed the costs of doing so. Also, the investment required is likely to be well within that which was invested by the Irish MNOs 2010–16, implying that the level of investment is not unprecedented.
90%–95%	2024 (90%) – 2027 (95%)	44–82	270–378	825–1,197	**Possible** The incremental cost of expanding coverage is greater than that for increasing coverage in the range 80% to 90%. However, the incremental cost is lower than for higher levels of coverage. We can therefore say with less certainty that the commercial case for expanding 30Mbit/s coverage will exceed the costs of doing so. However, the investment required is likely to be within that which was invested by the Irish MNOs 2010–16, implying that the level of investment is possible depending on individual operator's circumstances and commercial strategy.
95%–99.5%	2027 (95%) – 2042 (99.5%)	82–397	378–1,466	1,197–1,603	**Unlikely** The incremental cost of expanding coverage is much greater than that for increasing coverage at lower levels. It is therefore much less likely that the commercial case for expanding 30Mbit/s coverage will exceed the costs of doing so. Also, the investment required may exceed that which was invested by the Irish MNOs 2010–16, implying that the required level of investment may be unlikely.

Note: Date achieved at site growth rate of 2.5% CAGR. CAPEX refers to: CAPEX of new sites, including new 4G RAN equipment and new backhaul; plus CAPEX for two refreshes of 4G RAN equipment and two refreshes of backhaul; plus labour for the two refreshes (every eight years). * CAPEX, new sites and site upgrades are incremental, on top of that required to achieve coverage of 98.6% 3Mbit/s population coverage and 64% 30Mbit/s population coverage in 2020.

Cost data is presented in nominal terms (rather than in discounted present value terms) for ease of comparison to the levels of historical investment on an annual basis (see section 5.5.4).

Source: Oxera/Real Wireless.

The commercial roll-out of population coverage will affect the commercial roll-out of road coverage. Table 5.9 presents our assessment on commercial coverage regarding motorways and primary roads. The ‘very likely’ and ‘likely’ assessments relate to incidental coverage from achieving the ‘very likely’ and ‘likely’ population coverage targets (as set out in Table 5.8, above).

The ‘possible’ assessment relates to additional investment in achieving 90–95% motorway 30Mbit/s coverage (in addition to the incidental motorway coverage from achieving 90–95% population 30Mbit/s coverage). The ‘unlikely’ assessment relates to additional investment in achieving over 95% motorway 30Mbit/s coverage (in addition to the incidental motorway coverage from achieving 90–95% population 30Mbit/s coverage). Expanding primary road coverage is unlikely to be the priority of a commercial MNO, so this is not presented in Table 5.9.

Table 5.9 Greater 30Mbit/s road coverage, from mid-2020 onwards

	Target description	Motorway coverage	Primary road coverage	Estimated cost (CAPEX and OPEX)
Very likely	Incidental coverage arising from achieving 80–85% 30Mbit/s population coverage in 2022–23	Incidental: • 96.7–97.0%, 3Mbit/s • 69.8–77.1%, 30Mbit/s	Incidental: • 94.2–94.5%, 3Mbit/s • 53.1–61.8%, 30Mbit/s	*None in addition to the population coverage*
Likely	Incidental coverage arising from achieving 85–90% 30Mbit/s population coverage in 2023–24	Incidental: • 97.0–97.3%, 3Mbit/s • 77.1–83.8%, 30Mbit/s	Incidental: • 94.5–94.9%, 3Mbit/s • 61.8–71.5%, 30Mbit/s	*None in addition to the population coverage*
Possible	Incidental coverage arising from achieving 90–95% 30Mbit/s population coverage in 2024–27	Incidental: • 99.0–99.2%, 3Mbit/s • 83.8–90.0%, 30Mbit/s	Incidental from pop. 30Mbit/s: • 99.0–99.2%, 3Mbit/s • 83.8–90.0%, 30Mbit/s	
	plus: Further investment in motorway 30Mbit/s coverage reaching **90–95%**	Further coverage: • 99.2–99.7%, 3Mbit/s • 90.0–95.0%, 30Mbit/s		Further motorway coverage would cost €116m–€129m[1] if starting in mid-2020 (i.e. without the 30Mbit/s pop. coverage roll-out)
Unlikely	Incidental coverage arising from achieving 90%–95% 30Mbit/s population coverage in 2024–27	Incidental from pop.: • 99.0–99.2%, 3Mbit/s • 83.8–90.0%, 30Mbit/s	Incidental from pop. 30Mbit/s: • 99.0–99.2%, 3Mbit/s • 83.8–90.0%, 30Mbit/s	
	plus: additional investment in motorway 30Mbit/s coverage reaching **95–99.5%**	Further coverage: • 99.7–99.99%, 3Mbit/s • 95.0–99.5%, 30Mbit/s		Greater motorway coverage would cost €116m–€160m[2] if starting in mid-2020 (i.e. without the 30Mbit/s pop. coverage roll-out)

Notes: Costs (CAPEX and OPEX) are in 2017 present value terms.

[1] The difference between these figures (i.e. €13m) gives an estimate of the cost if starting from 95% 30Mbit/s population coverage. These figures are based in information derived from Scenario 7.

[2] The difference between these figures (i.e. €44m) gives an estimate of the cost if starting from 95% 30Mbit/s population coverage.

Source: Oxera/Real Wireless.

6 Effectiveness of approaches to promoting mobile connectivity in other EU member states

Noting that commercial investment will drive mobile connectivity to a certain level, ComReg asked Oxera and Real Wireless to:

- identify and consider the effectiveness of regulatory and/or governmental approaches taken (or proposed to be taken) within the EU and in other relevant jurisdictions to incentivise mobile connectivity investment beyond this level;
- provide observations on such approaches in relation to Ireland.

In doing so, we explore the effectiveness of coverage obligations and mobile network sharing, while also briefly considering public subsidies as approaches to improving mobile connectivity.

In support of this, we have studied the experiences of MNOs in five member states (Austria, Denmark, Finland, Sweden, and the UK).

This section provides an overview of the main findings with respect to the following three approaches to improving mobile connectivity.

- **Coverage obligations**—attaching coverage obligations to spectrum licences is a common way for regulators to increase levels of mobile connectivity. We explore how coverage obligations have been used in the five case study countries (section 6.1).
- **Public subsidies—**governments can use public subsidies to achieve greater mobile connectivity. We briefly describe how public subsidies have been used in the five case study countries (section 6.2).
- **Mobile network sharing**—MNOs often share elements of their mobile networks in order to reduce costs and increase coverage. We examine the effectiveness of this commercial, operator-driven strategy on increasing mobile connectivity in the five case study countries (section 6.3).The full study and analysis of the different approaches is in Annex 4.

6.1 Coverage obligations on spectrum licences

While mobile coverage obligations are very often used by European regulators, the reasons for and the form of them vary considerably across countries. For example, some countries adopt coverage obligations to promote investment in areas that MNOs may not find it commercially viable to cover (Interventionist Obligations), while others employ them to ensure a minimum level of national coverage is provided (Precautionary Obligations), or to increase the speed of roll-out. Many countries implement coverage obligations to achieve some combination of these, or even all three.

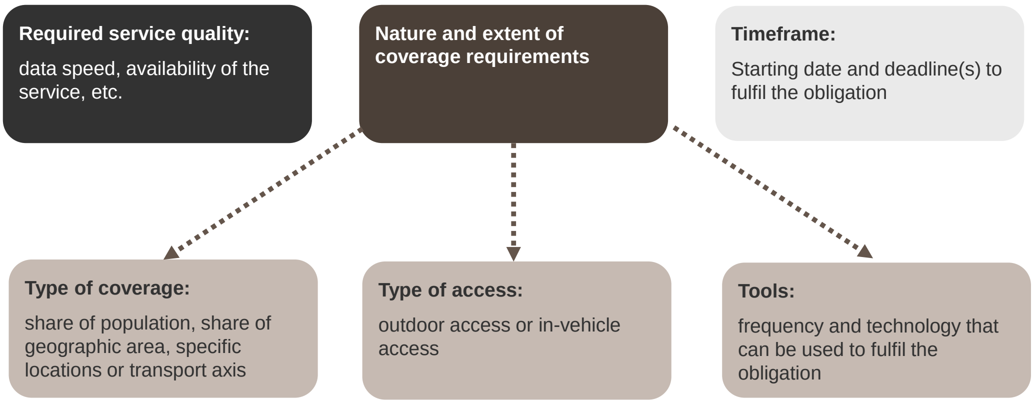
In Ireland, ComReg’s coverage obligation in the 2012 Auction, in general terms, was designed to promote competition, allow the potential for market entry and be in the best interest of consumers. In addition, it was designed to ensure the efficient use of the radio spectrum and, in particular, prevent cherry picking (such as in densely populated areas) that could destabilise overall competition. In setting a 70% population coverage level, ComReg observed that this is sufficient to provide coverage in all the townlands in Ireland with 50 inhabited houses or more.[82] In addition, ComReg believed that competition would drive actual coverage levels a considerable margin beyond the 70% popoulation requirement.

Our analysis of coverage obligations in the case study countries leads to the following observations:

- **coverage obligations are generally employed and designed in order to achieve specific objectives**—for example facilitating new entrants (e.g. Austria), increasing the availability of mobile connectivity in coverage black spots (e.g. Austria, Denmark and Sweden);
- **coverage obligations on 800MHz spectrum licences have a promoted the roll-out of 4G, including in rural areas**—most operators achieve their coverage obligations although they may also have achieved them without coverage obligations. Typically, regulators imposed a target of above 90% of the population. Some regulators also specified particular regions (e.g. Austria) or post codes (e.g. Denmark) that were required to be covered
- **coverage obligations can be set to oblige the roll-out of coverage in specific areas**—where specific areas are targeted, these are normally specified in advance and based on specific criteria (e.g. Austria, Denmark) although some degree of dynamism[83] could be built into the obligation (e.g. Sweden);
- **coverage obligations can be set to increase the speed of roll-out**—in areas in which the operator may already find it commercially viable to build a network (e.g. the UK);
- **appropriately specifying the obligation in detail (see Figure 6.1) is critical to the achievement of its objectives**—for example, in Ireland, where 37% of the population lives in rural areas[84], a population coverage requirement greater than 63% would, in effect, oblige an operator to provide services in rural areas in order to meet the licence obligation. In addition, specifying a high population coverage target in Ireland would require an operator to extend mobile connectivity to significant parts of the country's landmass. For example, the simulation results for an MBB 30Mbit/s service (see section 5.3) indicates that 90% population coverage would equate to 28% landmass coverage, whereas 99% population coverage would equate to a doubling of the landmass coverage to 59%;[85]

[82] See ComReg (2012), 'Multi-band Spectrum Release: Release of the 800MHz, 900MHz and 1800MHz Radio Spectrum Bands', 16 March.
[83] In Sweden, PTS included a dynamic coverage obligation in the 800MHz auction of 2011 to oblige one licensee (Net4Mobility—a JV between Tele 2 and Telenor), to cover all homes and business identified by PTS. The identification of locations to be covered took place annually from 2011 and in this way, PTS implemented a dynamic coverage obligation based on specific needs in rural areas (i.e. no access to 1Mbit/s and requested coverage). In 2012, PTS identified 628 homes and companies businesses that would be offered coverage and this required Net4mobile to cover 472 addresses (i.e. 75% of 628) by the end of 2013.
[84] Census 2016, available from the Central Statistics Office, www.cso.ie, accessed 24 July.
[85] The World Bank database, https://data.worldbank.org, accessed 24 July.

Figure 6.1 Coverage obligations specify a number of parameters



Source: Oxera/Real Wireless.

- **it may not be necessary to attach coverage obligations to all of the licenses in an award**—if the operator with the obligation rolls out coverage with the aim of meeting the target by the deadline, competition may incentivise other operators to deploy at a similar speed (e.g. Sweden, the UK). However, this may not have occurred in Denmark where the operator with the coverage obligation rolled out quicker than the others;
- **it is possible to design coverage obligations such that different areas of coverage can be assigned to different operators in an award**—this approach was successfully used in Denmark, although the end result of the auction was that the coverage obligation was placed on one operator;
- **setting the details of coverage obligations needs careful consideration**—due to risk of them being set too high for some bidders or them not being met in the future (e.g. Sweden[86]);
- **regulators should, and indeed are often legally obliged to assess coverage obligations to ensure that any such obligations are objectively justified and proportionate**—with respect to ensuring the efficient use of the radio spectrum and that such obligations are achievable;[87]
- **coverage obligations can be designed so that they do not deter new entrants**—for example Austria would have applied different coverage obligations to new entrants, had any won spectrum;
- **a coverage obligation is usually static in time**—it does not adjust to the emergence of more pressing needs in terms of mobile connectivity (as it is defined in advance of the auction). Sweden is an exception to this: the regulator identified new homes and places of businesses to be covered as part of the obligation on an annual basis. However, the operator in charge of

[86] In Sweden, Net4Mobility (a JV between Tele 2 and Telenor) failed to meet the coverage obligations as defined in their licenses, and the PTS defined a clear schedule for its future coverage obligations. It would therefore appear that the coverage obligations may have been too onerous for Net4Mobility. This might be because the specific addresses in the coverage obligations were set dynamically by the PTS on an annual basis following the auction or other practical considerations, such as the roll-out time required for Net4Mobility being too onerous for it.
[87] Most MNOs have met (or are on the way to meeting) their 800MHz coverage obligations, indicating that these coverage obligations seem achievable for MNOs, particularly where the roll-out is sufficiently long and the obligation itself is not excessive.

the mandatory coverage struggled to meet the coverage obligation, perhaps due to the dynamic requirements.

Overall, the benefits generated by the coverage obligations in each country highlight how the **coverage obligations should be designed around each country's characteristics—there is no 'one size fits all'**.

In the next section we briefly describe the use of public subsidies to increase mobile connectivity in the case study countries.

6.2 Public subsidies

There are an **increasing number of public subsidy schemes across the case study countries that aim to promote mobile connectivity**. These can be large or small schemes, depending on their scope, and can subsidise one (or more) operators or indeed infrastructure providers.

There are different ways that the government could give a public subsidy to MNOs: direct funding or tax breaks (VAT exceptions etc.). Public subsidies can also vary in their specificity: they can either define areas (which the MNO decides how to cover), or they define the precise location of subsidised sites to be built.

The case study countries have all deployed public subsidies to encourage greater mobile connectivity. These schemes vary in scope, from schemes targeted at improving backhaul to those aimed at building specific base stations in black spots. The mechanisms also vary, with loans from the European Investment Bank used in some countries. When designing a public subsidy it is important to consider the factors described in Figure 6.2.

Figure 6.2 Parameters of public subsidies

Type of funding:
subsidies, grant, loan

Beneficiary:
one vs. several operators, a joint-venture

Target:
flexibility vs. specific network elements (e.g. backhaul)

Tools:
frequency and technology that can be used

Source: Oxera/Real Wireless.

Public subsidies, however, come with risks for government. In particular, the government would need to ensure compliance with the State aid rules, which may require a formal State aid notification to the European Commission.

In the next section we briefly describe the use of mobile network and spectrum sharing to increase mobile connectivity in the case study countries and Ireland.

6.3 Mobile network sharing

Mobile network sharing is a commercial, operator-driven decision that is motivated particularly by the potential to save significant costs. We henceforth take spectrum sharing to be a category of mobile network sharing.

The likelihood of a network sharing agreement being commercially viable depends on the extent to which the operators involved have similar size assets (e.g. spectrum holdings, networks) or roll-out ambitions, and whether the operators use the same or compatible equipment vendors.

In the specific case of spectrum sharing, we note that it is likely to be more commercially attractive in areas where the parties have similar levels of traffic (or else one operator may benefit from the pooling of spectrum resources more than the other).[88]

While the potential benefits of network sharing can be seen, these need to be balanced against possible competition distortions that could arise, for example from reduced scope for differentiation, and decreased incentives to invest in increasing coverage and/or capacity.

From our analysis of the case study countries, we observe the following.

- Network sharing agreements can vary considerably in nature and scope, and the market circumstances and competitive landscape will dictate the extent to which different forms of sharing will deliver benefits. In short, the costs and benefits of network sharing agreements need to be assessed on a case-by-case basis.
- In some circumstances and where appropriate, regulators or competition authorities have taken actions to provide ex ante approval for sharing arrangements in accordance with competition law. For example, the Danish Competition Authority required commitments from the operators before approving the creation of the TT-Network joint venture.
- In terms of regulatory actions on network sharing as set out in the case study countries, regulators have taken decisions in accordance with relevant legislation that facilitate the functioning of the sharing arrangement. For example, the Swedish regulator allowed the operators to transfer spectrum rights to the joint venture, and the UK regulator granted specific powers to a joint venture in order to reduce obstacles to network roll-out. Similar to Ireland, joint bidding for spectrum at auction was allowed by both the Danish and Swedish regulators.

In relation to Ireland we observe the following.

- In line with ex post competition law assessment, ComReg has set out its current thinking on collaboration between wireless operators:[89]

  Recalling that there are many forms of collaboration and, further, that the benefits and drawbacks of each collaboration will depend on the specifics of the proposed collaboration, ComReg maintains that it cannot have a firm view on spectrum rights sharing (or pooling) and network sharing other than that it would look more favourably on agreements that would not unduly restrict competition and would deliver demonstrable benefits that are shared with end-users.

  Further, ComReg remains of the view that interested parties should be in a position to identify for themselves the types of potential issues and concerns (e.g. competition law) that could be raised by a proposed collaboration agreement.

  Oxera agrees with this case-by-case approach.
- There is currently one passive network sharing agreement (‘Mosaic’) between Eir and Three, while Vodafone has a standalone network. During the 2014 Three/O2 merger, Vodafone stated that it was ‘very keen’ to have

[88] This is a generally accepted view by industry sources. See for example Larsen, K. (2012), ‘Fundamentals of Mobile Network Sharing’, 15 July, slide 24, available at: https://www.slideshare.net/KimKyllesbechLarsen/fundamentals-of-mobile-network-sharing/24-Common_Frequency_SharingSolution_for_lowdemand, accessed 14 February. Or see Coleago Consulting (2015), ‘Mobile Network Infrastructure Sharing—Industry Overview & Coleago's Approach’, 12 February, slide 10, https://www.slideshare.net/StefanZehle/coleago-network-sharing-overview-v011-100215-cb, accessed 24 July.

[89] ComReg (2017), ‘Radio Spectrum Management Strategy 2016 to 2018’, 21 June, para 7.21–7.22.

a network sharing agreement in Ireland, which was seen by the European Commission as evidence that Eir continued to have a choice over which other operator to share networks with.[90] However, following a merger commitment to the European Commission, Eir and Three agreed to a strengthened Mosaic agreement. Further, in 2014, Vodafone and Three terminated their network sharing agreement.

[90] European Commission (2014), 'Case No COMP/M.6992 HUTCHISON 3G UK / TELEFONICA IRELAND: Merger Procedure Regulation (EC) 139/2004', Article 8 (2) Regulation (EC) 139/2004, 28 May, para. 1,009–1,010.

7 Recommendations

The use of, and demand for, mobile services in Ireland is growing significantly. This growth is expected to continue over the coming years, most particularly in light of the growing popularity of mobile data services, including mobile broadband (MBB).

As a starting point to considering how best to meet consumer demand for mobile connectivity, it is important to firstly recognise that this is a multi-faceted issue. The provision of mobile connectivity should not solely be confined to considering the services provided by macrosite mobile networks (i.e. the 2G, 3G, 4G networks, and future evolutions thereof).

Other networks and dedicated solutions can also play an important role in meeting mobile connectivity objectives. This is particularly pertinent for the provision of indoor connectivity service in light of the significant detrimental effect that building materials (such as windows, insulation, block and roofing materials) can have on the propagation of radio waves into buildings.

As set out in ComReg Document 18/73, the losses suffered by radio waves in penetrating these materials can lead to more than a 100-fold reduction in signal strength. To effectively address indoor mobile coverage, there are a number of specialised solutions which can be deployed by MNOs and consumers, including the use of Wi-Fi and native Wi-Fi calling on a fixed broadband connection to offload mobile data and voice traffic, mobile repeaters and femtocells. Further, some new IoT services can be provided via low power wide area networks.[91]

In addition, it is important to recognise that there are a number of possible regulatory and governmental approaches that could be employed to address or promote mobile connectivity. Such approaches include: the use of government taskforces; the inclusion of licence obligations in a spectrum award; public-private partnerships; and public funding schemes.[92] Furthermore, with the exception of the inclusion of licence obligations, which could occur when a spectrum award is held, the timing for implementation of these approaches can vary.[93]

Any approach that seeks to improve mobile connectivity must balance the potential consumer benefits with the associated costs (especially the significant network build costs). While the types of benefits and costs from intervention will likely be similar across countries, their respective magnitudes will likely vary,[94] and as a result any intervention will need to assess the benefits and costs on a case-by-case basis.

Notwithstanding the above, and as a result of the scope of work we have undertaken, we set out below 10 recommendations in relation to the

[91] For example, using narrowband-IoT or other LP-WAN technologies. Deployments using licence-exempt spectrum in the 868 MHz band also allow the possibility of end users deploying their own low power IoT network.
[92] For example, the MPBT is considering how to address and help alleviate connectivity issues with mobile phone and broadband services.
[93] For example, public funding schemes, where appropriate, could be initiated following a spectrum award, having due regard to the specific context and considerations at that time.
[94] This is because of the differences across countries on both the demand side (e.g. consumer preferences, including willingness to pay and service demands) and on the supply side (e.g. number of networks, degree of competition, nature of coverage, population density and degree of rural population). Furthermore, countries may differ in their starting points in terms of mobile connectivity, which can mean that the application of the same approaches in different countries would lead to sub-optimal outcomes in some.

consideration of potential coverage obligations for the Candidate Bands in Ireland.[95]

We group the recommendations into three themed categories, which are described in more detail below:

- Understanding the Irish context and associated network costs (of greater mobile connectivity) is critically important to the success of any intervention;
- Targeting population coverage is likely to be the most preferable approach in Ireland;
- A coverage obligation of 30Mbit/s to a high population level would appear feasible and is where we would recommend ComReg focus its attention.

Recommendations 1–4: understanding the Irish context and associated network costs (of greater mobile connectivity) is critically important to the success of any obligation

1. Coverage obligations should take into account the multi-faceted nature of connectivity and be designed around Ireland's distinct characteristics and priorities

The international case studies demonstrate that there is no 'one size fits all' approach to designing coverage obligations; regulators must tailor coverage obligations to the needs of their country, including: the specific connectivity objectives; the nature of population dispersion and geo-spatial factors; the degree of existing mobile coverage; the number of existing operators; the nature of competition in the market; and the degree of existing network sharing. In addition, given the multi-faceted nature of connectivity, complementary solutions can be an effective means of addressing certain connectivity challenges. For example the use of native Wi-Fi calling and mobile repeaters for indoor connectivity

In Ireland, it will be very important to account for the highly disparate population and the relatively low population density. Ireland has one of the most distributed and rural populations in Europe. For example, 37% of the population resides in rural areas, and 3% lives in 28% of the area. This means that providing high levels of population coverage in Ireland will likely require a higher percentage of geographic coverage than required in the other case study countries.

2. Any proposed mobile licence coverage obligation needs to recognise the costs of achieving that coverage

The level of coverage to be provided has clear implications for the cost of a mobile network. As shown by the mobile network cost analysis we have completed, the cost of increasing network coverage increases exponentially at high coverage levels.

For example, in the case of the 30Mbit/s MBB population coverage scenario, the costs of increasing coverage from 99.0% to 99.5% was €102m. This is over

[95] The Candidate Bands comprising of the 700MHz, 1.4GHz, 2.1GHz, 2.3GHz and 2.6GHz bands.

four times greater than the cost of increasing coverage from 97.0% to 97.5%, which is €24m.

3. Observations on what a commercial operator would likely roll out in the absence of coverage obligations provides the basis for considering the incremental cost of a coverage obligation

The incremental cost of a coverage obligation will come from the level of coverage required above what an operator would have achieved anyway. Interventionist coverage obligations need to balance the incremental cost of additional coverage (i.e. above those commercial levels) with the benefits that additional coverage may bring.

While this study has not modelled the commercial incentives to rolling out coverage, by comparing the costs of different levels of coverage with some assumption about how much Irish MNOs may be likely to invest in expanding network coverage over the coming years, we can produce some high-level views on possible coverage that may be delivered commercially. On the basis of this analysis, we find the following.

- It is **likely** that an Irish MNO will achieve (without intervention) 85–90% MBB population coverage with 30Mbit/s. It is estimated that this would be achieved by 2024.[96]
- It is **possible** that an Irish MNO will achieve (without intervention) 90–95% MBB population coverage with 30Mbit/s. It is estimated that this would be achieved by 2027.[97]
- It is **unlikely** that an Irish MNO will achieve (without intervention) 95 – 99.5% MBB population coverage with 30 Mbit/s.

On this basis, if there is a policy objective to achieve greater (or faster) mobile coverage, beyond that delivered by commercial operators, then an interventionist approach (be it regulatory or governmental) may well be required.

4. Commercial operators will likely focus on enhanced mobile broadband (MBB) services as the primary business case

Mobile broadband will be the primary business case for future mobile connectivity, and networks will be designed to predominantly deliver MBB services. Other services, such as Connected Vehicles (CV) and Industrial Internet of Things (IIoT) are likely to be complementary and may require significant network costs. These other complementary services may therefore be less appropriate for consideration in a coverage obligation, particularly where the benefits of these services is largely unknown.

In the case of IIoT, the locations where IIoT is required do not typically coincide with the locations where the population reside. There is therefore low incidental IIoT coverage associated with high population coverage, and the costs of providing IIoT coverage is high (see Annex 3 for further detail).

[96] This will generate the following incidental 30Mbit/s MBB coverage: 53–63% MBB geographic coverage; 77–84% MBB in-vehicle coverage of motorways; and 62–72% MBB in-vehicle coverage of national primary roads.

[97] This will generate the following incidental 30Mbit/s MBB coverage: 63–75% MBB geographic coverage; 84–90% MBB in-vehicle coverage of motorways; and 72–82% MBB in-vehicle coverage of national primary roads. It is also possible that a commercial operator will target additional motorway coverage of 30Mbit/s (without intervention), achieving 90–95% MBB in-vehicle motorway coverage with 30Mbit/s.

Recommendations 5–7: targeting population coverage is likely to be the most preferable approach in Ireland

5. **Coverage obligations should not be designed with a focus on providing ubiquitous geographic coverage as this would be extremely costly**

Coverage targeting geography (% landmass) is considerably more costly and takes much longer to roll out to high levels (assuming a constant network roll-out rate) than coverage targeting population.

As an example, it is estimated that 99.5% geographic coverage with 30Mbit/s by 2027 would cost over €1,860m. By way of contrast, providing 99.5% population coverage of 30Mbit/s by 2027 would cost €511m.

6. **Coverage obligations should be population focused primarily where people live, but also consider where people work, transit and commute, and places of interest**

The greatest benefit from MBB services is likely to be felt in the areas of Ireland where the population live, work and commute.[98] [99] Focusing on population coverage is a quicker and less costly method to provide services to people, rather than focusing on geographic coverage, which may yield little societal benefit.

Further, targeting population coverage also results in substantial incidental coverage. For example, achieving 90% population coverage with 30Mbit/s results in the following incidental 30Mbit/s coverage: 63% geography; 84% motorway; and 72% primary road.

7. **The costs for addressing black spots (i.e. the least populated 2–3% of the country) are likely to be substantial, and an MNO is unlikely to choose to cover these areas through commercial incentives alone**

The results of this study indicate that the costs of addressing black spots (i.e. the least populated 2–3% of the country) depend very materially on the level and quality of the required coverage (e.g. 3Mbit/s, 30Mbit/s). The costs (even for low levels of data throughput) can be substantial, as the marginal cost of coverage increases exponentially beyond specific levels. For example:

- the estimated costs of increasing 3Mbit/s MBB population coverage from 99.0% to 99.5% is €70m. This is over four times greater than the estimated cost of increasing coverage from 97.0% to 97.5%, which is €17m;
- the estimated costs of increasing 30Mbit/s MBB population coverage from 99.0% to 99.5% is €102m. This is over four times greater than the estimated cost of increasing coverage from 97.0% to 97.5%, which is €24m.

[98] All the case study countries had coverage obligations based on population coverage (although Denmark based an element of the 800MHz coverage obligation on geographic coverage).
[99] The MBPT focus group on mobile coverage identified four broad categories that encapsulate the locations where people are most likely to wish to use their mobile phone. These are: Areas where people live; Areas where people work; Transient and Commuting areas; and Areas where things happen.
Source: https://www.dccae.gov.ie/documents/MPBT%20Report_ENG.pdf

Recommendations 8–10: a coverage obligation of 30Mbit/s to a high population level where people live would appear feasible and is where we would recommend ComReg should focus its attention

8. **A coverage obligation with data speeds of 30Mbit/s[100] at cell edge to a high population level where people live (of, for example, 90–95% to be achieved by 2027, or somewhat earlier), would appear feasible given cost and network roll-out considerations**

This is in large part due to the expected availability of additional spectrum in or around mid-2020 and the potential for three-band carrier aggregation for the 700MHz, 800MHz and 900MHz bands. This allows the upgrading of existing sites to provide a 30Mbit/s service at substantially lower costs than building new sites.

Providing 30Mbit/s MBB coverage to 85–90% of the population is likely to be achieved by a commercial operator (without intervention) in 2023–24. Providing 30Mbit/s MBB coverage to 90–95% of the population is possible to be achieved by a commercial operator (without intervention) in 2024–27.

Therefore coverage obligations requiring 30Mbit/s speeds (at the cell edge) to a high proportion (e.g. 90–95%) of the population would appear to be feasible by 2027. Providing 90–95% 30Mbit/s population coverage would provide incidental geographic 30Mbit/s coverage of 63–75%.

9. **The specified timeframe for achieving a coverage obligation needs to balance the speed of roll-out versus costs and feasibility**

The appropriate timeframe for achieving a coverage obligation will depend to a large extent on the level and quality of the required coverage. For example, assuming a constant network roll-out rate of 2.5% per annum, the 30Mbit/s population coverage simulation results indicate that an operator would achieve 95% population coverage by 2027, and that it would take until 2042 to achieve 99.5% population coverage.

While coverage obligations can be used to ensure a faster roll-out (this was the one of the aims of Ofcom in the UK regarding the 800MHz auction), a hastened network roll-out can reduce the commercial attractiveness and feasibility of a coverage obligation. A hastened network roll-out:

- would be more costly. For example, an MNO may require more engineering staff, vehicles, and equipment for a faster roll-out. This requirement would result in the MNO incurring higher costs (than for a slower network roll-out)[101]; and
- may be less feasible.[102] For example, even if the MNO was able to invest in more engineering staff, vehicles, and equipment, the process of doing so would take time.

10. **Coverage obligations should promote competition and, in doing so, not discourage new market entry**

[100] 30 Mbit/s represents the target data rate for 2020, as set out in Article 6 of the EU Radio Spectrum Policy Programme (RSPP) Decision.
[101] The network costing model provides a lower bound estimate of the network costs where the speed of roll-out is significantly faster than the base case (2.5% CAGR). For more detail see section 5.
[102] For example, for the 30Mbit/s population simulation a 99.5% population coverage can be achieved by end-2027 with a network roll-out rate of 8.04% per annum from mid-2020. In mid-2020, an 8.04% network roll-out rate corresponds to a new site every two days or three upgrades per day, while a 2.5% network roll-out rate corresponds to a new site every week or an upgrade every two days.

The network costs to achieve a specific coverage level will be substantially higher, and the roll-out substantially longer, for a new market entrant than an incumbent operator (see Annex 3). To promote competition, and, in doing so, not discourage new market entry, the coverage obligations for a new market entrant may therefore need specific tailoring.

Specific provisions to not deter a new market entrant could be in the form of a less onerous roll-out time or coverage obligation level (for example, the 800MHz awards in Ireland or Austria). Alternatively, provisions could be made to allow certain bidders in an award (such as new market entrants) the possibility of avoiding the coverage obligation altogether (for example, the 800MHz award in UK or Denmark).

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Future mobile connectivity in Ireland

Annex 1: Identification of the modelled use cases

Prepared for
ComReg

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Contents

Figures and tables

A1 Identification of the modelled use cases

The content in this annex is referred to in sections 2 and 3 of the main report, ‘Future mobile connectivity in Ireland.

A1.1 Introduction

In this annex, we identify and describe the mobile connectivity services (or ‘use cases’) likely to evolve or emerge in Ireland over the foreseeable future (at least until 2025) relevant to the Candidate Bands. We identify eight possible use cases (the longlist) that could be commercially attractive to Irish MNOs and other service providers, and which could deliver economic benefits to Ireland.

Three of these possible use cases are selected, given their combined economic attractiveness and coverage deployment characteristics, to provide a valuable modelling exercise in support of the subsequent tasks of this project.

A1.1.1 Methodology

The key trends and possible services are identified by considering Ireland-specific extracts from existing research; interviews with Irish MNOs and stakeholders; secondary research; qualitative analysis of the mobile market; and our forecast model for operator deployments.[1]

The methodology did not include surveys of end-user demand, although comparisons were made, where possible, with demand patterns in other countries where similar services have already been launched, and the service providers were asked about their assessment of likely demand based on their market experience.

Data on European or global MNO intentions to deploy new use cases in the Candidate Bands was taken from a global survey of MNOs conducted by Rethink/Real Wireless in the Q4 2016. The response level was 86 Tier 1 and Tier 2 MNOs, 36 in the EU, providing a representative view of the intentions of MNOs regarding the deployment of new use cases.[2]

For MNOs across the world, there are two top-level objectives for future investment.

- To enhance the cost efficiency and user experience of existing services, such as MBB, by boosting data rates, device capacity, and coverage. This category also includes enhancing existing 2G-based M2M services in situations where they need additional data capability, or where the operator wishes to ‘refarm’ spectrum from 2G.
- To enable new services and revenue streams, such as the IoT, which may require far lower latency and/or higher levels of reliability than those that are delivered by LTE.

These parallel objectives have emerged from various surveys of operators’ 5G intentions around the world, such as Rethink Technology Research’s 2018 report ‘MNOs’ Choices in 5G: 5G evolution and deployment forecast 2017–2025’.[3]

[1] Interviews were conducted in summer 2017 with Airspan Networks, Ericsson, Imagine Communications, Eir, Tesco Mobile, Three Ireland, Vodafone Ireland, and VT Networks.
[2] Rethink Technology Research RAN Forecast Q416.
[3] Rethink Technology Research (2018), ‘MNOs choices in 5G; Slash costs or die’, 6 February, https://rethinkresearch.biz/report/mnos-choices-in-5g-slash-costs-or-die/, accessed 23 July.

A1.2 Use cases—global and European

In a survey of 82 MNOs across the world, conducted in Q4 2016, the respondents were asked to name all their likely future use cases for the next decade of commercial deployment. These included use cases that were initially deployed in 4G networks but could be enhanced or expanded via future networks. The seven most commonly cited use cases with global impact (and multiple sub-categories) are:

- enhanced mobile broadband (MBB), especially to support video (streaming content, social media video, and future advanced video formats such as 4K and 8K);
- connected vehicles (CV), both in-vehicle infotainment (IVI)—delivering MBB to a device inside the car—and safety/driver assistance—connecting to an antenna outside or inside the car itself; autonomous vehicles are seen only as a long-term service (late 2020s or beyond);
- smart cities, including integrated platforms to deliver smart parking, lighting, traffic management, citizen services, etc.;
- Industrial Internet of Things (IIoT): this category includes sensor-based and smartphone-based applications that improve the efficiency of industries, including manufacturing, logistics, energy, agriculture, and tracking;
- virtual reality/augmented reality (VR/AR) applications for consumers (e.g. gaming) and businesses (e.g. retail);
- fixed wireless access (FWA)—to deliver fixed broadband and quad-play (if the provider is an MNO rather than an FWA specialist) over a wireless link;
- connected healthcare, including personal fitness and symptoms monitoring, assisted living/social healthcare monitoring, and remote diagnostics.

In the European Union, MNOs placed a higher priority on enhanced MBB, fixed wireless access, CV, and healthcare than the global norm, although their definition of CV stopped short of autonomous vehicles in most cases and focused instead on driver assistance/safety and IVI.

Rethink/Real Wireless conducted a European-focused survey of 36 Tier 1 MNOs in the Q4 2016, asking about their most important use cases for expanded LTE or 5G networks and spectrum. The top seven use cases emerged as: [4]

- MBB—66%;
- CV—50%;
- Healthcare—42%;
- Fixed wireless—38%;
- Smart cities—37%;
- VR/AR—35%;
- IIoT—32%.

[4] These were ranked by the percentage of MNOs placing them in their top two most important use cases for their business model from 2016 to 2025.

The priorities of the European MNOs vary from country to country, affected by the country's level of market competition/saturation, population distribution, economic make-up, and other factors. Table A1 indicates the top three 5G use cases cited by the MNOs within selected countries, for comparison with Ireland. The UK is included for its proximity to Ireland; Denmark for its similar size and market structure; Finland for its significant rural population; and Germany as the largest EU market.

Table A1 Top three use cases in selected EU countries (in addition to MBB)

Country	Top three 5G use cases
UK	CV, smart city, healthcare
Denmark	Smart city, VR/AR, healthcare
Finland	IIoT, FWA, smart agriculture
Germany	CV, IIoT, smart city

Source: Rethink/Real Wireless MNO survey (Q416)

A1.3 Longlist of use cases—Ireland

Table A2 sets out the longlist of possible use cases identified during the summer 2017 interviews with Irish MNOs and stakeholders, as well as their high-level pros and cons.

Table A2 Longlist of possible use cases for Ireland and pros and cons

Use case	Pros	Cons
MBB (esp. video)	Proven demand	The ARPU-to-cost ratio is worsening
CV (in-vehicle infotainment (IVI) and safety)	Expected high growth in usage	Poor roadside coverage, sites issue
IIoT	Strong demand identifiable revenues, identifiable social/economic benefits. May help justify rural coverage	Rural coverage currently poor
Fixed wireless/wireless multiplay	High demand among rural population, help mobile-only players move into multiplay. 3.6GHz good spectrum for this. Can layer other services like smart home	Local competitors already established in market.
Enhanced M2M (e.g. asset tracking)	Some services already established in GSM, lowering risk	Will require better road and sometimes rural coverage
Smart home	Added value to build on fixed or mobile subscribers. Can be marketed where there is coverage—doesn't have to be universal	Competition from other players, e.g. Google, utilities. ARPUs uncertain
Healthcare (health monitoring)	Some apps easy to support (e.g. fitness monitoring). High social impact in rural areas but depends on coverage	Competition from other players, e.g. Apple. More challenging healthcare use cases involve high reliability, potential liability etc. (e.g. critical care monitoring)
Smart city	Additional services to layer on existing infrastructure, relatively few sites needed, way to work with partners	There are few cities and it might not scale to towns

Note: ARPU refers to average revenue per user.

Source: Oxera/Real Wireless analysis based on MNO interviews (2017).

These were cited as attractive use cases for the Candidate Bands by all of the Irish MNOs, with varying degrees of weighting.[5] Those that are centred on a home or fixed connection were also cited by Imagine, a FWA operator (i.e. fixed wireless, health monitoring, and smart home).

There are interesting differences between the Irish prioritisation of the use cases and the European average. Many of these relate to the challenges of extending coverage to rural areas and along roads, which makes Irish MNOs more cautious about services that require near-ubiquitous connectivity (e.g. smart metering) than those in more urbanised countries.

A1.4 The shortlisted use cases for modelling—Ireland

From the longlist of possible use cases for Ireland, we have assessed each use case and selected three use cases that are likely to be particularly relevant to Ireland. These are:

[5] MBB, CV, and IIoT were given high priority by all MNOs. The others were prioritised differently by different MNOs.

- MBB;
- CV—safety and driver assistance;
- IIoT.

Each of the use cases identified was examined and rated (based on stakeholder input, experience of other markets, and our own knowledge) on its potential to:

- enhance the business case for build-out in one or more Candidate Bands (often also including existing spectrum bands, such as 800MHz);
- drive demand for new services that would enhance the business case for extending coverage in challenging areas, such as rural communities and roads;
- have importance to the Irish economy;
- address a broad base of demand in the short term, and have the potential for future growth in terms of size and range of services that could be offered.

The selected use cases achieved a high level of interest among the MNOs and, for the purposes of the subsequent modelling exercise, they represent contrasting network behaviours and involve a different set of challenges and deployment requirements.

MBB is considered to be the core use case, i.e. the primary driver for extending capacity and coverage, while **the IoT use cases are considered to be use cases that would not justify additional network build-out in their own right**. However, when combined with the MBB service, they improve the overall business case by increasing potential service revenue, differentiation from competitors, and customer loyalty.

The reasons for selecting the three use cases for detailed modelling and for identifying MBB as the core case are set out below.

A1.4.1 MBB as the core use case

In relation to the three shortlisted use cases for Ireland, while some MNOs are developing MBB and IoT strategies in parallel, Irish MNOs, like most of their European counterparts, see **MBB as the core use case**. However, MNOs are acutely aware that voice and SMS usage is stalling or in decline, and that data ARPUs are starting to decline across Europe. The cost of deploying capacity to meet the rising data demand will be increasingly hard to justify with MBB alone.

The conclusion is clear—**operators will deploy infrastructure initially for their core use case, MBB, and then layer additional services on that network to improve the revenue model.** Many of these additional services will be IoT services, which will not put significant demands on network data capacity, though they may have other requirements—such as low latency or high reliability. Some MNOs will address those with software upgrades to selected base stations (e.g. for NB-IoT or future IoT technology).

Many of the non-MBB use cases discussed with the Irish MNOs will initially be deployed in LTE networks and spectrum, sometimes using evolutions of LTE, such as NB-IoT, for low-power wide-area network (LPWAN) services. In the future, when 5G is deployed, there will be the ability to enhance these services by adding, for instance, mission-critical or very low-latency applications. The ability to deploy new services without major technology enhancements, but as the market dictates, is very important to the mobile business case in Ireland.

Irish MNOs are clear that they will most likely introduce the future technologies when the ecosystem is mature and the commercial need is clear (probably in the early to mid-2020s). In this respect, they are in line with many other EU MNOs.

A1.4.2 Mobile broadband

Description

As outlined above, based on our interviews with Irish MNOs, MBB remains the primary driver for network build-out and is the heart of the MNO business model. For instance, Three is investing €300m to provide a 225Mbit/s '4G Plus' service and completing the consolidation of its network with that of O2 to improve LTE capacity and coverage;[6] Vodafone has completed its national LTE network upgrade to boost capacity, coverage and efficiency and layer on NB-IoT in many locations[7]; Eir is investing €50m to build and connect 100 extra mobile sites and boost population coverage to 95%.[8]

The MNOs are also looking at ways to improve the cost-effectiveness of extending rural coverage. The Irish MNOs believe that more sub-1GHz spectrum will be a primary enabler and, ideally, they would wish to aggregate multiple sub-1GHz bands, e.g. 800MHz with 700MHz or 900MHz, but there are technical challenges in implementing this.[9]

Why this use case was selected

Some other factors in choosing MBB as a use case include the following.

- Addressable market—in Q3 2017, smartphones accounted for approximately 92.8% of mobile subscriptions (excluding dedicated MBB and M2M).[10] In similar markets, penetration is expected to reach 98% by 2020. Users may also have additional cellular devices in the future. For example, most secondary devices (such as tablets) currently rely mainly on WiFi, but in the future there may be cellular access for cars, wearable devices, and other devices to drive further usage.
- Spectrum—MBB can be deployed with many spectrum bands, some of which are coverage-oriented (e.g. 700MHz and other sub-1Ghz spectrum bands), and others which are capacity-oriented (e.g. the 2.3GHz and 2.6GHz bands).
- Future expansion potential—higher data rates and device capacity will enable additional services, such as higher-grade video. Mobile networks will

[6] Three (2015), 'Three extends FREE 4G promotion for all customers until July 2016', 11 June, https://press.three.ie/press_releases/three-extends-free-4g-promotion-for-all-customers-until-july-2016/, accessed 23 July.
[7] Vodafone (2016), 'Vodafone is first to announce NB-IoT launch markets', 19 October, https://www.vodafone.com/business/news-and-insights/press-release/vodafone-is-first-to-announce-nb-iot-launch-markets, accessed 23 July.
[8] Weckler, A. (2016), 'Eir to spend €50m in countrywide mobile network coverage expansion', *The Irish Independent*, 14 July.
[9] Analysys Mason (2015), 'LTE carrier aggregation requires careful consideration when valuing mobile spectrum', 18 June, http://www.analysysmason.com/About-Us/News/Newsletter/LTE-CA-Jun2015/, accessed 23 July.
[10] ComReg (2017), 'Irish Communications Market: Quarterly Key Data Report: Data as of Q3 2017', 14 December.

continue to be enhanced, with improved technologies and additional spectrum, to provide a wide umbrella area of MBB coverage.

- Alternative to cellular? A considerable percentage of wireless data traffic is carried by WiFi, either offloaded by the MNO or selected by the user. WiFi can fill a gap where mobile coverage is lacking, although it has limitations in terms of range and reliable quality of service (especially outdoors) and limited in terms of rural coverage and full mobility.

A1.4.3 Connected vehicles—safety and driver assistance

Description

CV implies services to do with safety, driver assistance, and vehicle monitoring that do not involve connectivity to a vehicle's antenna (inside or outside) or mobile devices inside a vehicle. Applications include eCall (an EU system introduced in April 2018), accident or congestion warning alerts, vehicle-to-vehicle alerts, and so on.

Some of the development of vehicle safety use cases will be undertaken under the auspices of pan-EU projects seeking to evolve and promote ADAS (advanced driver assistance systems).[11]

Why this use case was selected

A high level of interest in CV was expressed among all MNOs, despite the challenges of roadside site access. This use case can be deployed initially using existing spectrum (especially for MNOs—notably Vodafone, which is deploying NB-IoT in 800MHz LTE sites), and then extended later with new spectrum.

The potential for vehicle safety/monitoring is seen as more immediate than for in-vehicle infotainment (IVI) because the high levels of data expected to be necessary for IVI would require additional spectrum. Also, NB-IoT lends itself to deployment from macrosites at some distance from the roadside, rather than requiring the close roadside base stations likely to be necessary for IVI or autonomous vehicles.

Initially, many driver-assistance services can be delivered using existing LTE technologies, provided reliable road coverage can be achieved in low-band spectrum to deliver a signal to every vehicle antenna. Note that some future services, such as fully autonomous vehicles, may require ultra-low latency for some operations. However, we believe ultra-low latency to be a niche requirement at least until 2025.

Based on other markets, a high level of uptake can be expected, improving the MNOs' business case for extending roadside coverage (subject to site access permits). This use case will drive deployment in sub-1GHz spectrum (NB-IoT

[11] Vehicle-based intelligent safety systems that could improve road safety in terms of crash avoidance, crash severity mitigation, and protection and post-crash phases. ADAS can, indeed, be defined as integrated in-vehicle or infrastructure-based systems that contribute to more than one of these crash-phases. For example, intelligent speed adaptation and advanced braking systems have the potential to prevent a crash or mitigate the severity of a crash—see European Commission (2016), 'Advanced driver assistance systems', November, https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/ersosynthesis2016-adas15_en.pdf, accessed 23 July.

or other LPWAN now, 700MHz later). It will also provide insights into another longlisted use case—vehicle asset tracking.[12]

Some key factors for its selection include the following.

- Addressable market—in 2017, 131,356 new cars were registered.[13] In 2015, the number of vehicles on the road in Ireland crossed the 2.5m mark for the first time, 1.9m being private cars (Department of Transport figures).[14]
- Timing—where cell sites are in place, services could be available within one year if initially launched in NB-IoT. However, availability on all roads would be subject to site access and additional build-out.
- Most important Candidate Bands—700MHz, though deployment could start in 800MHz with NB-IoT.
- Key service characteristics—low latency (but see above about ultra-low latency), roadside coverage, driver assistance (but not life-critical).
- Comparable uptake levels—among the countries trialling various forms of mandatory or voluntary ADAS systems that include wireless elements are Austria, Belgium, Denmark, Finland, France, Hungary, the Netherlands, Spain, Sweden, and the UK, as well as the USA, Canada, and Japan.
- In terms of revenue potential, one study estimates that total revenues from ADAS equipment and services will top €5bn by 2021.[15] There is uncertainty about the share of service revenues that will accrue to MNOs, but there are several ways that a car connection can be monetised, such as direct subscription fees, in-car connectivity, etc.

A1.4.4 Industrial Internet of Things

Description

The Industrial Internet of Things (also known as the 'Industrial IoT' or 'IIoT') refers to the connection of large numbers of physical objects to the Internet via sensors within an industrial context—mainly in the sectors of manufacturing, logistics, energy, agriculture, fishing, oil and gas, and aviation. The IIoT combines M2M communication, industrial big-data analytics, cybersecurity, human–machine interface (HMI), and SCADA industrial controls.[16]

Why this use case was selected

A high level of interest was expressed by all MNOs and by fixed wireless access operator Imagine. The IIoT is seen as a set of services with a significant addressable market and identifiable revenue opportunity for MNOs and other stakeholders, as well as additional commercial benefits such as reduced churn in rural areas.

In Ireland, the MNOs and other stakeholders expressed particular interest in the following sectors:

[12] McKinsey & Company (2016), 'Automotive revolution—perspective towards 2030', January. This report finds adoption rates of 28% of drivers in China, 23% in Germany, and 17% in both the USA and South Korea.
[13] National Vehicle Statistics, http://www.simi.ie/Statistics/National+Vehicle+Statistics.html, accessed 23 July.
[14] Irish Government Economic & Evaluation Service (2016), 'Transport Trends: An Overview of Ireland's Transport Sector', April.
[15] SBD (2016), 'Europe ADAS Forecast', June.
[16] Definition based on that of the Industrial Internet Consortium, http://www.iiconsortium.org/, accessed 23 June.

- agriculture (arable and animal farming, forestry);
- fisheries (coastal and inland);
- manufacturing;
- logistics;
- energy.

All of these sectors are important to the Irish economy, but to connect them to the IIoT will require very broad coverage as many of their locations are in rural or remote areas. The Irish MNOs expressed particular interest in the potential demand from agriculture, given the country's large base of farms.

The IIoT is seen as a scalable opportunity. Individual services can be rolled out one by one, according to levels of short-term demand and ease of deployment. This might be done on a request basis for rural industries, or the cases might be decided by the MNO based on perceived demand levels. Additional services can then be layered on as technologies and usage evolve, and as infrastructure and coverage increases.

Some key factors include the following.

- Addressable market—Ireland's distributed population means there are large numbers of rural or suburban businesses that could benefit from connectivity to an IoT network with broad coverage. For example:
  - over 122,000 (Q3 2017) people are employed in manufacturing, with many small factories (95% have fewer than 500 people) that could achieve better scale and productivity via IIoT;[17]
  - there are almost a 140,000 farms in Ireland, averaging 5 hectares in size; the agri-food sector generated 5.7% of gross value added and 8.5% of national employment in 2015.[18]
- Timing—where there is pent-up demand, some services would be delivered as soon as coverage is available in any particular area. These services might initially be those delivered to homes and areas of population via LTE expansion in sub-1GHz bands, or fixed wireless. Since most of the services are low data rate, they could also make use of existing GSM coverage.
- There is also the potential for IIoT services to be provided in licence-exempt spectrum over networks such as LoRa or Sigfox. Irish telecoms provider VT Networks has built a national Sigfox network on its infrastructure and is targeting 1m device connections within three years.
- Most important Candidate Bands—sub-1GHz spectrum is essential for these services. Initial deployment is likely to be in 800MHz, especially where NB-IoT is being deployed (notably by Vodafone). Extended coverage and 5G services will be enabled by 700MHz and aided by access to fibre backhaul following the roll-out of the NBP.
- Key service characteristics—wide coverage, low data rates. Most services do not require real-time response or ultra-low latency. IIoT services will

[17] Eurostat, www.ec.europa.eu/Eurostat, accessed 23 July. Forfás (2013), 'Making it in Ireland: Manufacturing 2020', April.
[18] Teagasc (2017), 'Agriculture in Ireland', https://www.teagasc.ie/rural-economy/rural-economy/agri-food-business/agriculture-in-ireland/, accessed 23 July.

typically be bundled with MBB apps such as eGovernment, as well as general MBB connectivity for industrial users.

- Uptake levels—a study by Wikibon estimates that IIoT investment will increase from $20 billion in 2012 to $514 billion in 2020. Current deployments are highest in the USA.[19]

A1.5 Providing coverage for the use cases

For MBB, the Irish MNOs claim to be currently achieving close to 90% geographical coverage—compared to population coverage in the 'high 90s' for 4G data and 98% for outdoor voice. In our interviews, these MNOs indicated that they believe that with 700MHz LTE (possibly aggregated with other sub-1GHz bands), they could reach 97% geographic coverage by approximately 2022, with improved cell edge performance.

The remaining 3% is still a challenge, but the early achievement of 97% geographic coverage would be a clear economic gain, and it would likely take population coverage higher than the 98% that MNOs are currently targeting for 2020.

For roads, coverage levels are below 90%—all three MNOs express the view that they would aim to boost that to the high 90s, but only if they could get roadside sites, which they see as a government/highways agency issue.

Carrier aggregation is key to MBB objectives. MNOs hope that the technical challenges of aggregating multiple sub-1GHz bands can be addressed by industry so that they can improve MBB rural coverage and capacity with combinations of 800MHz, 900MHz, and future 700MHz spectrum.[20]

The MNOs express the view that IoT use cases would not justify additional network build-out in their own right, but—when combined with MBB—they improve the overall business case by increasing potential service revenue, differentiation from competitors, and customer loyalty. A combination of higher data rates and higher perceived value for money can reduce churn, as Analysys Mason's report 'The Connected Consumer Survey' shows.[21]

Those factors could prove to incentivise MNOs to extend coverage or upgrade sites. This view is held by many MNOs in other markets and is reflected in some analyst studies. For example, a Rethink survey of EU MNOs in 2016 found that only 9% of MNOs believed that a new network build-out could be justified entirely by IoT services (except in the case of a software upgrade, such as NB-IoT), though 68% expected to deploy such services within three years of 5G roll-out.[22]

For the IIoT, more extensive rural coverage will be needed to reach all potential users, many of whom have facilities outside towns and need to support mobile hand-off between them, especially for asset-tracking purposes. These factors are unlikely to drive additional rural coverage in their own right (except for low data rate services), but they will improve the business case for extending MBB coverage to locations that are currently underserved.

[19] Wikibon (2013), 'Defining and Sizing the Industrial Internet', 27 June, http://wikibon.org/wiki/v/Defining_and_Sizing_the_Industrial_Internet, accessed 23 July.
[20] Analysys Mason (2015), 'LTE carrier aggregation requires careful consideration when valuing mobile spectrum', 18 June, www.analysysmason.com/About-Us/News/Newsletter/LTE-CA-Jun2015/, accessed 23 July.
[21] Analysys Mason (2016), 'Connected Consumer Survey 2016: Mobile Customer Satisfaction in Europe, South Korea and the USA', April.
[22] Rethink Technology Research (2018), 'MNOs choices in 5G; Slash costs or die', 6 February.

The large cells of NB-IoT (and future 700MHz IoT networks) would help to extend coverage for the IIoT beyond the footprint of MBB for low data rate applications, such as animal monitoring, while using the same infrastructure as MBB. NB-IoT increases signal coverage by up to seven times compared to GSM, according to Vodafone Group.[23] It can be deployed easily; Vodafone says that it takes just a few hours to implement a software update, and over 80% of its base stations can be updated in that way.[24]

If an MNO decided to deploy NB-IoT to support the IIoT, it could be rolled out in existing 800MHz spectrum and achieve higher rural coverage than for MBB from the same infrastructure.

Even better results are expected in 700MHz because of its slightly better propagation characteristics, and especially in terms of the efficiencies of the 5G New Radio. However, waiting for 700MHz would extend the timescale to 2021/2022, and, of course, some MNOs will use 700MHz to extend LTE.

A1.6 Other use cases

As outlined in previous sections, there are other use cases for the Candidate Bands that have a high level of MNO and stakeholder interest and potential for social and economic impact. These are worth noting for possible future study, but they are excluded from the detailed modelling for reasons indicated below.

Fixed wireless access

The fixed wireless access business model has already been established in the 3.6GHz band by Imagine and other FWA providers, and MNOs may now be interested in offering FWA services to complement their rural models and potentially achieve an all-wireless quad play bundle. Fixed-line operators may also use FWA to fill wireline coverage gaps as speeds improve.

FWA was excluded for modelling because international experience suggests it remains a niche case—although a profitable one for specialised operators.

Smart home and smart healthcare

Although the uptake in peer markets suggests there would be high levels of consumer adoption of smart home and smart healthcare services, MNOs cannot currently see a proven business model. Rather than being business cases in their own right, smart home and healthcare/fitness are likely to be additional applications that improve the overall user experience within a fixed or mobile MBB network. Therefore, these use cases are unlikely to drive additional build-out.

Enhanced M2M/asset tracking

This use case is seen as an extension of existing M2M services in 2G. The value proposition once these are migrated to higher data rates and LTE is unclear and largely case-specific. The potential is to enhance existing customer relationships and services rather than drive brand-new business, so this will not drive build-out by itself. MNOs that deploy NB-IoT will, however, be keen to implement as many M2M services as possible to maximise revenue from that platform. There will be insights into this from CV modelling.

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[23] Vodafone (2017), 'The future is in our hands with the commercial launch of NB-IoT in Vodafone Spain', 23 January, https://www.vodafone.com/content/index/what/technology-blog/nbiot-commercial-launch-spain.html, accessed 23 July.
[24] Ibid.

Smart cities

This is not a coverage-based use case and is therefore not considered for modelling. The fact that smart city services rely on targeted capacity rather than universal coverage make them attractive to MNOs and other stakeholders, but that is offset by the risks of fragmentation if each city and town adopts a different approach (e.g. using licence-exempt spectrum and technologies like LoRa and Sigfox). MNOs need to secure a bigger share of the value chain than just connectivity fees, but that means working with new partners, including local authorities, and building service platforms to support high-value capabilities, such as security and device management, and generate big data revenues. This is in the early days of development, although, according to our stakeholder surveys, MNOs are working with local authority associations. Nevertheless, the relatively non-urbanised nature of Ireland means that smart cities are taking a lower priority for Irish MNOs than those in other markets, such as the UK or Germany.

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Future mobile connectivity in Ireland

Annex 2: Technical information and assumptions

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Figures and tables

A2 Technical information and assumptions

A2.1 Introduction

This is the technical annex to Oxera and Real Wireless's report on future mobile connectivity in Ireland. The information in this annex complements the information set out in section 4 of the report, which provides an overview of the steps in our model and its main parameters and assumptions.

The purpose of this annex is to provide further details on the mechanism and parameters used in the mobile network costing model. The annex is structured as follows:

- indoor mobile coverage considerations;
- land cover, land use, and road and rail information for Ireland;
- modelling parameters and assumptions;
- the merit function and the network expansion model;
- definitions used for the percentage coverage results.

A2.2 Indoor mobile coverage considerations

In this study indoor population coverage is not modelled since - among other things - the conditions for receiving a mobile signal indoors can vary significantly by building and by room-to-room within a building thus making it impractical to estimate a loss that would accurately reflect indoor reception. Providing in-building coverage from outdoor mobile networks has been a long-standing challenge in the mobile industry. This is due to a number of factors, including the limitations on the spectrum (e.g. its propagation characteristics, available capacity, etc.), the distance from the site to the building, the signal attenuation characteristics of building materials, and the performance of the mobile handset.

In relation to the latter two items, two technical reports recently published by ComReg (see below) highlight the significant challenges in providing indoor coverage from an outdoor mobile network.

In relation to mobile handset voice performance, ComReg published a Technical Report (ComReg Document 18/05) in February 2018 that suggests a variation in performance of up to 14dB between the handsets tested.[1] This means that for voice calls, some handsets have poorer reception than others. ComReg has indicated that it shortly expects to issue a further report that will assess handset data performance.

Regarding the effect of building materials on indoor mobile performance, in August 2018, ComReg published a technical report (ComReg Document 18/73) that found that the use of modern building materials (e.g. windows, block materials, and roofing) can have a significantly detrimental effect on the propagation of radio waves into buildings constructed using these materials. The losses suffered by radio waves in penetrating these materials ranges from 20dB up to 60dB—that is a reduction in signal strength of at least 100 (and up to 1 million) times.

A further problem associated with providing in-building coverage is not so much the increase in the average path loss, but the great increase in the variability of path loss that must be allowed for. ComReg Document 18/73 observes that MNOs and regulators are not able to specify one loss parameter that could guarantee indoor coverage. Therefore, depending on the chosen materials, type, and age of the building, in addition to the radio frequency, the resulting total attenuation could easily be sufficient to make it impossible for mobile handsets to operate effectively. These constraints also make accurate indoor coverage predictions problematic, as there could be significant room-to-room variation within the same building.

To effectively address indoor mobile coverage, there are a number of specialised solutions that can be deployed by MNOs and consumers.

- Consumers can use Wi-Fi and native Wi-Fi calling on a fixed broadband connection to offload mobile data and voice services. In Document 18/73, ComReg acknowledges that eventually (and in most instances), native Wi-Fi calling is likely to be the most effective mechanism to improve indoor reception issues. Consumers who have both an internet connection and a Wi-Fi calling-enabled phone would be able to avail of Wi-Fi calling. Eir is the only Irish MNO to have rolled out native Wi-Fi calling on its network, and it is currently adding additional supported devices to extend the reach

[1] ComReg (2018), 'Mobile Handset Performance (Voice)', 6 February.

of the service.[2] ComReg is actively encouraging all mobile service providers to follow suit, and it notes that Vodafone plans to launch 'VoWi-Fi' (Voice over Wi-Fi) in 2018; it is indicated that this is expected to provide a similar service to Vodafone customers.[3] In the UK, all four MNOs have deployed Wi-Fi calling.[4]

- Mobile repeaters can be used. In simple terms, a mobile repeater is a device that amplifies a signal it receives and re-transmits it to a mobile device in order to enhance the indoor coverage in situations where the signal is weak. Following a recent public consultation, ComReg has put in place licence exemption arrangements[5] for the general usage of mobile phone repeaters that meet specific technical requirements.[6] Within the bounds of these requirements, such repeaters will have no restrictions on the number of operators or technologies it may service, be it single/multi-operator or single/multi-band.

- Indoor femtocells have been deployed by some MNOs and may be a solution for larger commercial buildings (e.g. shopping centres, airports etc.).

A2.3 Land cover, land use, road and rail information for Ireland

This section explains the database-related information on Ireland that is used in the model. This relates to:

- land cover and use information;
- Information on the road and rail networks in Ireland.

It should be noted that we do not model coverage in tunnels, nor the cost associated with providing coverage in them. Tunnels need specialised solutions—either a repeater at the entrance and exit, or a leaky feeder.

A2.3.1 Land cover, land use and clutter information

For the assessment of coverage, a clutter database is used to describe potential obstacles to radio propagation—such as high-rise buildings, urban dwellings, and trees and foliage. We use a land cover database as proxy of the clutter database.

For the assessment of where demand may be requested for different services, we use several databases:

- an address database (Eircode[7]) and the latest census for where population lives;
- a thoroughfare database for where the roads and rail networks are laid out; and

ee https://www.eir.ie/Wi-Ficalling/, accessed 23 July.
[3] Kennedy, J. (2017), 'Vodafone to launch voice over 4G and Wi-Fi in Ireland in early 2018', 26 July, https://www.siliconrepublic.com/comms/vodafone-voice-lte-Wi-Fi, accessed 23 July.
[4] See http://www.three.co.uk/discover/three_intouch; http://ee.co.uk/help/phones-and-device/Wi-Fi-calling; https://www.o2.co.uk/help/apps/tu-go; https://www.vodafone.co.uk/explore/network/network-improvements/wi-fi-calling/, accessed 23 July.
[5] See http://www.irishstatutebook.ie/eli/2018/si/283/made/en/pdf: "Wireless Telegraphy Act 1926 (Section 3) (Exemption Of Mobile Phone Repeaters) Order 2018".
[6] These include automatic standby/shutoff, anti-oscillation, maximum uplink and downlink power, maximum system gain and automatic gain control. See ComReg (2018), 'Permitting the General Use of Mobile Phone Repeaters: Response to ComReg Consultation Document 17/103 and Final Decision', 28 June.
[7] EIRCODE address database May 2017, provided by ComReg.

- a land cover database, as a proxy of the land use database, for where IIoT devices may be located.

We use the land cover database, combined with information on the location of buildings, to set modelling restrictions on the maximum distance between a building and a new macrosite (if there are no buildings in close proximity, we consider it likely that there would be no utilities nearby—power, etc.).

In assessing coverage, the area of the country was divided into 50m x 50m pixels for population, 100m x 100m pixels for thoroughfare, and 200m x 200m pixels for geographical coverage calculations. The size of the pixel was chosen to achieve a balance between area granularity and computational load in processing the results. Each pixel represents a receiver point.

The land cover information used in our model is shown in Table A2.1. The percentage field shows the percentage of the land in Ireland for each land cover label. The maxDist field shows the maximum distance used in the model between a building and a new site, and the mobile broadband (MBB), industrial Internet of things (IIoT), and connected vehicle (CV) fields provide information on whether a land cover label is targeted for these services in a simulation scenario.

Table A2.1 Land cover breakdown

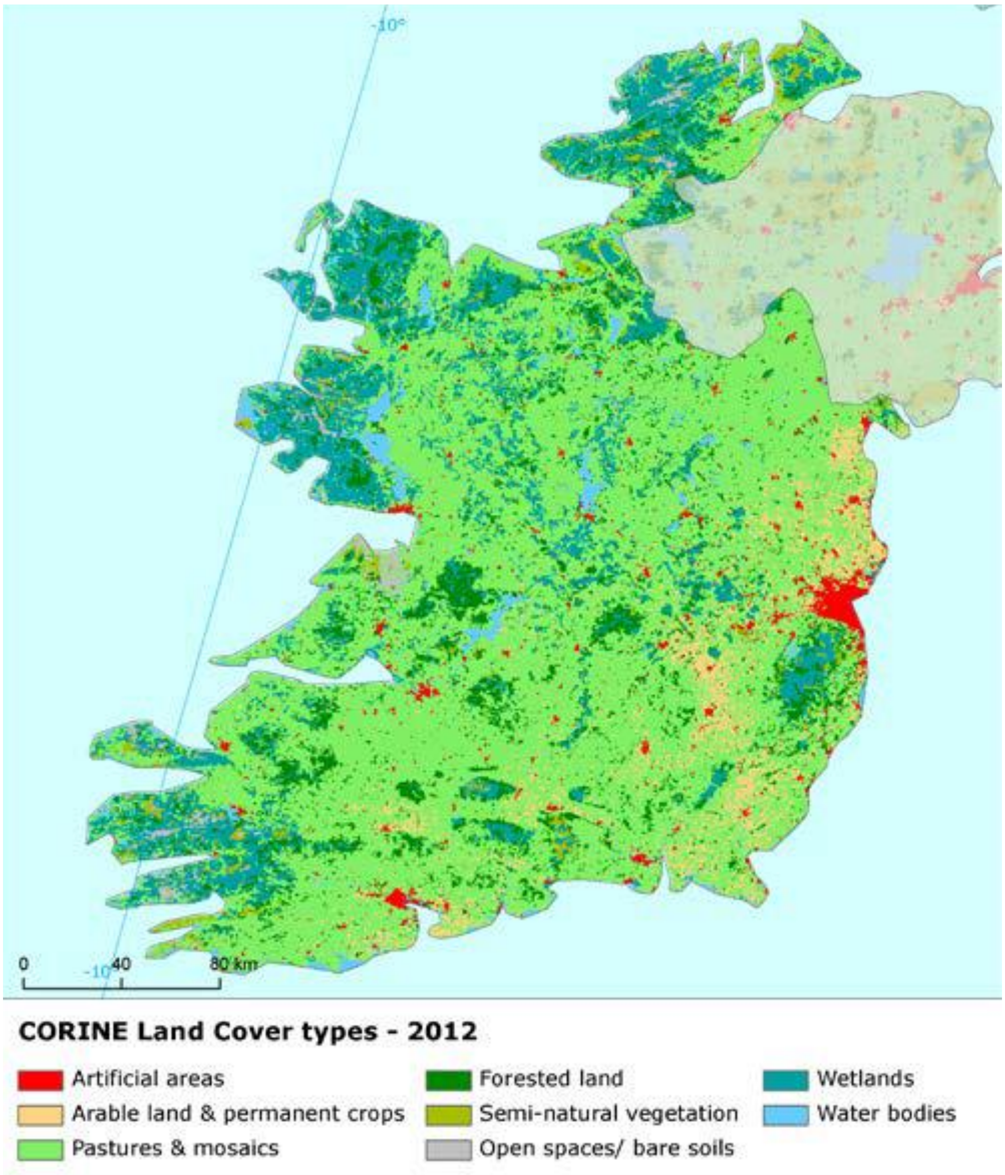
GRID CODE	LABEL3	Percentage	MBB	Situation for IIoT	CV	maxDist
18	Pastures	50.820	If addresses are present	Outdoors	If addresses are present	2.00
6	Airports	00.035		Outdoors		0.05
3	Industrial or commercial units	00.137		Indoors		0.05
7	Mineral extraction sites	00.125		Outdoors		0.05
5	Port areas	00.010		Outdoors		0.50
12	Non-irrigated arable land	07.620		Outdoors		2.00
21	Land principally occupied by agriculture, with significant areas of natural vegetation	06.241		Outdoors		2.00
9	Construction sites	00.033		Outdoors		0.05
20	Complex cultivation patterns	02.057		Outdoors		2.00
41	Water bodies	01.668		Outdoors		0.05
43	Estuaries	00.421		Outdoors		0.05
44	Sea and ocean	00.218		Outdoors		0.05
40	Water courses	00.110		Outdoors		0.05
8	Dump sites	00.010		Outdoors		0.05
37	Salt marshes	00.056		Outdoors		0.05
36	Peat bogs	15.438		N/A		0.05
29	Transitional woodland shrub	05.942		N/A		1.00
24	Coniferous forest	03.230		N/A		0.50
2	Discontinuous urban fabric	01.510		N/A		0.05
26	Natural grasslands	01.261		N/A		1.00
27	Moors and heathland	00.781		N/A		2.00
25	Mixed forest	00.420		N/A		0.50
23	Broad leaved forest	00.411		N/A		0.50
32	Sparsely vegetated areas	00.292		N/A		1.00
11	Sport and leisure facilities	00.268		N/A		0.50
35	Inland marshes	00.232		N/A		0.05
31	Bare rocks	00.205		N/A		0.05
39	Intertidal flats	00.232		N/A		0.05
30	Beaches, dunes, sands	00.125		N/A		1.00
4	Road and rail networks and associated land	00.060		N/A		2.00
1	Continuous urban fabric	00.040		N/A		0.05
10	Green urban areas	00.038		N/A		0.05
42	Coastal lagoons	00.008		N/A		0.05

Note: The land cover database is used as proxy for clutter and land use databases. The breakdown is sorted with decreasing number of IIoT devices at national level.

Source: Oxera/Real Wireless.

Figure A2.1 shows a map of Ireland with the land cover information.[8]

Figure A2.1 Land cover map of Ireland



Source: Land cover Ireland, European Environment Agency, 2012.

Modelling restrictions for the deployment of new sites

The maxDist field in Table A2.1 identifies the restrictions used in the model for the deployment of new sites.[9]

- A site can be commissioned up to 50m from a building and on a land cover pixel that is characterised as peat bogs.
- A site can be commissioned up to 500m from a building and on a land cover pixel that is characterised as coniferous forest.

[8] European Environment Agency (2017), 'Ireland land cover country fact sheet 2012', 7 September, https://www.eea.europa.eu/themes/landuse/land-cover-country-fact-sheets/ie-ireland-landcover-2012.pdf/view, accessed 23 July.
[9] It should be noted that in order to achieve high geographical coverage, these restrictions were occasionally lifted to allow these simulations to progress. This means that the estimated costs when targeting high geographical coverage are likely to be conservative.

- A site can be commissioned up to 1km from a building and on a land cover pixel that is characterised as transitional woodland shrub.
- A site can be commissioned up to 2km from a building and on a land cover pixel that is characterised as pastures.
- A site cannot be commissioned 100m from a building and on a land cover pixel that is characterised as peat bogs, because the associated cost for power and backhaul would be prohibitive.
- A site cannot be commissioned 1km from a building and on a land cover pixel that is characterised as coniferous forest, because the associated cost for power and backhaul would be prohibitive.
- A site cannot be commissioned 1.5km from a building and on a land cover pixel that is characterised as transitional woodland shrub, because the associated cost for power and backhaul would be prohibitive.
- A site cannot be commissioned further than 2km from a building, regardless of land cover.

Targeting coverage for MBB, CV, and IIoT

To target coverage for MBB, CV, and IIoT, Table A2.1 identifies the following.

- For MBB population coverage, we target and report service on any land use type as long as there are addresses on the pixel.
- For CV, we target and report service on any land use type as long as there is thoroughfare (i.e. road or rail) on the pixel.
- For IIoT, we target and report service on those land use types that have ‘Indoors’ or ‘Outdoors’ listed in the IIoT field. For example:
    - pastures and land use associated with water are assessed assuming that an outdoor IIoT service is required for agriculture and fishing;
    - industrial or commercial units are assessed assuming that an indoor IIoT service is required.

IIoT weightings for different land use types

In targeting IIoT coverage, we allocate IIoT weightings to the different land cover types where IIoT would be targeted. We identified four main groups of IIoT categories that reflect an assumed density of IIoT devices for that group. A weighting of 1 is applied to land cover types with sparse sensors (e.g. pastures), while higher weightings are applied to land cover types with denser usage. For example, a weighting of 1,000 is applied to airports and ports as it is assumed that lots of machines and tags could use the IIoT in that land cover type. The IIoT weightings are set out in Table A2.2.

Table A2.2 IIoT weighting per land cover type

	Sparse sensors (IIoT weight = 1)	Sensors (IIoT weight = 10)	Lots of machines (IIoT weight = 100)	Lots of machines and tags (IIoT weight = 1,000)
Land cover types	non-irrigated arable land pastures complex cultivation patterns land principally occupied by agriculture, with significant areas of natural vegetation salt marshes water courses water bodies estuaries sea and ocean	dump sites	industrial or commercial units mineral extraction sites construction sites	port areas airports

Source: Oxera/Real Wireless.

A2.3.2 Road and rail information for Ireland

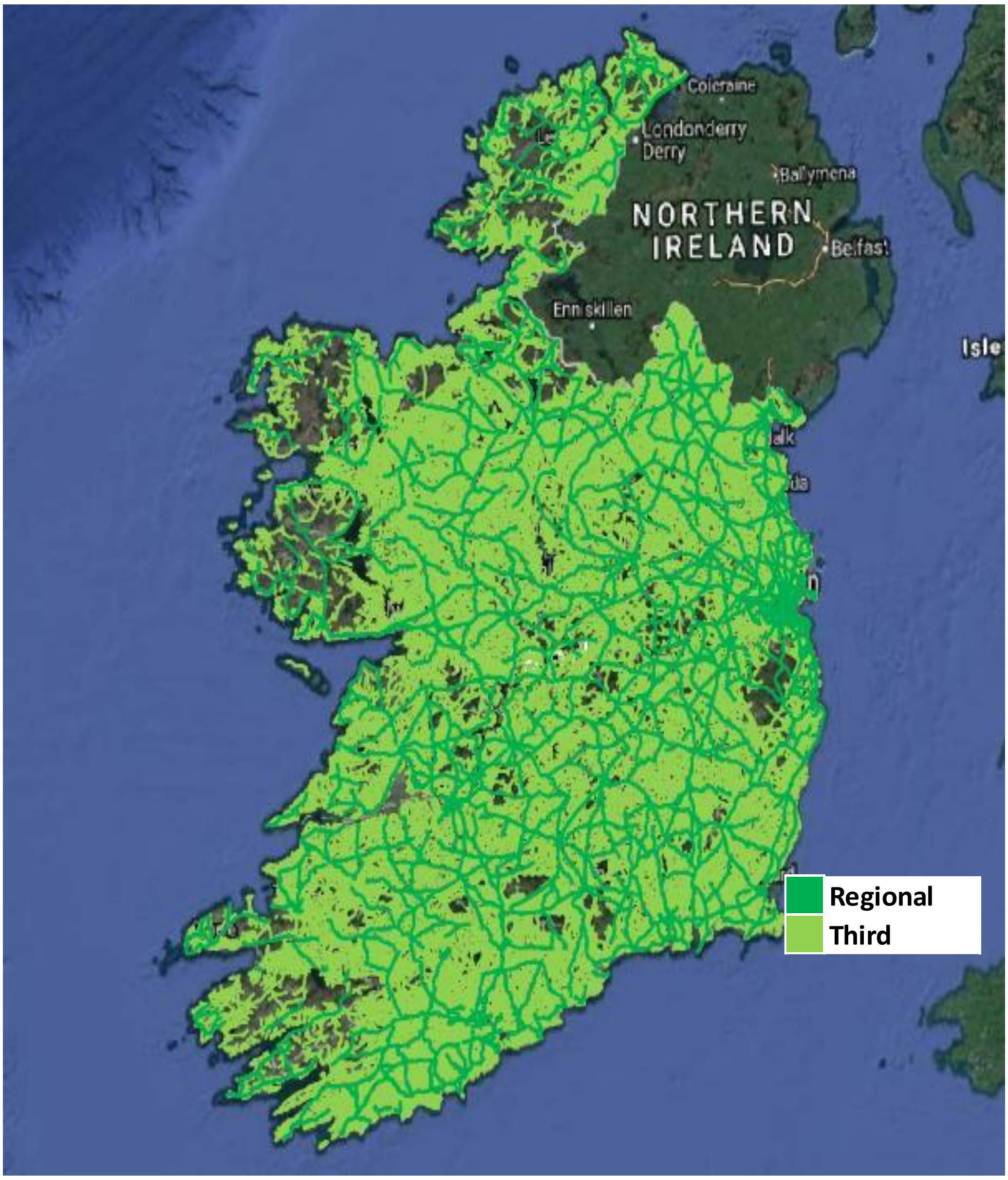
Road and rail maps for Ireland are presented in Figure A2.2, Figure A2.3, and Figure A2.4.

This information is used by the model when targeting thoroughfare coverage and when presenting information for thoroughfare coverage.

Figure A2.2 Map of motorways, national primary roads, and national secondary roads in Ireland

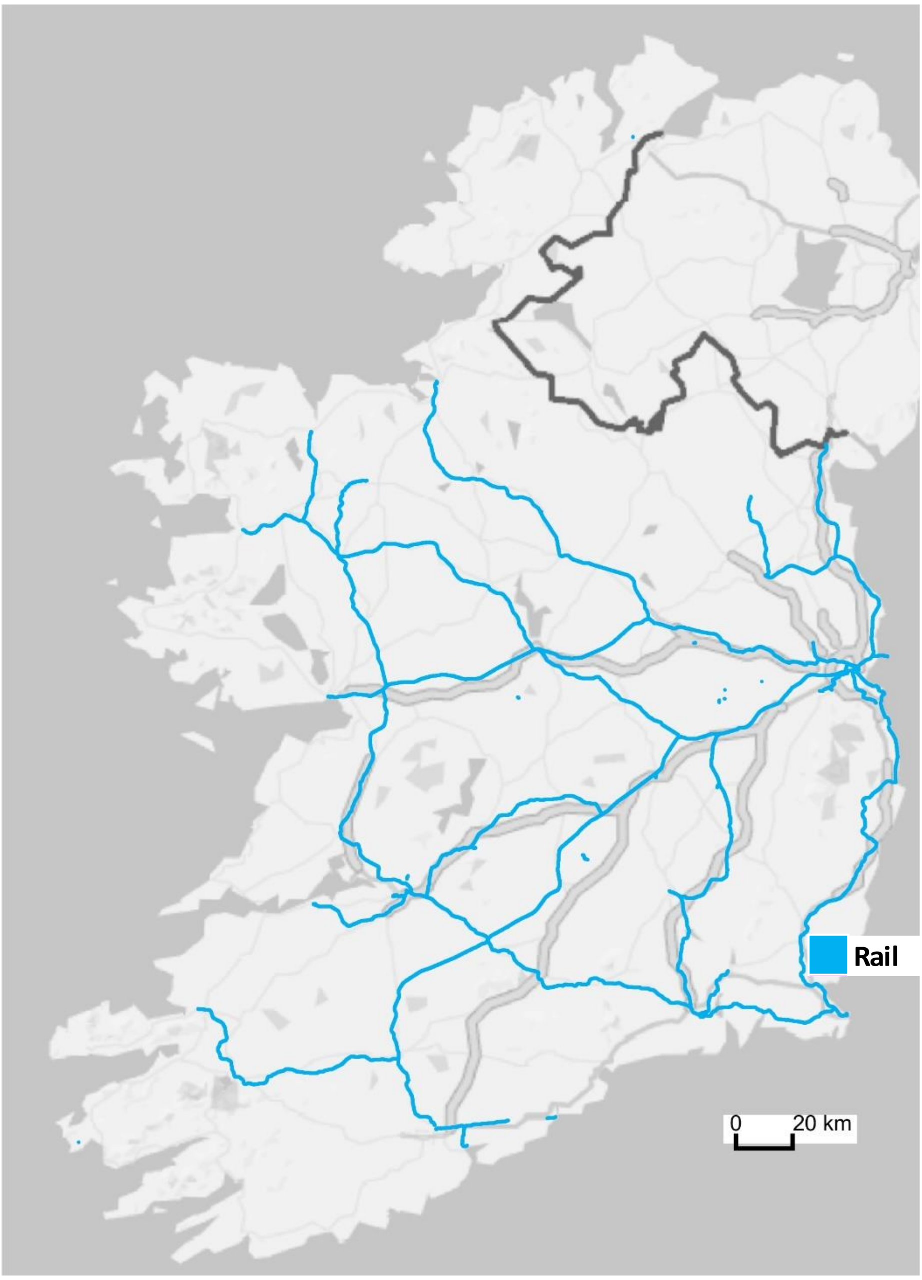
Source: Oxera/Real Wireless.

Figure A2.3 Map of regional and third roads in Ireland



Source: Oxera/Real Wireless.

Figure A2.4 Map of rail in Ireland



Source: Oxera/Real Wireless.

A2.4 Modelling parameters and assumptions

This section sets outs detailed information on the modelling parameters and assumptions used in the model. This complements the information set out in section 4 of the main report.

A2.4.1 Capacity

User throughput is a function of many variables—including the network load, which depends on the network capacity. This can vary from operator to operator. Cell edge single user throughput (SUTP) in a lightly loaded network provides the fundamental limit of a cell capability and is independent of the network load.

SUTP is defined as the downlink bit rate that can be successfully delivered to a single active user per cell at a particular depth and consistency of coverage. This is the downlink bit rate or download speed that a user could experience when not contending with other users for service in that cell, so that the cell delivers the maximum possible data rate to a single user consistent with the signal quality experienced by that user.

The signal quality is determined by assuming that all cells are simultaneously active and devoting most of their resources to serving users with data. If more than one user was active at any one time in the cell, e.g. if the network was more heavily loaded, each user would receive a share of the maximum throughput. This is a useful metric used to derive the coverage obligations by regulators.[10] Therefore, we use the SUTP metric during this study.

Since the user traffic and capacity aspects are not considered, the cost calculation also does not consider the cost of increasing the additional carrier to increase the capacity. We only consider the cost of increasing coverage.

A2.4.2 Propagation and path loss model assumptions

We use ITU-R 1812-4, which is widely used by the industry for the estimation of the coverage at mobile frequencies.[11] ITU-R 1812-4 is the latest version of the ITU-R P 1812 propagation model available at the time of this study. This model has also been used by Ofcom for its coverage verification process.[12]

We note that ITU-R 1812 ranges are terrain and clutter specific. For example, ranges can be larger or smaller than those of COST231. However, the overall trend of reduction in range with an increase in frequency is a physical property observed from both models.

Given that the propagation losses among neighbouring bands are very similar and well within the statistical error of the propagation model, we bundle propagation into the modelling of three spot frequencies, as outlined below:

- 700, 800 and 900MHz are modelled as 800MHz;

[10] See, for example, Ofcom (2010), ‘Annexes to Advice to Government on the consumer and competition issues relating to liberalisation of 900MHz and 1800MHz spectrum for UMTS’, October. Real Wireless, (2012), ‘Technical analysis on the cost of extending an 800MHz mobile broadband coverage obligation for the United Kingdom’, January.

[11] International Telecommunications Union (2007), ‘A path-specific propagation prediction method for point-to-area terrestrial services in the VHF and UHF bands’, November, https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.1812-0-200711-S!!PDF-E.pdf, accessed 23 July.

[12] Ofcom (2012), ‘4G Coverage Obligation Notice of Compliance Verification Methodology: LTE’, 12 November.

- 1800MHz is modelled as 1800MHz;
- 2100MHz, 2300MHz and 2600MHz are modelled as 2300MHz.

A2.4.3 Carrier aggregation

As outlined in section 4, we assume that three-band Carrier Aggregation is available from mid-2020 onwards as follows:

- for Spectrum Portfolio 1, we use Carrier Aggregation of 2 x 10MHz of 700MHz spectrum, 2 x 10MHz of 800MHz spectrum and 2 x 10MHz of 900MHz spectrum;[13]
- For Spectrum Portfolio 2, we use Carrier Aggregation of 2 x 10MHz of 700MHz spectrum and 2 x 20MHz of 2.6GHz spectrum.[14]

This assumption is informed by our discussions with the Irish MNOs in section 2 of the main report, where we found that Irish MNOs would likely use the 700MHz band—possibly aggregated with the other two sub-1GHz bands—to enhance coverage. Furthermore, with technological advances and handset churn, we believe that it is realistic to expect that there will be a sufficient penetration of the three-band Carrier Aggregation feature in handsets by 2020.

We are aware that in the real world, some macrosites may be equipped with more bands to provide for increased capacity. We do not model this as we consider that it would not contribute to coverage.

Furthermore, noting that the cost of network expansion is dominated by site CAPEX (i.e. civil works, acquisition) and OPEX, we observe that the cost difference for a new site with active radio equipment supporting one, two, or three bands is sufficiently small so as to reasonably assume that all new sites are equipped with three bands for an incumbent MNO and two bands for a new-entrant MNO.

A2.4.4 Indicative range of Carrier Aggregation spectrum combinations

Carrier aggregation can be a useful feature to enhance the capacity and extend the coverage of mobile networks.

Figure A2.5 shows the indicative range expected in rural terrain with some terrain obstructions for a new macrosite using the Carrier Aggregation combinations for Spectrum Portfolio 1 and Spectrum Portfolio 2, as outlined above.

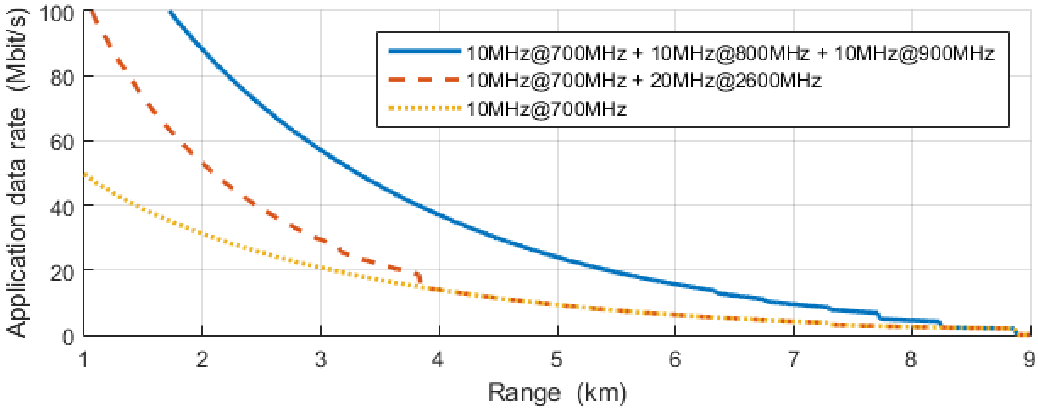
For Spectrum Portfolio 1, three-band Carrier Aggregation of the 700MHz, 800MHz, and 900MHz bands significantly extends the indicative range of a macrosite in rural terrain for application data rates greater than 2.3Mbit/s.

For Spectrum Portfolio 2, two-band Carrier Aggregation of the 700MHz and 2600MHz bands extends the indicative range of a macrosite in rural terrain for application data rates greater than 14Mbit/s. For example, for an application data rate of 50Mbit/s, the indicative range is approximately 2km using Carrier

[13] Spectrum Portfolio 1, as shown in Table 4.5 in the main report, represents the spectrum that would be available to an incumbent MNO assuming that the spectrum in the Candidates Bands is assigned symmetrically among the three MNOs in mid-2020.
[14] Spectrum Portfolio 2, as shown in Table 4.6 in the main report, represents the spectrum that could be available to a new entrant MNO on the assumption that it were assigned 2 x 10MHz from the 700MHz band and 2 x 20MHz from the 2.6GHz band in mid-2020.

Aggregation, whereas it would only be approximately 1km for a single carrier of 2 x 10MHz of 700MHz spectrum.

Figure A2.5 Indicative range expected in rural terrain for different spectrum combinations



Note: Based on COST231 propagation model assuming terrain losses of 12.6dB. In conjunction with the use of the Hata model, 12.6dB was found to be the average terrain loss value across the UK. Source: Real Wireless for Ofcom (2012), 'Methodologies used for the analysis of costs relating to a coverage obligation at 800MHz', July.

Source: Oxera/Real Wireless.

A2.4.5 Link budget parameters

Using the link budget parameters set out in Table A2.3, a Signal to Interference plus Noise Ratio (SINR) value is calculated at the receiver points using the specifics details (e.g. throughput, service, etc.) of the simulation scenario.

Table A2.3 RF input parameters for modelling

Parameter	Units	Value
User Equipment		
UE Antenna Height	meters	1.5
UE Max Power	dBm	23
UE Antenna Gain	dB	0
UE Noise Figure[1]	dB	7/8/9/10[2, 3, 4, 5]
UE cables, combiners or connectors	dB	0
Base Station		
BS EIRP/10MHz	dBm/10MHz	64
BS EIRP reduction	dB	6[6]
BS Antenna Gain[7]	dB	16.5–18.8 (average 17.5)
BS Cable Coupling Connecter Losses	dB	0
BS Interference Margin Degradation	dB	3
General		
Body loss for MBB, foliage/aging loss for non MBB	dB	2.5
Penetration Loss for MBB and non MBB[8]	dB	0±0 (outdoor IIoT) 9±7 (indoor IIoT) 14.68±7.89 (MBB UE in-train) 15.4±8.28 (MBB UE in vehicle)
Network Loading	%	85
Cell-area coverage confidence	%	95 for MBB 99.999 for CV/IIoT
Minimum DL SINR with RX diversity from two antenna elements	dB	-5

Note: [1] 3GGP TS 36.101, Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (EU) radio transmission and reception. [2] 1400, 2100, 2300MHz bands. [3] 3600MHz band. [4] 2600MHz band. [5] 700, 800, 900, 1800MHz bands. [6] We applied 6dB power reduction from the maximum transmitted power for all bands considered in this study, as we found that the average transmitted power is approximately 6dB below the maximum allowed EIRP in UMTS macrosite sites with sectored antennas from Ofcom Sitefinder data (source: Ofcom Sitefinder data). [7] Real Wireless for Ofcom (2012), 'Techniques for increasing the capacity of wireless broadband networks: UK, 2012–2030?', March. [8] Ofcom (2011), 'Consultation on assessment of future mobile competition and proposals for the award of 800MHz and 2.6GHz spectrum and related issues', March.

Source: Oxera/Real Wireless.

Note that the maximum cell range was set to 14,531m, which corresponds to Random Access Channel (RACH) preamble format 0.

For the IIoT/CV scenarios, the modelling includes the coverage improvement due to multi-server connectivity. Multiple servers decrease the overall probability of link failure of the IIoT/CV connection. We considered up to two fallback servers (in addition to the main server), meaning that an IIoT/CV link failure occurs when the link fails to all servers in the vicinity. We assumed that the links were independent from one another.

Table A2.4 presents the Maximum Allowable Path Loss (MAPL) and indicative range for three spectrum combinations for the MBB 3Mbit/s, 30Mbit/s, and 50Mbit/s application data rates.

For example, it indicates that for Carrier Aggregation of the three sub-1GHz bands (2 x 10MHz of 700MHz + 2 x 10MHz of 800MHz + 2 x 10MHz of 900MHz), the MAPL for the MBB 3Mbit/s outdoors service corresponds to 132.0dB at 700MHz, 133.0 dB at 800MHz, and 133.8 dB at 900MHz, giving an indicative range of 8,230 m.

Table A2.4 MAPL levels (dB) and indicative range (m) for 3Mbit/s, 30Mbit/s, and 50Mbit/s outdoor coverage

	Maximum Allowable Path Loss (dB)			Indicative range (m)		
	3Mbit/s	30Mbit/s	50Mbit/s	3Mbit/s	30Mbit/s	50Mbit/s
2x10MHz @ 700MHz	130.3	111.0	99.3	7,370	2,090	970
2x10MHz @ 700MHz + 2x10MHz @ 800MHz + 2x10MHz @ 900MHz	700MHz: 132.0 800MHz: 133.0 900MHz: 133.8	700MHz: 122.7 800MHz: 123.7 900MHz: 124.5	700MHz: 118.0 800MHz: 119.0 900MHz: 119.8	8,230	4,470	3,290
2x10MHz @ 700MHz + 2x20MHz @ 2600MHz	700MHz: 130.3 2600MHz: 142.4	700MHz: 116.3 2600MHz: 128.3	700MHz: 111.0 2600MHz: 123.1	7,370	2,950	2,090

Note: The indicative range in this table has been calculated assuming Hata open/rural, BS antenna height 20m agl, and 12.6dB of terrain losses.

Source: Oxera/Real Wireless.

A2.4.6 Number of sectors and antenna configuration per site

All existing and new macrosites are assumed to have three sectors. We do not explicitly model the antenna patterns and we assumed that the synthetic MNO optimises the network, i.e. azimuths and tilts, so that the main lobe points towards the cell-edge.

We assume that all sectors are equipped with a cross polarised antenna of two elements, and that antennas are multiband (17.5/ 18 dBi gain for sub-1GHz and other bands, respectively).

A2.4.7 User equipment

MBB

For MBB, we assume the 3GPP Rel 8 LTE standard for the MBB link budget calculations and that the MBB UE are equipped with two elements, and thus the working assumption is 2x2 MIMO. The cell-area coverage-confidence is 95%.

When targeting or presenting MBB coverage for population and geographical area, the MBB UE is assumed to be an outdoor handheld terminal.

When targeting or presenting MBB coverage for thoroughfare, we assume that the MBB UE would be in-vehicle or in-train.

CV/IIoT

For CV/IIoT, we assume 512kbit/s and 384kbit/s throughputs respectively, and that the cell-area coverage-confidence is 99.999%.

For CV UE, we assume that the devices are on-vehicles or on-trains (i.e. no penetration losses applying) equipped with two cross-polarised antenna elements.

For IIoT UE, we assume that the devices would be predominantly outside machines, except in the case of the land use type defined as indoor (i.e. industrial or commercial units), in which case penetration losses would apply. UE are assumed to be equipped with a single antenna element.

A2.4.8 Calculation of the standard new site roll-out rate

To calculate a new site network roll-out rate for this model, we examined the historical information (2013–2017) of licensed sites per frequency band (800MHz, 900MHz, 1800MHz, and 2100MHz) for Meteor and Vodafone to identify a suitable site deployment rate. The historical information of licensed sites of the Irish MNOs is assumed to be a good representation of new site network growth in Ireland.

For the purposes of this study, ComReg provided the four-year growth rate (2013–2017) of licensed sites in the frequency bands with the highest number of sites (i.e. the 900MHz band for Vodafone and the 900MHz and 2100MHz bands for Meteor). We consider that this provides a good proxy for the historical network growth in Ireland.

The average four-year new site growth rate was circa 10–10.5%, and from this we calculated that the CAGR site deployment is circa 2.5%. Although this is smaller than the site deployment rate in the UK,[15] we used a CAGR of 2.5% as the average historic new site network roll-out growth rate for the simulations.

The site deployment rate depends on the strategy of the MNO. For instance, MNOs could deploy sites at a faster rate, particularly when deploying a new technology, to get the first-mover advantage.

A2.4.9 Macrosite upgrade rate

We assume that it takes five times longer to commission a new site, compared to performing a carrier upgrade or using a Shared Access site. The time is calculated from the following equation:

$$d = d_0 + 365.25 \log_{10}\left(\frac{s_0 + s_n + s_u w_u + s_s w_s}{s_0}\right) / \log_{10}(1 + c)$$

where:

- d is the date of network expansion action—network expansion actions that were considered were commissioning a new site, carrier upgrade, or accessing to a shared site;
- d_0 is the date of the macrosite database, which is assumed to be 1 May 2017 and is used to create the synthetic macrosite database;

[15] Ofcom (2009), 'Application of spectrum liberalisation and trading to the mobile sector', 13 February.

- s_0 is the number of macrosites of the synthetic network;
- s_n is the number of new macrosites;
- s_u is the number of upgraded macrosites;
- $w_u = 1/5$ is the weight applied to carrier grades;
- s_s is the number of shared sites;
- $w_s = 1/5$ is the weight applied to accessing shared sites;
- $c = 0.025$ is the CAGR.

A2.4.10 Network costs

Evidence to support the CAPEX and OPEX costs parameters used in this study includes the costs in the ComReg mobile termination model that is discussed in ComReg Documents 18/19 and 18/19c, as well as evidence from Ofcom.[16] We present the costs in Table A2.5 and Table A2.6.

Table A2.5 CAPEX costs for new sites, upgrades, and a site refresh

	Item	CAPEX (€k)	Lifetime (years)	Nominal annual cost trend
New sites	Site	250	25	0%
	Active radio equipment	10.5	8	-3%
	Backhaul	8	8	-3%
Upgrades	Active radio equipment	10.5	8	-3%
	Labour	0.5	n/a	0%
Site refresh	Active radio equipment	10.5	8	-3%
	Backhaul	8	8	-3%
	Labour	0.5	n/a	0%

Source: Oxera/Real Wireless.

Table A2.6 OPEX costs

Item	OPEX (€k)	Nominal annual cost trend
Site	15	-3%
Active Radio equipment	15% of CAPEX	-3%
Backhaul	25% of CAPEX	-3%

Source: Oxera/Real Wireless.

Site refresh refers to the replacement cost for the radio equipment at the end of the radio equipment's lifespan.

The site sharing CAPEX for a new operator is assumed to be 30% of the new greenfield CAPEX. It includes additional site build costs, such as larger tower/pole mounts, supports for larger cabins, and larger BTS room requirements. The OPEX for a new operator on a shared site is assumed to be the same as a new site.

[16] See Ofcom (2018) 'Improving mobile coverage: Proposals for coverage obligations in the award of the 700 MHz spectrum band' [Link] paragraphs 330 - 335

A2.5 The merit function and the network expansion model

A2.5.1 The merit function

We used a merit function to decide how to expand the network model. The tool chooses the spectrum combination leading to the maximum merit. The merit function is defined as follows:

Merit = benefit / cost_of_network_expansion,

where:

- cost_of_network_expansion is the 20-year present value of deploying, upgrading, or sharing a site;[17]
- benefit is defined in relation to the specific scenario—for example, it could be based on:
  - the number of people (based on a combination of premises covered (from Eircode)[18] and population density (from CSO))[19] within the coverage area that otherwise would not get coverage at the target throughput;
  - geographical area covered that otherwise would not get coverage at the target throughput;
  - the number of IIoT devices within the coverage area that otherwise would not get coverage at the target throughput;
  - weighted thoroughfare lengths (see below) covered that would otherwise not get coverage at the target throughput.

Note that in order for the optimiser to decide between investment choices (i.e. expanding with a carrier upgrade or with Shared Access, or by installing a new macrosite), the cost of each choice is calculated in cost_of_network_expansion.

For example, in 2018, in the case of a new macrosite, the cost is:

- CAPEX of the site, unchanged with time;
- CAPEX of new active equipment, nominal cost trend (-3%) from the 2017 value;
- CAPEX of new backhaul, nominal cost trend (-3%) from the 2017 value;
- CAPEX for end of 8-year life cycle of active equipment, nominal cost trend (-3%) from the 2017 value, discounted by 8 years;
- CAPEX for end of 16-year life cycle of active equipment, nominal cost trend (-3%) from the 2017 value, discounted by 16 years;
- CAPEX for end of 8-year life cycle of backhaul, nominal cost trend (-3%) from the 2017 value, discounted by 8 years;

[17] Note that the present value period of 20 years was selected independently of the asset lifetime of a site (25 years).
[18] EIRCODE address database May 2017, provided by ComReg.
[19] Census database 2016, Central Statistics Office

- CAPEX for end of 16-year life cycle of backhaul, nominal cost trend (-3%) from the 2017 value, discounted by 16 years;
- CAPEX for end of life cycle labour after 8 years, nominal cost trend (0%) from the 2017 value, discounted by 8 years;
- CAPEX for end of life cycle labour after 16 years, nominal cost trend (0%) from the 2017 value, discounted by 16 years;
- OPEX for the macrosite over 20 years, i.e. in 2018, 2019… 2037, nominal cost trend (-3%) from the 2017 value, discounted by 0, 1… 19 years, respectively;
- OPEX for the active radio equipment over 20 years, i.e. in 2018, 2019… 2037, nominal cost trend (-3%) from the 2017 value, discounted by 0, 1… 19 years, respectively;
- OPEX for the backhaul over 20 years, i.e. in 2018, 2019… 2037, nominal cost trend (-3%) from the 2017 value, discounted by 0, 1… 19 years, respectively.

The calculations use a discount rate of 8.63%.[20]

Benefit for thoroughfare weightings for the CV scenario

In the CV simulation scenario, the benefit for thoroughfare is calculated using the following weightings applied to rail and the different road category types:

benefit for thoroughfare = Motorway + 0.1*Nat_primary + 0.01*Nat_Second + 0.001*Regional + 0.0001*Third + Rail

where:

- Motorway is the length of Motorway thoroughfare type within the coverage area that otherwise would not get coverage at the target throughput;
- Nat_primary is the length of Nat_primary thoroughfare type within the coverage area that otherwise would not get coverage at the target throughput;
- Nat_Second is the length of Nat_Second thoroughfare type within the coverage area that otherwise would not get coverage at the target throughput;
- Regional is the length of Regional thoroughfare type within the coverage area that otherwise would not get coverage at the target throughput;
- Third is the length of Third thoroughfare type within the coverage area that otherwise would not get coverage at the target throughput;

  Rail is the length of Rail thoroughfare type within the coverage area that otherwise would not get coverage at the target throughput.

A2.5.2 The network expansion model

The network expansion model expands the estimated coverage by:

[20] ComReg 14/136, 'Cost of Capital: Mobile Telecommunications, Fixed Line telecommunications, Broadcasting (Market A and Market B), 18 December 2014.

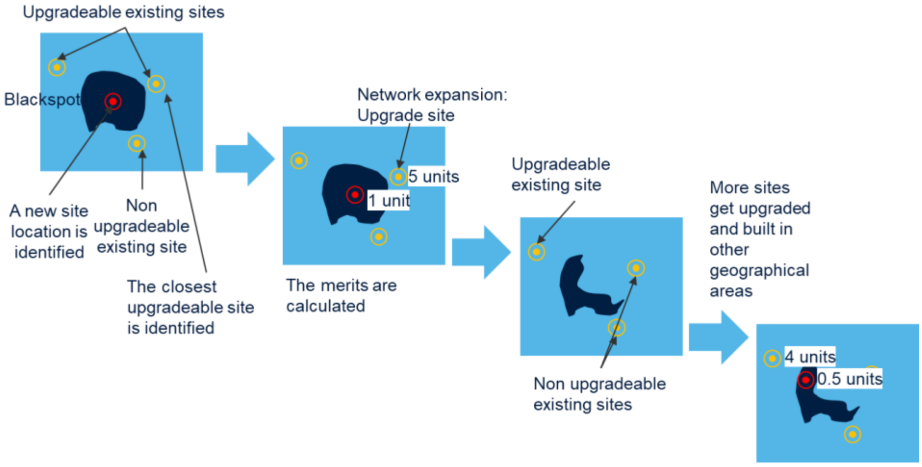
1. deploying new sites, where there is a benefit (noting that 'benefit' is defined by calculations conducted in merit functions as set out above);
2. upgrading existing sites with new spectrum bands (this only applies after mid-2020);
3. deploying shared sites (this option only applies to the site sharing scenario).

The model carries out the following steps to decide the expansion option as explained below.

4. Find the black spot with the largest unserved demand—for example, population target, geographic area target, IIoT devices for IIoT target, or thoroughfare roads/rail for CV target.
5. Within the black spot, the model selects the geometric mean and median as two initial site polled locations.
6. From the initial polls, the model predicts the path loss to every demand point within an approximately 14km radius using the propagation model. Clutter and terrain variations are also considered for this prediction.
7. The path loss values are compared with the maximum acceptable path loss (MAPL) value determined from a link budget to decide if a certain demand point is covered or not. If the calculated path loss for a given demand point is smaller than the MAPL value, then the demand point is considered as a point covered by the site.
8. The site with the minimum path loss is considered as the service site for demand locations that are served by more than one site.
9. The optimiser then polls nearby locations, repeating steps 3–5, until the location that leads to maximum merit is found. The merit is defined as the ratio of the benefit of the site over its cost. For example, for a population target where a new site would provide service to 1,447 people who otherwise would not have service, and where the site cost is €100,000, the merit of this site is 1,447/100,000.
10. Before proceeding with the new macrosite installation, the model examines if there are any upgradeable macrosites close to the candidate new site location. The closest upgradeable macrosite is selected as the candidate for upgrade.
    1. The model calculates the merit for both the site upgrade option and for the new site option and selects the network expansion option that has the greater merit. The only upgrade option we consider is upgrading the sites with the additional spectrum bands available from mid-2020.
    2. If there is a sharing option, then its merit is also calculated here.
11. Steps 1–7 are repeated for the remaining unserved demand areas.

As a result of this iterative process, a black spot may not be eliminated by a single expansion action. Figure A2.6 shows a series of graphs where the black spot is first reduced and then considered again. Thus, the network expansion for a particular black spot could involve a number of new sites, upgrades of existing sites, and access to another infrastructure provider.

Figure A2.6 Site expansion process (an illustrative example)



Source: Oxera/Real Wireless.

A2.6 Definitions for the percentage coverage results

This section sets out the definitions used for presenting the percentage coverage results for the different coverage classifications.

- **Population percentage (Ireland):** the number of people in Ireland that are covered with outdoor MBB, over the total number of people in Ireland. The geolocation of the people was based on a combination of premises covered (from Eircode) and population density (from CSO).
- **Population percentage (regional):** number of people in a region that are covered with outdoor MBB, over the total number of people in that region. For example, number of people in South East that are covered, over the total number of people in South East.
- **Motorway:** length of motorways covered with in-vehicle MBB, over total length of motorways in Ireland.
- **Nat primary:** length of national primary road-type covered with in-vehicle MBB, over total length of national primary road-type in Ireland.
- **Nat second**: length of national second road-type covered with in-vehicle MBB, over total length of national second road-type in Ireland.
- **Regional**: length of regional road-type covered with in-vehicle MBB, over total length of regional road-type in Ireland.
- **Third:** length of third road-type covered with in-vehicle MBB, over total length of third road-type in Ireland.
- **Rail**: length of rail covered with in-carriage MBB, over total length of rail in Ireland.
- **Area percentage:** land area that is covered with outdoor MBB, over sovereign land area of Ireland.
- **IIoT percentage:** number of IIoT devices that are covered with IIoT, over all IIoT devices in Ireland.
- **CV—motorway:** length of motorways covered with on-vehicle CV service, over total length of motorways in Ireland.
- **CV—nat primary:** length of national primary road-type covered with on-vehicle CV service, over total length of national primary road-type in Ireland.
- **CV—nat second:** length of national second road-type covered with on-vehicle CV service, over total length of national second road-type in Ireland.
- **CV—regional**: length of regional road-type covered with on-vehicle CV service, over total length of regional road-type in Ireland.
- **CV—third**: length of third road-type covered with on-vehicle CV service, over total length of third road-type in Ireland.
- **CV—rail**: length of rail covered with on-carriage CV service, over total length of rail in Ireland.

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Annex 3: Additional simulation results

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A3 Additional simulation results

There are seven main scenarios:

- Scenario 1: 3Mbit/s population coverage
- Scenario 2: 30Mbit/s population coverage
- Scenario 3: 3Mbit/s geographic coverage
- Scenario 4: 30Mbit/s geographic coverage
- Scenario 5: 3Mbit/s motorway & primary roads coverage
- Scenario 6: 30Mbit/s motorway & primary roads coverage
- Scenario 7: 30Mbit/s motorway coverage

Further details can be found in the sections below.

A3.1 Scenario 1: 3Mbit/s MBB population coverage

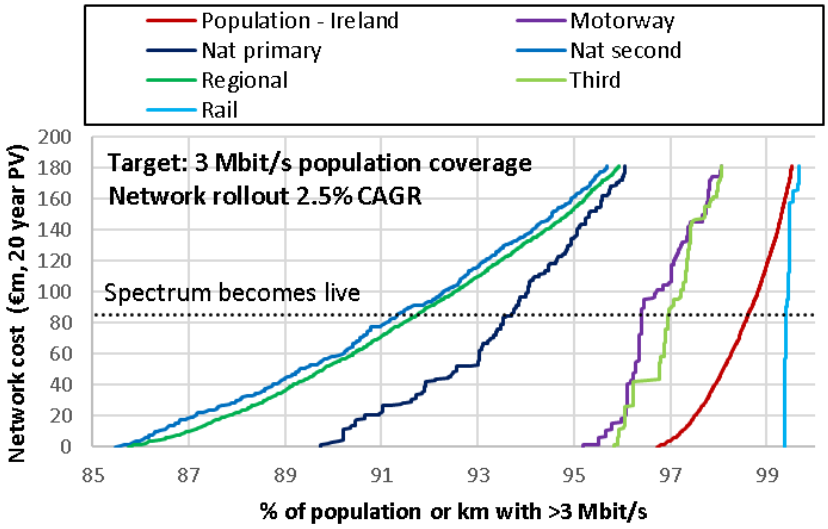
In scenario 1, the targeted coverage focuses on 3Mbit/s MBB population coverage, which is increased from 96.7% to 99.5%. When expanding this coverage, incidental coverage is also provided for other application data rates, other services and for other coverage measures. The incidental population coverage for the 30Mbit/s and 50Mbit/s MBB services is presented in section 5 of the main body of the report. This section presents the incidental 3Mbit/s MBB coverage for roads and rail and coverage maps of the MBB service.

A3.1.1 Incidental MBB 3Mbit/s coverage for roads and rail

Figure A3.1 and Table A3.1 set out the incidental 3Mbit/s MBB in-vehicle coverage for roads and rail. The estimated network costs are based on a network roll-out speed of 2.5% CAGR, which results in a roll-out period of eight and a half years (2017–25).

From these results, it can be seen that coverage on roads and rail grows in proportion to population coverage. This can be explained by the fact that roads are usually lined with, or end with, residential addresses. All road types have MBB 3Mbit/s coverage beyond 90% by mid-2020. It can also be seen that all road types have less pronounced increasing coverage than that of population. This is expected, because many roads run through parts of the country that may not be significantly populated.

Figure A3.1 Scenario 1: Incidental 3Mbit/s MBB coverage of roads and rail



Source: Oxera/Real Wireless.

Table A3.1 Scenario 1: Incidental 3Mbit/s coverage

Year	Population	Geographic	Rail in-carriage idealised-track[1]	Motorway in-vehicle	National primary roads in-vehicle	National secondary roads in-vehicle
Start	96.7%	82.1%	99.4%	95.2%	89.7%	85.5%
End	99.5%	92.6%	99.7%	98%	96%	95.5%
Change	+2.8%	+10.5%	+0.30%	+2.80%	+6.30%	+10.00%

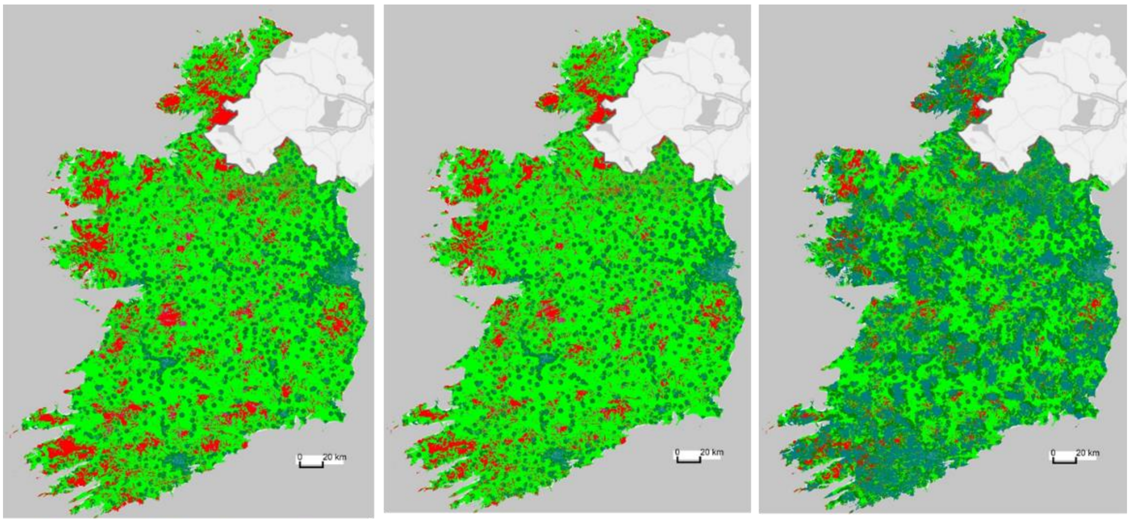
Source: Oxera/Real Wireless.

A3.1.2 Coverage maps

Coverage maps for scenario 1, applying different percentages of population coverage, are shown in Figure A3.2.

[1] Signal propagation predictions can only be as accurate as the digital terrain map (DTM) database. For rail predictions, this argument is reinforced if narrow embankments and cuttings exist along the line. For a coverage assessment undertaken for the rail industry, it was considered necessary to work with 5m resolution. However, the DTM that we were supplied with was 10 x 10m; therefore, the cuttings will be missed.

Figure A3.2 Scenario 1 coverage maps (3Mbit/s MBB population coverage)



Coverage: 97% of population | Coverage: 98% of population | Coverage: 99.5% of population

No coverage
Less than 3 Mbps
Between 3 Mbps and 30 Mbps
Between 30 Mbps and 50 Mbps
Greater than 50 Mbps

Source: Oxera/Real Wireless.

A3.2 Scenario 2: 30Mbit/s MBB population coverage

In scenario 2, the targeted coverage is 30Mbit/s MBB population coverage, which is increased from 62.4% to 99.5%. The incidental population coverage for the 3Mbit/s and 50Mbit/s MBB services is presented in section 5 of the main body of the report. This section presents the incidental 30Mbit/s coverage for roads and rail and coverage maps of the MBB service.

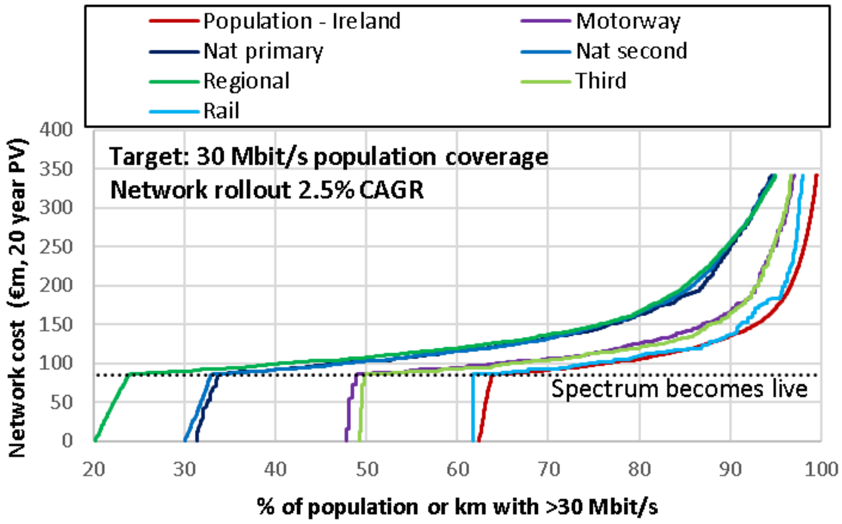
A3.2.1 Incidental 30Mbit/s coverage for roads and rail

Figure A3.3 and Table A3.2 set out the incidental 30Mbit/s MBB in-vehicle coverage for roads and rail. The estimated network costs are based on a network roll-out speed of 2.5% CAGR, which results in a roll-out period of 26 years (2017–43).

Similar to the results of scenario 1, the coverage on all road types is less than that of population coverage, and coverage on thoroughfare types appears to grow in proportion to population coverage. For scenario 2, all road types have 30Mbit/s MBB coverage beyond 90% when the 30Mbit/s population coverage exceeds 98.27%.

Note that it is more costly to serve rail with the higher 30Mbit/s data rate target. This is because the starting macrosite synthetic network of 2017 may already have been dimensioned for voice on the rail corridors, and adapting it for data could be costly. Alternative approaches could be explored, for example where the target is to deliver an even higher data rate service, beyond 100Mbit/s, to antennas on the top of the train that would then act as proxy for customer broadband service.

Figure A3.3 Scenario 2: Incidental 30Mbit/s MBB coverage of roads and rail



Source: Oxera/Real Wireless.

Table A3.2 Scenario 2: Incidental 30Mbit/s coverage

Year	Population	Geographic	Rail in-carriage idealised-track[2]	Motorway in-vehicle	National primary roads in-vehicle	National secondary roads in-vehicle
Start	62.4%	18.3%	61.7%	47.8%	31.3%	30.1%
End	99.5%	90.6%	98.0%	97%	94.6%	95.0%
Change	+37.1%	+72.3%	+36.3%	+49.2%	+63.3%	+64.9%

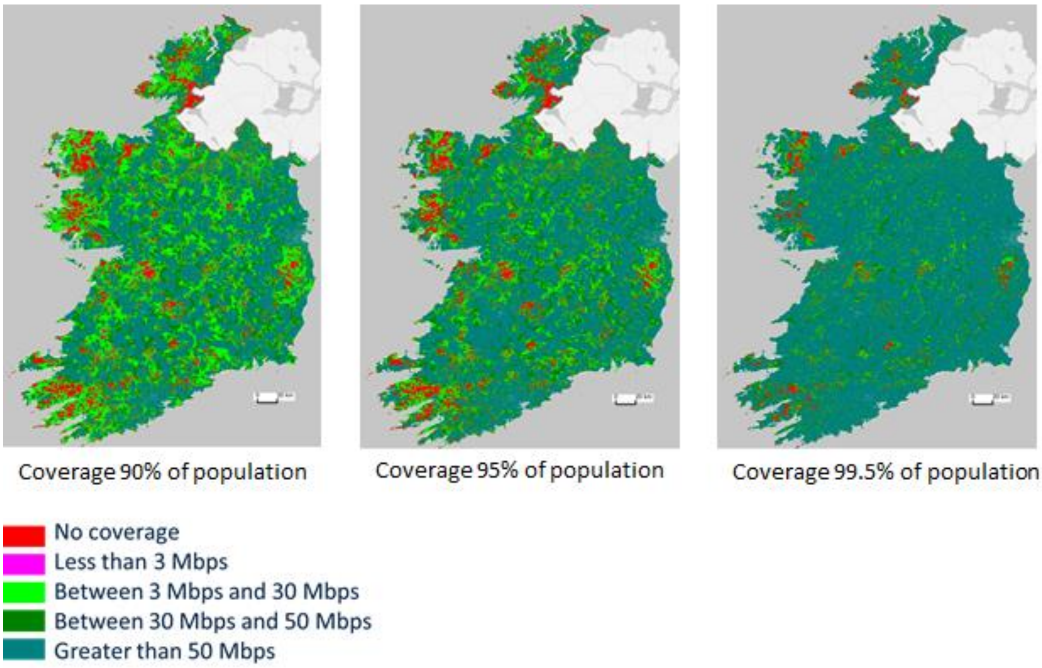
Source: Oxera/Real Wireless.

A3.2.2 Coverage maps

Coverage maps for scenario 2 for different percentages of population coverage are shown in Figure A3.4.

[2] Signal propagation predictions can only be as accurate as the digital terrain map (DTM) database. For rail predictions, this argument is reinforced if narrow embankments and cuttings exist along the line. For a coverage assessment undertaken for the rail industry, it was felt necessary to work with 5m resolution. However, the DTM that we were supplied with was 10 x 10m; therefore, the cuttings will be missed.

Figure A3.4 Scenario 2 coverage maps (30Mbit/s MBB population coverage)



Source: Oxera/Real Wireless.

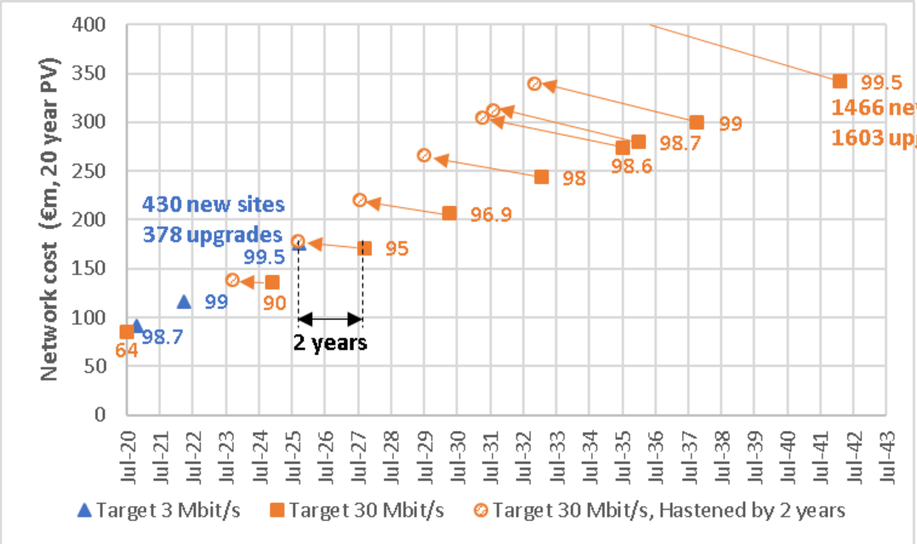
A3.3 Comparing scenarios 1 and 2

The network roll-out CAGR determines the rate at which new sites and upgrades are deployed. The standard network roll-out CAGR used in the simulations is 2.5%. This is based on the 2013–17 site deployment of Vodafone and Meteor. For scenario 2, this results in a network roll-out period of 26 years to provide 99.5% population coverage for 30Mbit/s. Quicker roll-out periods are possible with a higher network roll-out CAGR.

As discussed in section 5 of the main body of the report, faster roll-outs are less feasible and more costly. The network costing model provides a lower bound estimate of the cost of rolling out networks faster than 2.5% CAGR.

Figure A3.5 shows the impact on estimated network costs where the scenario 2 roll-out time period is shortened by two years in order to achieve 95% population coverage for 30Mbit/s MBB service provision in 2025. This requires the CAGR to be 3.85% from mid-2020 onwards, and increases the costs by €7m.

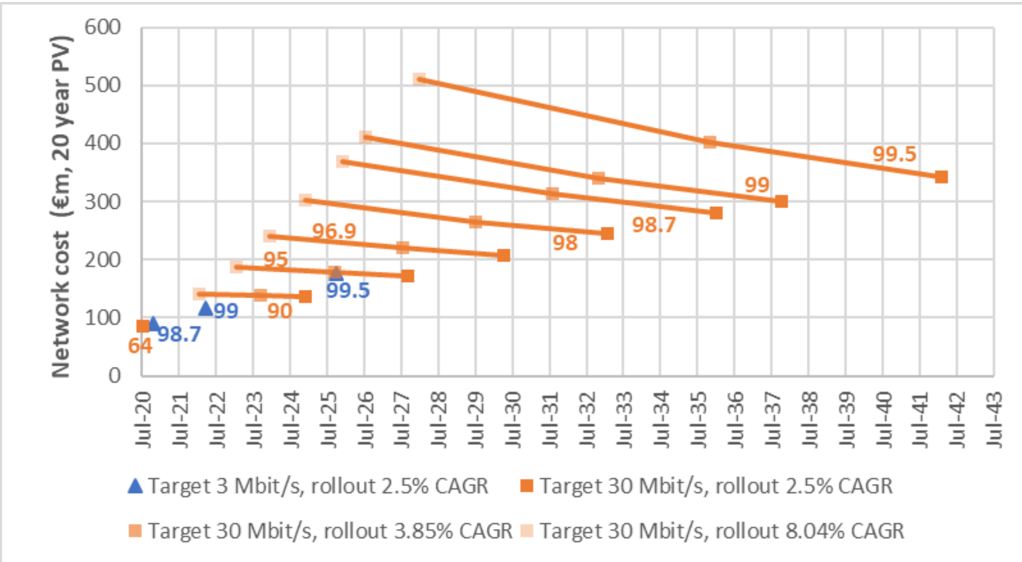
Figure A3.5 The impact of increasing the speed of scenario 2 roll-out after mid-2020 from 2.5% to 3.85% CAGR



Source: Oxera/Real Wireless.

Figure A3.6 shows the effect of reaching 99.5% population coverage of 30Mbit/s at the end of 2027 (which requires a network roll-out speed of 8.04% CAGR). The lines represent iso-curves. For example, all points on the 99.5 line correspond to 99.5% population coverage for variable time and network cost.

Figure A3.6 The impact of increasing the speed of scenario 2 roll-out after mid-2020 from 2.5% to 8.04% CAGR



Source: Oxera/Real Wireless.

Three things should be noted here.

First, a network roll-out speed of 2.5% CAGR means that the higher percentages of population coverage can only be achieved over decades. For example 99% population coverage would be reached in 2037 and 99.5% would be reached in 2042. We note that such long time-spans introduce uncertainty around the validity of modelling assumptions such as costs.

Second, the cost of deploying a network to achieve 99.5% coverage by 2027, i.e. with a network roll-out rate of 8.04% CAGR, is €541m. The additional cost for hastening the network roll-out is €170m. As a comparison in mid-2020, the network roll-out speed of 2.5% CAGR corresponds to a new site every week or an upgrade every two days, whereas the speed of 8.04% CAGR corresponds to a new site every two days or three upgrades per day.

Third, as noted in section 5 of the main report, faster network roll-outs are more costly and may be less feasible. The model provides a lower bound estimate of the costs of quickening network roll-out. This is because although the 'CAPEX—new site' cost element includes payment of staff, and totals €250k, the following potential cost implications are not taken into account in the cost model.

- Potential additional staff acquisition to perform the increased roll-out speed. The cost model assumes that the same staff volume (e.g. engineers and crew on the field), can establish new sites at the requested rate.
- Additional support teams to optimise the fast-growing network.
- Delivery logistics.

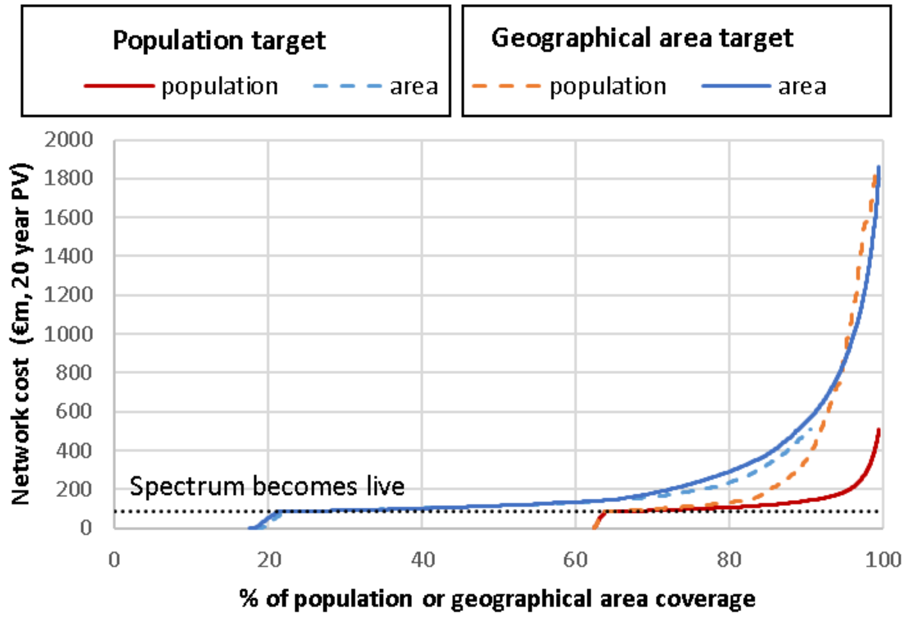
A3.4 Comparing scenarios 2 and 4

Figure A3.7 compares the coverage and costs of scenarios 2 and 4. Scenario 2 relates to 30Mbit/s MBB population coverage, and scenario 4 relates to 30Mbit/s MBB geographic coverage

To achieve completion in 2027, from mid-2020 onwards scenario 2 grows at 8.04% CAGR, and scenario 4 grows at 19.96% CAGR. Geographic coverage is also more costly to provide as it requires more sites.

For example, 96% MBB 30Mbit/s population coverage requires an investment of €210m, whereas 96% MBB 30Mbit/s geographic coverage requires €970m and an additional 18 months. Alternatively, a network investment of €350m could either achieve 98.5% population coverage or 83.5% geographic area coverage (both regarding MBB 30Mbit/s).

Figure A3.7 Comparison between scenarios 2 and 4 (30Mbit/s population coverage versus 30Mbit/s geographic coverage)



Source: Oxera/Real Wireless.

A3.5 Comparing scenarios 3 and 4

Comparing scenario 3 (3Mbit/s geographical coverage) and scenario 4 (30Mbit/s geographical coverage) illustrates the impact of increasing the bandwidth from 3Mbit/s to 30Mbit/s.

For 99.5% geographical coverage, the 3Mbit/s target would require growth of 10.4% CAGR to be achieved within the 10-year roll-out frame, whereas the 30Mbit/s target would require a more aggressive network growth of 19.96% CAGR.

Table A3.3 summarises the 3Mbit/s coverage that can be achieved with costs of €145m. A 30Mbit/s target appears to result in relatively high incidental 3Mbit/s coverage.

Table A3.3 3Mbit/s coverage achieved with €145m costs

	Scenario 3 (where 3Mbit/s coverage is the target)	Scenario 4 (where 3Mbit/s coverage is incidental)
Number of new sites & site upgrades	307 new sites & 217 upgrades	279 new sites & 715 upgrades
Geographical coverage	92.3%	85.2%
Population coverage	99.02%	97.6%
Motorway coverage	98.3%	96.7%
National primary coverage	96.1%	92.3%
National second coverage	94.3%	88.1%
Regional coverage	94.4%	88.7%
Third coverage	99.6%	97.1%
Rail coverage	99.6%	99.8%

Source: Oxera/Real Wireless.

A3.6 Comparing scenarios 6 and 7

By comparing scenario 7 (30Mbit/s motorway coverage) and scenario 6 (30Mbit/s motorway and primary road coverage), we observe the impact of adding primary roads to the coverage target.

If scenario 6 is met within ten years from 2017, then the joint target additionally requires 385 new macrosites, 251 carrier upgrades, and €117m. Scenario 7 can be achieved with the historic growth of 2.5% CAGR within the ten-year frame, by mid-2024, whereas scenario 6 would require a more aggressive network growth of 3.78% CAGR.

Table A3.4 gives the 30Mbit/s coverage that can be achieved with a budget of €160m.

Table A3.4 30Mbit/s coverage achieved with €160m costs

	Scenario 7	Scenario 6
Number of new sites & site upgrades	369 new sites & 141 upgrades	354 new sites & 290 upgrades
Motorway coverage	99.5%	98%
National primary coverage	39%	73%
National second coverage	42%	50%
Regional coverage	39%	49%
Third coverage	65%	71%
Rail coverage	65%	67%

Source: Oxera/Real Wireless.

Table A3.5 summarises the coverage that is expected by deploying a variable number of new sites from mid-2020 under the different scenarios.

Table A3.5 30Mbit/s coverage achieved for a given number of new sites (100, 150, or 196 new sites)

Number of new sites from mid-2020	**100**	**100**	**150**	**150**	**196**	**196**
Scenario #	7	6	7	6	7	6
Number of upgrades from mid-2020	116	177	124	233	140	294
Completion date with 2.5% CAGR	Aug 2022	Nov 2022	Jun 2023	Nov 2023	Apr 2024	Oct 2024
Motorway coverage	95%	95%	98%	97%	99.5%	98%
National primary coverage	38%	47%	38%	63%	39%	76%
National second coverage	41%	43%	42%	47%	42%	51%
Regional coverage	37%	40%	38%	46%	39%	51%
Third coverage	63%	65%	64%	69%	65%	72%
Rail coverage	64%	65%	64%	66%	65%	67%

Source: Oxera/Real Wireless.

A3.7 Comparing scenarios 5 and 6

By comparing scenario 5 (3Mbit/s motorway and primary road coverage), and scenario 6 (30Mbit/s motorway and primary road coverage), we can see the impact of increasing the bandwidth from 3Mbit/s to 30Mbit/s.

The 3Mbit/s target can be achieved by mid-2023 with a network roll-out speed of 2.5% CAGR, whereas the 30Mbit/s target would require a more aggressive network growth of 3.78% CAGR in order to reach completion by 2027.

Table A3.6 summarises the 3Mbit/s coverage that is expected with a budget of €145m from the two targets. A 30Mbit/s target appears to result in relatively high 3Mbit/s coverage. The last 3.5% coverage of national primary roads (from 96% to 99.5%) is estimated to cost €132m.

Table A3.6 3Mbit/s coverage achieved with €145m costs

	Scenario 5	Scenario 6
Number of new sites & site upgrades	327 new sites & 50 upgrades	315 new sites & 227 upgrades
Motorway coverage	99.996%	99.88%
National primary coverage	99.5%	96%
National second coverage	92%	93%
Regional coverage	93%	93%
Third coverage	98%	98%
Rail coverage	99.5%	99.5%

Source: Oxera/Real Wireless.

A3.8 Additional simulation results for the other scenarios

There are five other scenarios:

- Scenario 8: 30Mbit/s population coverage—new entrant
- Scenario 9: 50Mbit/s population coverage
- Scenario 10: 30Mbit/s population coverage—site sharing
- Scenario 11: 30Mbit/s population coverage to 95%, then IIoT coverage
- Scenario 12: 30Mbit/s population coverage to 95%, then CV coverage

Further details can be found in the sections below.

A3.9 Scenario 8: 30Mbit/s population coverage—new entrant

In Scenario 2, the network roll-out is undertaken with the target of increasing the 30Mbit/s population coverage. In scenario 8, we assessed the cost of a network roll-out for a potential new entrant in the mobile sector with zero macrosites in mid-2020. The target was set to 30Mbit/s to coincide with the availability of the new spectrum in mid-2020.

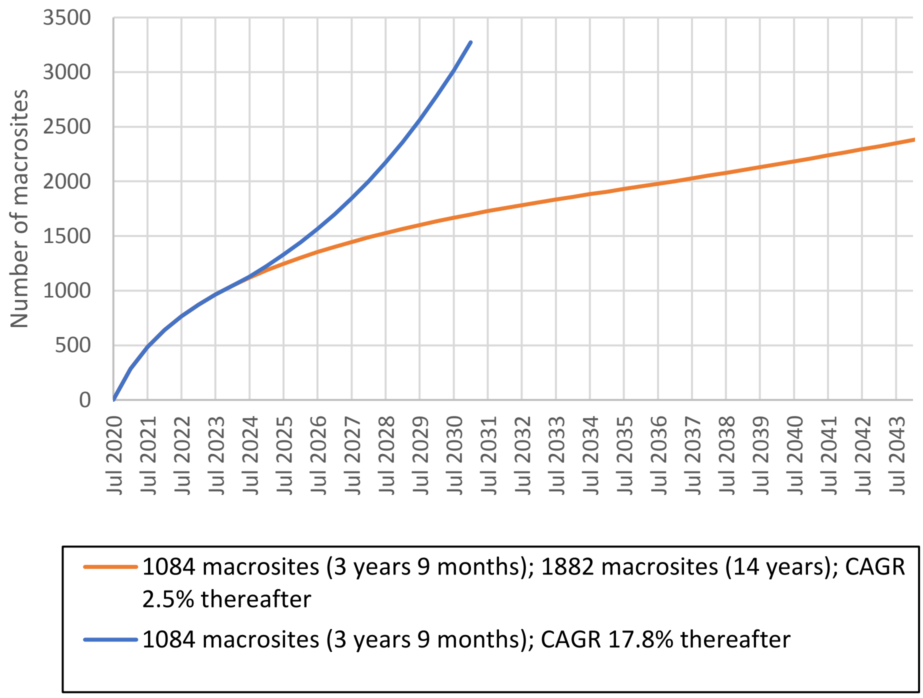
The network requires 3,272 three-sector macrosites to provide 30Mbit/s service to 98% of the population. This number is greater than that for an incumbent MNO. An incumbent MNO can deliver 30Mbit/s coverage to 98% of the population with 1,882 existing plus 711 new macrosites, i.e. 2,593 macrosites in total. This is because the incumbent can use carrier aggregation of 30MHz across three sub-1GHz bands, whereas with spectrum portfolio 2 the new entrant only has access to 10MHz in the sub-1GHz bands plus 20MHz at 2.6GHz.

A network roll-out rate of 2.5% CAGR would result in several decades before the new entrant reached a network size that is on par with the incumbent networks.

Strictly speaking, a CAGR on a network size of zero is not possible. To better represent the roll-out strategy of a new entrant we assumed a logarithmic growth in the early years and then used two variants for network evolution thereafter (see Figure A3.8):

- moderate—1,084 macrosites within 3 years and 9 months; 1,882 macrosites in the first 14 years (a similar network size to current incumbent MNOs); a network roll-out CAGR of 2.5% afterwards;
- aggressive—1084 macrosites within 3 years and 9 months; a network roll-out CAGR of 17.8% thereafter. This achieves the target of at least 98% population coverage with 30Mbit/s by end-2030.

Figure A3.8 Two variants for the network evolution of a new entrant targeting 30Mbit/s population coverage (Scenario 8)

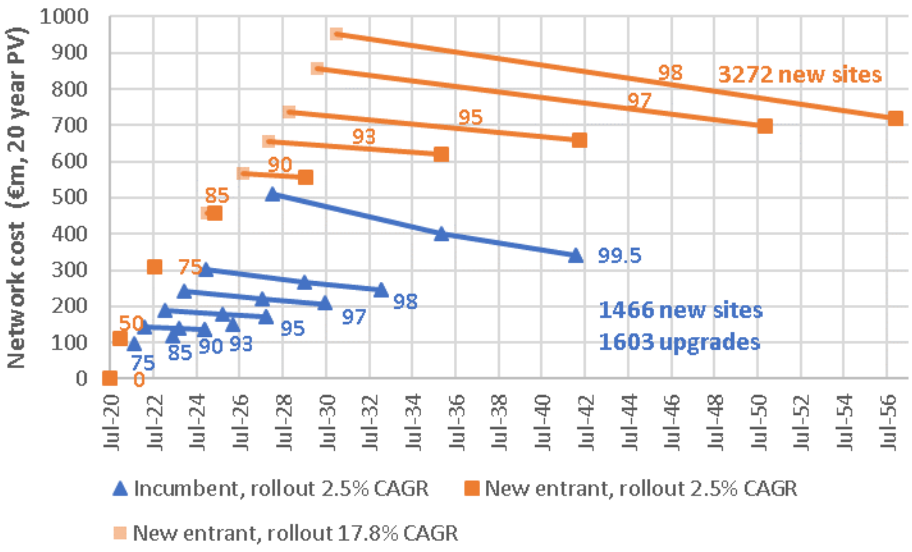


Source: Oxera/Real Wireless.

As expected, the target of 30Mbit/s population coverage is costlier for a new entrant, relative to an incumbent (see Figure A3.9). Regarding the moderate network roll-out, 96% population coverage with 30Mbit/s could be achieved with €190m for an incumbent, but it would require €680m and two decades longer for a new entrant. We note that the latter cost has a greater degree of uncertainty as the model predicts further into the future.

For coverage above circa 95% and assuming the 2.5% CAGR, the new entrant seems to achieve greater advances in coverage with less cost. This is because the new entrant starts from a low base (0 sites, 0% coverage) and such advances in coverage are later in time when network costs have depreciated.

Figure A3.9 Comparing scenarios 2 and 8



Source: Oxera/Real Wireless.

A3.10 Scenario 9: 50Mbit/s population coverage

In Scenario 9, the network roll-out is undertaken with the target of achieving 50Mbit/s population coverage. The switch of the target from 3Mbit/s to 50Mbit/s coincides with the availability of the new spectrum in mid-2020.

To expand the network from 43.6% to 80% population coverage of 50 Mbit/s, the network requires 280 new three-sector macrosites and 1,045 carrier upgrades to existing macrosites.

Figure A3.10 shows that the cost of providing coverage for 58% of the population with the minimum throughput level of 50Mbit/s is approximately €100m. The corresponding cost (i.e. cost of providing coverage for 58% of the population with the minimum throughput level of 50Mbit/s) using a network targeted for 3Mbit/s (see section 5 of the main report) is €181m. In this case, an additional investment of €80m is required if we try to provide at least 50Mbit/s throughput using a network targeted for 3Mbit/s.

Figure A3.10 Scenario 9: 50Mbit/s population coverage

Note: The 3Mbit/s and 30Mbit/s curves here relate to incidental coverage, as the target is 30Mbit/s.

Source: Oxera/Real Wireless.

A3.11 Scenario 10: 30Mbit/s population coverage—site sharing

In scenario 10, the target is 30Mbit/s MBB population coverage (as in scenario 2) where the costs are for an MNO that has access to the existing infrastructure provider, Shared Access. The switch of the target from 3Mbit/s to 30Mbit/s coincides with the availability of the new spectrum in mid-2020.

We used a site database provided by Shared Access, which provides sites for MNOs and is currently working with Three Ireland.[3] It has arrangements with sports clubs whereby base station sites could be developed at these club locations. Given that these locations will already have an access road and power, these could be a lower-cost solution to providing some sites in rural locations. Furthermore, as the site owner has already agreed to a wireless site being developed, these sites are a much better prospect for development than other random locations. Shared Access has rights to 3,012 sites in Ireland. We utilised the Shared Access site locations in our simulation process to assess the site sharing scenarios whenever the site is at the right location to meet the requirement.

We assessed the cost savings that are attributed to two alternative schemes of accessing sites.

- **Shared Access sites are the only shared sites**. During network roll-out we identify locations that are suitable for network expansion by querying the Shared Access infrastructure database for proximity to areas that lack service. Access to an existent Shared Access macrosite is assumed to provide a 30% cost saving compared to a macrosite price if that was to be commissioned by the synthetic operator. Synthetic network carrier upgrades incur at full cost, as they are not shared with other providers. This corresponds to the ‘first-mover’ MNO without considering that other MNOs may also wish to extend coverage and thus share the incurred costs. Therefore, this scheme corresponds to a conservative estimate of the benefits of site sharing.

- **All new sites and upgrades are on shared sites**. All new macrosites that are commissioned by the synthetic operator are automatically shared with other MNOs, and the cost reduction to the synthetic MNO is 30% of the non-shared price. All macrosite carrier upgrade costs incurred by the synthetic MNO are automatically shared with other MNOs, and the cost reduction to the synthetic operator is 30% of the non-shared upgrade price. This scheme corresponds to an optimistic estimate of the benefits of sharing, because in the real world the other MNOs may already have coverage in the area or may not be interested to extend coverage. Note that in this scheme sharing is only considered for new sites or upgraded carriers, although if existing sites were also shared it would lead to further savings.

Results where Shared Access sites are the only shared sites (conservative estimate of the benefits of site sharing)

When the population coverage reaches 99.5%, 29% of the new macrosites of the synthetic MNO were chosen from the Shared Access sites. This means

[3] See Shared Access website, http://www.sharedaccess.com/about-us/.

that there are some Shared Access macrosites at locations that are suitable to site sharing. The number of sites that can be shared through Shared Access is limited because the location of Shared Access sites is not always suitable for the hypothetical operator (which may result in coverage gaps that would require further new sites/upgrades).

Table A3.7 summarises the site numbers and the expected savings before and after the spectrum live date. Since we assumed a cost reduction of 30% when sharing a site, and if upgrade cost is neglected, the expected cost reduction from sharing is proportional to the shared sites over the new site count. Before the spectrum becoming live, the expected savings are about 7%. After the spectrum goes live, there is a large expense on upgrades, and therefore sharing shows subdued benefits at about 5%.

Table A3.7 Expected savings from the site share scenario, where Shared Access sites are the only shared sites

	Before mid-2020	After mid-2020
Number of new sites for the synthetic network (including those needed from Shared Access)	164	414
Number of upgrades (cost not shared)	3	1,508
Number of sites from Shared Access	37	128
Expected cost savings compared to no site sharing	7%	5%

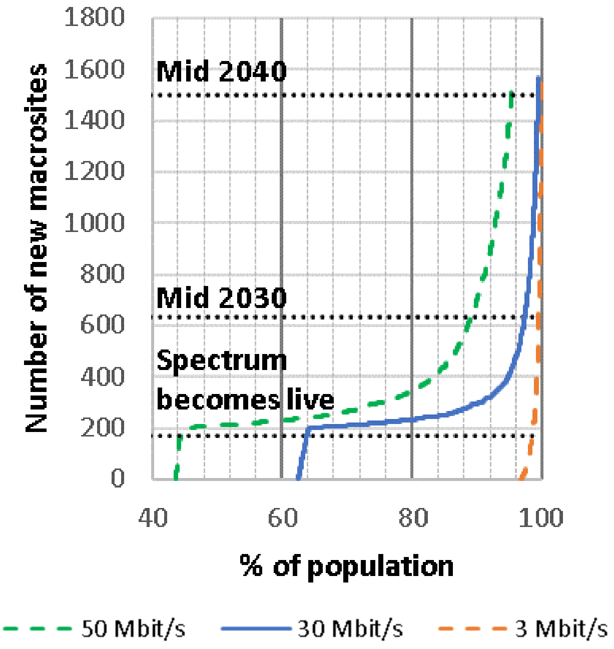
Source: Oxera/Real Wireless.

Figure A3.11 shows the cost of new site building exercise for scenario 10, where Shared Access sites are the only shared sites.

The network requires 740 new three-sector macrosites, 1,508 carrier upgrades of existing macrosites to provide 30Mbit/s to 98% of the population. Importantly, of those 740 new sites, only 164 Shared Access sites were in the right areas to share. The low proportion of sites that are shared in this case limits the cost savings from site sharing.

This shows that an additional 740 new sites plus 1,508 upgrades are required to increase the coverage up to 98% population. 1,309 new sites are required to provide the coverage for 99.5% of the population with at least 30Mbit/s. Of those 1,309 new sites, only 260 shared access sites were in the right locations to share.

Figure A3.11 30Mbit/s population coverage—site sharing, where Shared Access sites are the only shared sites



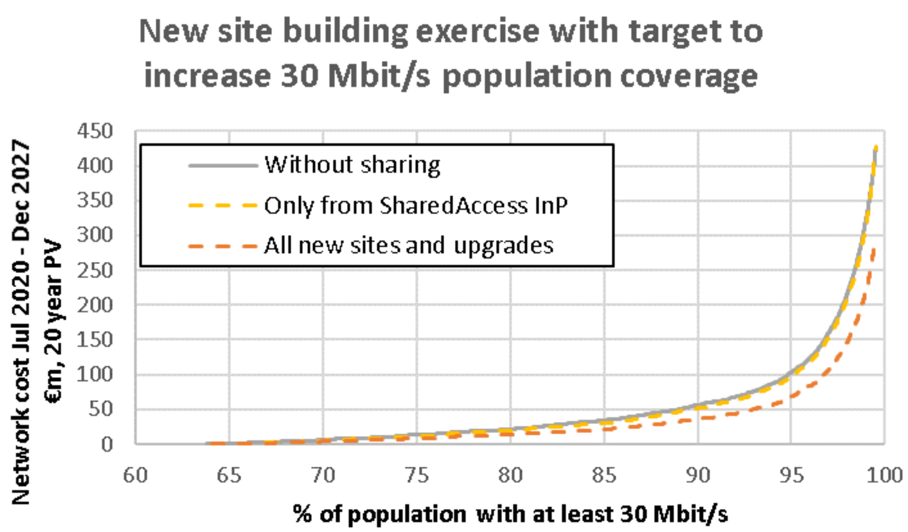
Source: Oxera/Real Wireless.

We also note that the site sharing leads to faster network roll-outs. The faster roll-out means that the cost of roll-out is incurred sooner—in present value terms, the cost of the network roll-out may appear greater (as future costs are discounted less). However, as shown in **Error! Reference source not found.**, ite sharing does indeed reduce costs for the hypothetical MNO.

A3.12 Comparing scenarios 2 and 10

Figure A3.12 shows the comparison between scenario 2 (30Mbit/s population coverage) and scenario 10 (30Mbit/s population coverage—Site sharing). It shows two cost curves for scenario 10, to illustrate the cost impact of being able to share all new sites/upgrades versus only being able to share Shared Access sites.

Figure A3.12 Comparing scenarios 2 and 10 (after mid-2020)



Source: Oxera/Real Wireless.

A3.13 Introduction to non-MBB services, IIOT and CV

As explained in section 3 of the main report, we selected the IIoT and CV use cases for further analysis.

In our simulations, we followed an approach whereby site deployment is primarily driven by the need to increase 30Mbit/s MBB population coverage up to a certain level (95%). We selected 95% following discussions with ComReg, and not on a full commercial viability analysis.

Once the sites are deployed targeting population coverage of MBB, we calculated the incidental IIoT and CV service coverage from those sites. Then the target of network expansion was changed to either IIoT or CV coverage, depending on the simulation.

We consider this approach likely to be taken by MNOs pursuing IIoT or CV coverage. It is based on the standard MBB business to consumer model, subsequently addressing the vertical markets and other opportunities (i.e. B2B) by making enhancements to existing assets. During the 4G roll-out, most European MNOs, including all the Irish MNOs, initially focused on enhancing the business performance for existing services, with new services starting to be introduced later.

Therefore, many of the non-MBB use cases discussed with the Irish MNOs will initially be deployed in 4G networks and spectrum, sometimes using evolutions of LTE such as NB-IoT for low-power wide-area network (LPWAN) services. We followed a similar approach for the CV service (where coverage is required on roads and rail).

Our simulation approach for the IIoT and CV is summarised below:

- **until mid-2020**: site placement is driven by 3Mbit/s MBB population coverage;
- **mid-2020 to 95% 30Mbit/s population coverage**: site placement is driven by MBB population coverage with a target of 30Mbit/s;
- **after 95% 30Mbit/s population coverage**: site placement is driven by the areas where IIoT/CV coverage is required.

We assume that the cost of a 700MHz carrier upgrade is similar, regardless of whether the carrier is used for MBB alone, or also for non-MBB services. In fact, industry sources seem to suggest that NB-IoT and LTE-M can be supported by software upgrades to base station software and firmware, and that is generally the case despite each vendor supporting features in individual ways.

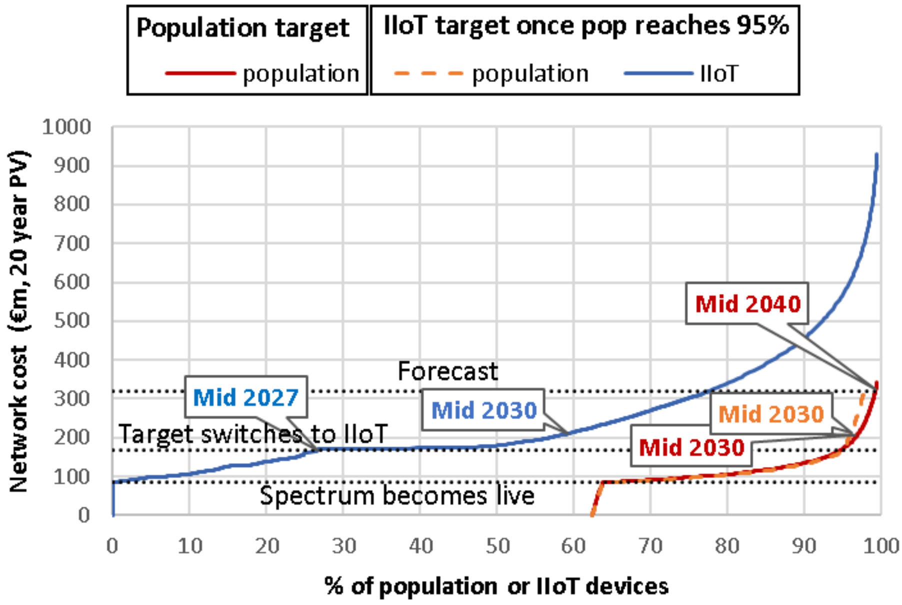
A3.14 Scenario 11: 30Mbit/s population coverage to 95%, then IIoT coverage

We assume that the IIoT service is served with LTE Rel. 8 or beyond, and not legacy technologies such as NB-IOT, and that IIoT is available from mid-2020.[4]

[4] We are aware that Vodafone has announced the launch of NB-IoT services. However, not all MNOs have started IIoT deployments, and our simulation should be representative of the market as a whole. Furthermore, this is a B2B proposition rather than a B2C proposition. Several national IoT deployments have suffered from a lack of appropriate industrial grade devices for the targeted application, inexperience of MNOs regarding the marketing of a new set of B2B services, and concerns from users about data security

Figure A3.13 below shows that, as the network roll-out targets population coverage and the network is upgraded with 700MHz spectrum, the incidental IIoT coverage increases from 0 to 27%. In mid-2027, the 30Mbit/s coverage reaches 95% of the population, and the target is switched to IIoT based deployment. Therefore, after mid-2027, IIoT receives a significant boost in coverage, because the network roll-out targets IIoT coverage rather than MBB.

Figure A3.13 Scenario 11: Cost to increase IIoT coverage



Note: Solid lines depict how the coverage percentage increases when targeted by the network roll-out. A dashed line shows the incidental population coverage when the target is IIoT.

Source: Oxera/Real Wireless.

Figure A3.13 shows that an MNO that targets population will not reach relatively high levels of IIoT penetration. IIoT coverage seems to advance towards relatively high percentages only when it is targeted as a service. This is because the locations where IIoT is required do not coincide with the locations where the population lives.

We also observe that the focus to improve IIoT coverage, from 27% to 57%, costs €40m and can be implemented in approximately two years with the network roll-out speed of 2.5% CAGR. The focus to improve IIoT coverage has a negative effect on population coverage: an additional investment of €200m corresponds to 96.7% population coverage when targeting population coverage, but only 95.9% population coverage when targeting IIoT coverage.

NB-IOT observations: If an MNO was to deploy NB IoT on all existing macrosites, then we estimate that this would result in approximately 85% of the geographical coverage in 2017. Although we have not assessed the NB-IoT coverage, we can estimate this by considering the MBB geographical coverage for low dates. The actual NB-IOT/IIoT coverage may differ from the low rate MBB coverage for several reasons.

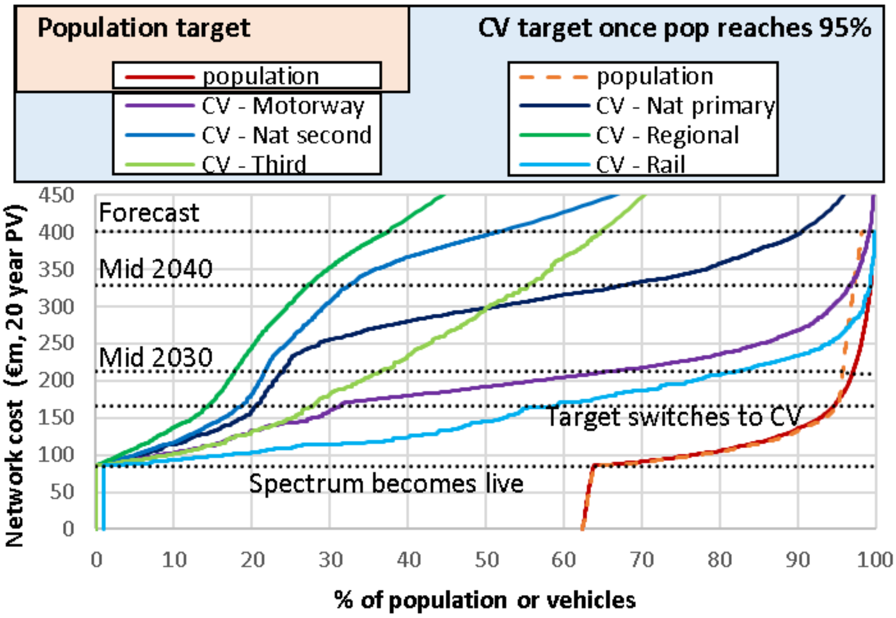
when operating over national carrier networks. An end-to-end ecosystem needs to be established for IIoT to be widely available. It is unlikely that growth in IIoT would be sufficiently high to influence the site deployment strategy in the next three years. It is also evident (see Annex 1) that we do not see a significant drive to deploy sites to increase the IIoT coverage. For these reasons we expect slow adoption curves for these services, or at least not insufficient levels of growth to foresee large market adoption before the new spectrum becomes live.

- IIoT has similarities to geographical coverage as pastures is a dominant land cover type and it is assumed that IIoT devices are spread evenly on its area; however, other land cover type are not considered as sources of IIoT demand. It is unclear how this would affect the coverage.
- Inexpensive IIoT receivers are designed with only one antenna element. This would impair diversity and, in isolation, would result in lower coverage compared to the estimated indicative coverage above.
- IIoT requires higher reliability compared to MBB. This in isolation would result in lower coverage compared to the indicative value.
- IIoT benefits from multi-server connectivity and server fallback. This in isolation would result in greater coverage compared to the indicative value.
- IIoT benefits from narrowband transmission, half baud rates, repetition, relay/buddy modes. These in isolation would result in greater coverage compared to the indicative value. However, in practice, these would be reserved for deep indoor locations.

A3.15 Scenario 12: 30Mbit/s population coverage to 95%, then CV coverage

The cost and coverage for the CV scenario (scenario 12) is shown in Figure A3.14.

Figure A3.14 Scenario 12: Cost to increase CV coverage



Note: Solid lines depict how the coverage percentage increases when targeted by the network roll-out. A dashed line shows the incidental population coverage when the target is CV.

Source: Oxera/Real Wireless.

We make the following observations from Figure A3.14.

- As the network roll-out targets population coverage and the network is upgraded with the 700MHz spectrum, the incidental CV coverage increases from 0% to the levels summarised in Table A3.8.

- In mid-2027, the 30Mbit/s coverage reaches 95% of the population, thus the site placement strategy is switched to CV deployment. Hence, the CV coverage receives a significant boost in 2027. This is particularly apparent on the relatively large increases in coverage to motorways and rail routes.
- Coverage of the third road type seems to benefit from the new sites and upgrades, which appears to be disproportionate in comparison to national primary and secondary roads. Visual inspection of the geography (see Figure A2.3) indicates this is because third roads are generally evenly distributed around the country (including close to motorways), whereas the locations where motorways exist are different from where national primary and national secondary roads are located.
- Except for motorway, rail, and third roads, CV coverage seems to advance towards relatively considerable percentages only when it is targeted as a service. This is because the locations where national primary and national secondary and Regional CV is required do not coincide with the locations where the population lives.
- An MNO that only targets population will not reach relatively high levels of CV penetration.
- The focus to improve CV coverage (rather than population coverage) has a negative effect on population coverage: an additional investment of €190m results in 96.3% population coverage when targeting population coverage, but only 95.5% population coverage when targeting CV coverage.

Table A3.8 CV coverage at two points in time: the switch of target from population to CV, and with a €24m investment following the switch

	Incidental CV coverage from the network roll-out targeting population coverage	With a €24m investment on CV following the switch and circa 1.5 years with the network roll-out speed of 2.5% CAGR
Motorway coverage	31%	48%
National primary coverage	21%	22%
National second coverage	19%	20%
Regional road coverage	14%	16%
Third road coverage	28%	32%
Rail coverage	59%	72%

Source: Oxera/Real Wireless.

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Future mobile connectivity in Ireland

Annex 4: Evidence on the effectiveness of approaches to promoting mobile connectivity in other EU member states

Prepared for
ComReg

November 2018

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A4 Evidence on the effectiveness of approaches to promoting mobile connectivity in other EU member states

A4.1 Annex structure

This Annex sets out a study on the effectiveness of coverage obligations as follows:

- context and framework (section A4.2);
- coverage obligations in spectrum licences (section A4.3);
- public subsidies (section A4.4);
- findings with regards to mobile network sharing (section A4.5).

A4.2 Context and framework

In this section, we:

- explain the scope and purpose of this part of the study, and why commercial investment may be insufficient to reach levels approaching ubiquitous mobile connectivity (section A4.2.1);
- explore the current situation in Ireland (section A4.2.2);
- explain why we focus on low-frequency spectrum (section A4.2.3);
- describe why the case study countries were chosen (section A4.2.4);
- detail the framework we use to judge the success of interventions in the case study countries (section A4.2.5).

Last, in section A4.2.6, we give the structure of the remainder of the Annex.

A4.2.1 Introduction

The scope and purpose of this part of the study

Noting that commercial investment will drive mobile connectivity to a certain level, ComReg has asked Oxera and Real Wireless to:

- identify and consider the effectiveness of regulatory and/or governmental approaches taken (or proposed to be taken) within the EU and in other relevant jurisdictions to incentivise mobile connectivity investment beyond this level;
- provide advice on such approaches in relation to Ireland.

Five countries are studied—Austria, Denmark, Finland, Sweden, and the UK. We primarily explore the use of coverage obligations and mobile network sharing, and we briefly look at public subsidies.

Our case studies focus on the roll-out of 4G using 800MHz spectrum (5G has not yet been deployed in Europe). However, our observations and advice could equally apply to any future mobile technology as future mobile connectivity is likely to involve a low-frequency coverage layer (i.e. the 700MHz band).

We also note that useful information on the approaches taken by other European countries to improving mobile connectivity can be found in the 2017 BEREC/RSPG joint report on 'Facilitating mobile connectivity in "challenge areas"'.[1]

Commercial investment alone may be insufficient to achieve ubiquitous mobile connectivity

Where possible, ComReg seeks to rely on competitive forces to promote service deployment via innovation and investment. As set out in its 'ECS Strategy Statement: 2017–2019',[2] one of ComReg's strategic goals relating to investment (Goal 13) is that competitive incentives facilitate efficient commercial investment in infrastructure and services to the widest extent possible. Other ComReg strategic goals relevant to the management of radio spectrum include the promotion of competition (Goal 5), the facilitation of investment (Goal 15), and the use of mobile coverage obligations to promote investment where proportionate (Goal 17).

However, in some instances, commercial incentives alone (even in competitive markets) are likely to be insufficient to achieve ubiquitous mobile connectivity. In such cases, appropriate regulatory and/or governmental intervention may be required to improve the market/end-user outcomes. This very point is noted by ComReg in its Electronic Communications Strategy:[3]

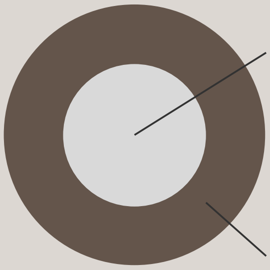
> Unregulated, electronic communication markets may not provide the right, or adequate, incentives for investment. Reliance on market-based incentives alone would also lead to non-provision of services to non-economic end-users.

Box A4.1 sets out the commercial incentives to provide mobile connectivity in different areas, identifying where interventions may be appropriate, in order to increase mobile connectivity.

[1] BEREC and RSPG (2017), 'BEREC and RSPG joint report on Facilitating mobile connectivity in "challenge areas"', 22 December.
[2] ComReg (2017), 'Electronic Communications Strategy Statement: 2017–2019', 13 April, para. 7.11.
[3] Ibid. p.11.

Box A4.1 Commercial incentives to provide mobile coverage

In general, MNOs will only increase network capability (including coverage and capacity) where the cost of the investment is anticipated to be recovered by the future returns directly attributable to it. Usually, the investment is justifiable in areas characterised by high levels of population density, meaning intervention may be needed to promote investment in less densely populated (rural) areas, as the figure below illustrates.



Note: Not to scale.

Source: Oxera.

Rural areas are less likely to be covered with ubiquitous mobile coverage because the costs of building and running a mobile network are greater, and the potential MNO revenues are less (fewer potential customers).

The investment is the upfront CAPEX (and ongoing OPEX) that is incurred by the MNO when building and running the network. The cost of building and running the coverage layer of a mobile network is greater in rural areas due to the increased cost of backhaul and electricity. The future returns from mobile connectivity (to the MNO) are the revenues from potential customers that live or work in the area covered (plus any revenues from being able to offer all customers mobile connectivity in the area should they travel there). The revenues from covering sparsely populated areas are less than that from covering urban areas (as there are fewer potential customers per site). Thus the population and population density influence the likelihood that the operator faces commercial incentives to cover an area.

This is more likely to be the case in Ireland, where 3% of the population lives across 30% of the land.[1]

However, we note that an MNO may have some incentive to roll out in some sparsely populated areas to provide widespread coverage for future mobile connectivity use cases such as for the Industrial Internet of Things (IIoT) or connected vehicles (CV) (see Section 2 of the main report).

Competition will also impact the commercially-delivered level of coverage, as MNOs may compete to be the MNO with the most mobile coverage (i.e. compete on quality of service). For example, if one MNO achieves a very high level of coverage then there would be competitive pressure on the other MNOs to achieve a similar level of coverage, or else risk losing customers.

The IIoT and CV use cases and the effect of competition may act to increase the size of the area in which it would be commercially viable to roll out connectivity.

Note: [1] Census 2011, available from the Central Statistics office, www.cso.ie, accessed 17 July.

Source: Oxera.

As shown in Box A4.1, commercial incentives alone are very unlikely to deliver ubiquitous mobile connectivity, especially in a country such as Ireland (due to its geo-spatial factors). For policymakers, this therefore raises the question of whether such an outcome can and should be achieved through interventions.

It is also noted that Ofcom have been undertaking similar considerations in regard to the ultimate cost of providing widespread connectivity. For instance, Ofcom's CEO Sharon White stated in a 2018 speech that: "[a]ccording to our estimates, to provide good mobile coverage across virtually all of the UK landmass would cost up to about £6 billion.”[4]

Enabling the provision of mobile connectivity to ‘non-economic end-users’ in sparsely populated regions of Ireland may be a socially desirable objective for policymakers, and initiatives may be appropriate to fill any gap between societal demands and commercial viability in respect of sufficient coverage provision. Additional investment in mobile connectivity could be achieved through a number of different regulatory and/or governmental interventions, and this could be made more commercially viable through mobile network sharing.

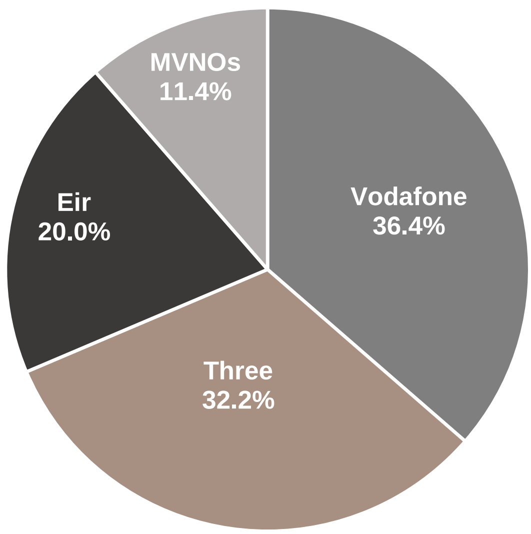
A4.2.2 The current situation in Ireland

The current situation in Ireland is highly relevant for assessing the suitability and choice of mechanism to increase future mobile connectivity.

The population distribution of Ireland is of particular relevance for future mobile connectivity. Ireland has one of the most distributed and rural populations in Europe, and much of Ireland is sparsely populated–Ireland has a relatively low population density of 70 people per km^2, considerably lower that the EU average, falling to as low as 27 people per km^2 in rural areas.[5] There are certain parts of the country that are difficult to reach; based on past experience, if left to commercial incentives these areas may not benefit from future mobile connectivity. Commercial incentives also depend on the dynamics of the retail mobile market (e.g. the level of competition in the market, and whether there is competition on levels of coverage).

The market shares of each operator in Ireland as of the Quarter 2 of 2018 are demonstrated in the figure below. Vodafone is the market leader with 36% market share. The second and third players, Three and Eir, have the only network sharing agreement that currently exists in Ireland—the ‘Mosaic’ agreement.

Figure A4.1 Retail mobile market shares in Ireland (by subscriptions)



Note: Excluding mobile broadband and M2M subscriptions.

[4] Ofcom (2018). https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/solid-progress-further-to-go-for-connected-britain
[5] Census 2016, available from the Central Statistics office, www.cso.ie, accessed 17 July.

Source: ComReg (2018), 'Quarterly Key Data Report Data as of Q2 2018', ComReg 18/79, 13 September.

The provision of mobile services to Irish consumers relies largely on the availability of spectrum. ComReg plans to release additional spectrum, on a service and technology neutral basis but potentially for use by mobile telecoms services. The spectrum currently assigned to MNOs in Ireland is listed in Table A4.1.

Table A4.1 Currently assigned mobile spectrum bands in Ireland

Frequency band	Current Technology usage in Ireland	Year of first assignment to MNOs
800MHz	4G	2012
900MHz	2G/3G	Pre-2000
1.8GHz	2G/4G	Pre-2000
2.1GHz	3G	2002
3.6GHz	FWA/4G	2017

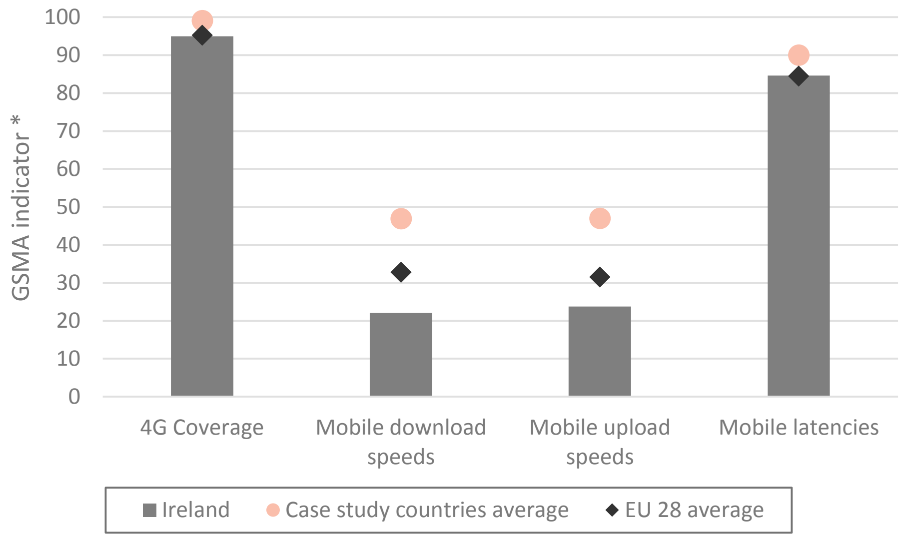
Note: FWA—fixed wireless access. FWA is not a mobile service, but it does use spectrum for the provision of wireless broadband services which is also assigned to mobile operators (i.e. the 3.6 GHz band).

Source: Oxera.

It is informative to compare mobile connectivity in Ireland to relevant comparators. Mobile connectivity in Ireland exhibits good levels of coverage and network performance. However, according to the GSMA mobile connectivity index, mobile download and upload speeds were lower in Ireland in 2016 than in the case study countries and Europe as a whole.[6] Similarly, OpenSignal found that from July to October 2017, Ireland had lower 4G availability than all of the case study countries and lower average 4G speeds than four of the case study countries (with the exception of the UK).[7] However, the European Commission found that, in June 2016, Ireland had similar 4G coverage (as a percentage of households) to the case study countries and slightly higher than the European average: 96.7% 4G coverage in Ireland compared to 96.6–100% in the case study countries and the EU28 average of 96.0%.[8, 9]

[6] GSMA mobile connectivity index, https://www.mobileconnectivityindex.com/, accessed 24 July.
[7] OpenSignal (2017), 'The State of LTE (November 2017)', November.
[8] European Commission (2017), 'Study on broadband coverage in Europe 2016', 21 September.
[9] Differing results can be explained by the different methodologies towards measuring mobile network coverage and quality. For example, the Commission data comes from surveys of MNOs and NRAs, while the OpenSignal data comes from user-downloaded applications on mobile devices.

Figure A4.2 International comparison of 4G coverage and network performance in Ireland (2016)

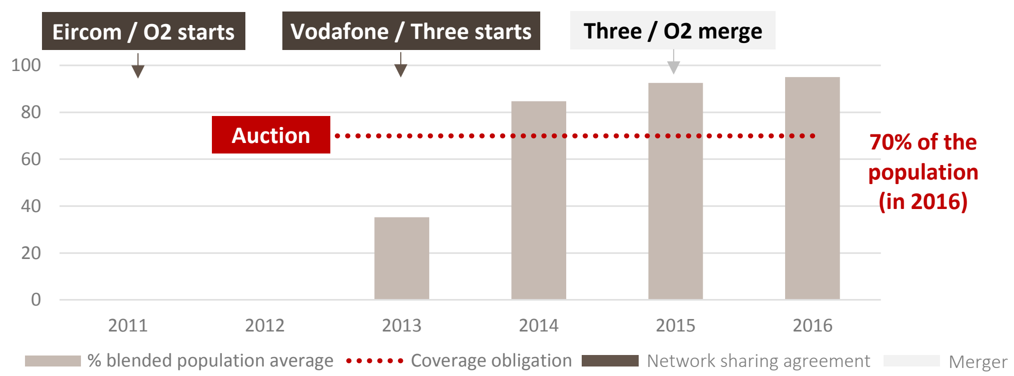


Note: * GSMA indicators range from 0–100, with a score of 100 indicating best infrastructure. Case study countries: Austria, Denmark, Finland, Sweden, and the UK.

Source: GSMA mobile connectivity index, Oxera analysis.

Figure A4.3 summarizes the evolution of 4G coverage and the mechanisms implemented in Ireland. As shown, there are coverage obligations in Ireland on the 800MHz band, and there have been two network sharing agreements (although only one—Eir/Three—is still in existence).

Figure A4.3 4G coverage and deployment mechanism in Ireland



Source: GSMA mobile connectivity index, Eurostat, and Oxera analysis.

Coverage obligations in Ireland

In November 2012, ComReg concluded the multi-band spectrum award process that offered rights of use across the 800MHz, 900MHz, and 1.8GHz spectrum bands for the period 2013–30.[10] The 800MHz band comprised six lots of paired spectrum.

For each licence, the licensee must achieve and maintain a minimum coverage obligation of 70% of the population within three years from the commencement date of the licence for an existing MNO, and within seven years for a new

[10] ComReg (2012), 'Results of the Multi-Band Spectrum Award Process', 5 December.

entrant.[11] In addition, a new entrant must meet an interim coverage obligation of 35% of the population within three years. The licensee could use any of its licensed frequency bands (900MHz, 1.8GHz, 2.1GHz or 800MHz) to fulfil this obligation. ComReg awarded 800MHz spectrum licences to three existing MNOs: Meteor Mobile (Eir), Telefonica Ireland (Three acquired this licence), and Vodafone Ireland.[12]

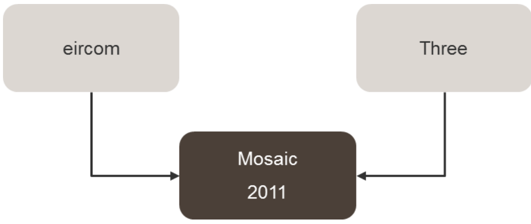
In setting the coverage obligation, ComReg considered that while retail competition would likely drive actual coverage levels beyond the levels of its proposed obligation, it was nevertheless appropriate to set a coverage obligation. Among other things, ComReg noted that there was no guarantee that market forces alone would ensure the efficient use of spectrum and that the setting of a coverage obligation would prevent cherry-picking (such as in densely populated areas) that could destabilise overall competition. Furthermore, ComReg noted that a 70% population coverage level is sufficient to provide coverage in all the townlands in Ireland with 50 inhabited houses or more.[13]

ComReg regularly carries out drive test measurements in order to assess compliance with coverage obligations—the latest report is from April 2017, when all three operators had LTE coverage above 70%.[14] Although not required by the coverage obligation, ComReg also tested the average speed data and found that 4G speeds in a mobile scenario were on average 3.6 times faster than those on 3G.

Mobile network sharing in Ireland

Initially signed in 2011 between Eir and Three (then O2), the Mosaic network sharing agreement was extended in 2014 to facilitate the roll-out of LTE services. The agreement involves the sharing of 2,000 sites, including site equipment, power supply, towers, and transmission. The maintenance of this sharing agreement was one of the commitments Three made to the European Commission in exchange for approval for its acquisition of O2 in 2014.[15]

Figure A4.4 Mobile network sharing agreements in Ireland



Source: Oxera.

In 2012, Vodafone and Three announced a 50/50 joint venture to passively share physical network and site infrastructure in over 2,000 locations across

[11] ComReg (2012), 'Multi-band Spectrum Release', 25 May.
[12] ComReg (2012), 'Frequency Arrangements and Results of the Multi-Band Spectrum Award Process', 5 December.
[13] See ComReg (2012), 'Multi-band Spectrum Release: Release of the 800 MHz, 900 MHz and 1800 MHz Radio Spectrum Bands: Response to Consultation and Decision', 16 March.
[14] ComReg (2018), 'Assessment of Mobile Network Operators' Compliance with Licence Obligations (coverage), Winter 2017', 2 April.
[15] Three Ireland (2014), 'Three and eircom reach network sharing agreement', https://press.three.ie/press_releases/three-and-eircom-reach-network-sharing-agreement/, accessed 24 July.

the country.[16] This arrangement, however, was terminated after the acquisition of O2 by Three, which involved a settlement of €14.6m.[17]

ComReg has set out its current thinking on collaboration between wireless operators:[18]

> Recalling that there are many forms of collaboration and, further, that the benefits and drawbacks of each collaboration will depend on the specifics of the proposed collaboration, ComReg maintains that it cannot have a firm view on spectrum rights sharing (or pooling) and network sharing other than that it would look more favourably on agreements that would not unduly restrict competition and would deliver demonstrable benefits that are shared with end-users.
>
> Further, ComReg remains of the view that interested parties should be in a position to identify for themselves the types of potential issues and concerns (e.g. competition law) that could be raised by a proposed collaboration agreement.

In the Irish auctions of 2012 (800MHz, 900MHz and 1.8GHz) and 2017 (3.6GHz), joint bidding at the application stage was permitted[19] but not used. In the 3.6GHz Award, a separate innovation to joint bidding, alliance bidding in the assignment stage, was permitted and used by two winning bidders. This allowed the two bidders to bid together in the assignment stage of the auction to align as much as possible the spectrum assigned to them across regions.

Public subsidies in Ireland

The National Broadband Plan (NBP) is a government initiative aimed at delivering high-speed broadband throughout Ireland, and particularly to harder-to-reach rural areas. The NBP's ambition is to achieve connections to 100% of premises across Ireland within three to five years of commencement of large scale roll-out.[20]

The public subsidy is intended to be provided to a private network operator to deploy and operate the network. The intervention maintains technology neutrality, which means that the network operator can provide connections using any technology, including wireless infrastructure, provided it meets the high speed broadband service requirements of the intervention.

The procurement process commenced in December 2015. In April 2017, the Irish government finalised the Broadband Intervention Map, which shows the premises which will require state intervention.[21] It covers approximately 540,000 premises, which includes 21% of the national population and 61% of farms. As of 31 January 2018, one bidder remained in the process.[22]

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[16] Three Ireland (2012), 'New 50/50 joint venture company established to manage shared physical infrastructure', https://press.three.ie/press_releases/13-jul-12-vodafone-ireland-and-three-ireland-announce-strategic-partnership-to-share-network-infrastructure/, accessed 24 July.
[17] *The Irish Independent* (2016), 'Profits drop 24pc to €60.3m at Vodafone last year, quarterly revenue grows 3.4pc', 4 February. https://www.independent.ie/business/irish/profits-drop-24pc-to-603m-at-vodafone-last-year-quarterly-revenue-grows-34pc-34421527.html, accessed 24 July.
[18] ComReg (2017), 'Radio Spectrum Management Strategy 2016 to 2018', 21 June, para. 7.21–7.22.
[19] ComReg (2012), 'Multi-band Spectrum Release Information Memorandum', 25 May; ComReg (2016), '3.6 GHz Band Spectrum Award Information Memorandum', 24 August.
[20] DCCAE (2012), 'Delivering a Connected Society: A National Broadband Plan for Ireland', 30 August.
[21] Merrion Street (2017), 'Naughten finalizes the Broadband Intervention Map for National Broadband Plan and signs eir commitment to build out to 300,000 rural premises on a commercial basis', 4 April.
[22] DCCAE (2018), 'Statement by the Minster for Communications Denis Naughten TD following the withdrawal of eir from the National Broadband Plan (NBP) Procurement Process', 31 January, https://www.dccae.gov.ie/en-ie/news-and-media/press-releases/Pages/Statement-by-the-Minister-for-Communications.aspx, accessed 24 July.

A4.2.3 Why we focus on low-frequency spectrum bands

Low-frequency spectrum travels greater distances than high-frequency spectrum, but the higher bandwidth available at high frequencies provides the ability to carry more data. This is illustrated in Figure A4.5. There is, therefore, a trade-off between low and high frequencies, with MNOs typically holding a balanced portfolio of both. The three 4G mobile networks in Ireland are built on a coverage layer of 800MHz spectrum, with extra 4G capacity (the capacity layer) using the 1.8GHz frequency band.

Low-frequency spectrum is used to provide network coverage, while high-frequency spectrum is typically added to the network in urban (i.e. densely populated) areas to provide more network capacity (to carry the greater quantity of traffic).

Figure A4.5 Propagation characteristics

Source: Oxera.

In general, the more onerous coverage obligations are typically placed on low-frequency spectrum licences. Coverage obligations can be placed on higher frequency spectrum, but the bands' lower coverage characteristics mean that the obligations tend to be less onerous. For example, in the UK the coverage obligations on the 2.1GHz band were to cover 90% of the population, in comparison with the 800MHz band, which had coverage obligations of 98% of the population.[23, 24]

It was widely recognised before it was awarded that the 800MHz band would be crucial for providing 4G connectivity as it was a low-frequency band (and therefore the most cost-effective to provide widespread coverage). For many countries, therefore, this was the most appropriate band for coverage obligations to be applied by regulators. In Ireland, while 4G/LTE coverage to the rural areas was provided with the 800MHz band, the first technology updated by operators after the 2012 Irish award was the roll-out of 3G/UMTS[25] into the 900MHz band—which is another sub-1GHz band with good propagation characteristics.

As identified in the main report, ComReg is progressing with its plans to release further spectrum, which could include the release of spectrum from one or more of the Candidate Bands under consideration in this study—namely spectrum in the 700MHz, 1.4GHz, 2.1GHz, 2.3GHz, and 2.6GHz bands.

The lower-frequency band (e.g. 700MHz) will help MNOs provide widespread coverage of mobile connectivity, while the higher-frequency bands (e.g. 2.3GHz, 2.6GHz) will help MNOs provide capacity to offer high-quality mobile

[23] Originally 80% of the population. See Ofcom (2013), 'Ensuring 3G coverage compliance', 7 November, https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2013/3g-coverage-compliance, accessed 24 July.
[24] Ofcom (2012), '4G Coverage Obligation Notice of Compliance Verification Methodology: LTE', 24 July.
[25] The Universal Mobile Telecommunications System (UMTS) is a third-generation mobile cellular system.

connectivity. Furthermore, the RSPG noted the 700MHz band would be important for providing coverage of 5G services.[26]

A4.2.4 The case study countries

The case study countries identified by ComReg are listed in Table A4.2, along with whether coverage obligations and network sharing arrangements are present in each country.

Table A4.2 Case study matrix

	Coverage obligations (section A4.3)	Mobile network sharing (section A4.5)
Austria	✓	✓
Denmark	✓	✓
Finland	✓	✓
Sweden	✓	✓
UK	✓	✓

Source: Oxera.

We also briefly explore public subsidies in each of these countries (section A1.5).

Different approaches have been chosen by regulators and MNOs in each of these countries regarding the deployment of LTE services. All five have spectrum licence coverage obligations, direct public subsidies, and network sharing. However, the nature and the specification of each of these mechanisms varies across the countries.

The three Nordic countries have some of the highest coverage rates and speeds in Europe, with Sweden being the first country in the world to launch a commercial LTE network.[27] Like Ireland, Austria and Finland also have three major MNOs. Finally, it makes sense to consider the United Kingdom, as it is Ireland's closest geographical neighbour.

In addition to the approaches chosen by regulators and MNOs, population demographics play a crucial role in determining the extent, quality, and cost-effectiveness of deployment of mobile services. The demographics of the chosen case study countries exhibit varying degrees of similarity with those of Ireland, providing important context to the discussion of the relative merits of any approach. Table A4.3 illustrates several of these statistics.

[26] European Commission (2018), 'RADIO SPECTRUM POLICY GROUP STRATEGIC SPECTRUM ROADMAP TOWARDS 5G FOR EUROPE: RSPG Second Opinion on 5G,' 30 January.
[27] Ericsson (2009), 'World's first 4G/LTE network goes live today in Stockholm', 14 December, https://www.ericsson.com/en/press-releases/2009/12/worlds-first-4glte-network-goes-live-today-in-stockholm, accessed 24 July.

Table A4.3 Ireland compared to case study countries

	Total population (millions)	Rural population (% of pop)	Landmass (000's km²)	Population density (pop. per km²)	Blended 4G coverage in year before 800MHz auction (%)
Ireland	5	37	70	70	0
Austria	9	14	84	106	24
Denmark	6	11	43	136	54
Finland	6	19	338	18	69
Sweden	10	10	447	24	48
United Kingdom	66	9	244	271	17

Note: Blended average calculated as the average of the percentage of households (source: Eurostat) and the percentage of population (source: GSMA) covered by 4G.

Source: Oxera, World Bank Database, Eurostat, GSMA mobile connectivity index. All figures are for the end of 2016, except landmass, which is as of 2012.

Considering population density by itself does not necessarily provide an accurate evaluation of the challenges in extending coverage. It is possible for a country to have a low population density (owing to largely uninhabited areas of its landmass) while also having concentrated urban areas. This could make it easier for MNOs to reach high levels of population coverage while neglecting geographical coverage (at the expense of rural populations). Since rural areas might lack coverage of existing mobile and broadband services in the first place, the impact of LTE for users in these areas could possibly be far higher in such a context.

While Finland and Sweden both have population densities of fewer than 25 people per square kilometre, making them more sparsely populated than Ireland with 69 people per square kilometre[28], Ireland has the highest proportion of rural population of all five countries being considered—a population coverage requirement greater than 64% in Ireland would oblige operators to provide services in rural areas in order to meet the licence obligation. By comparison, provision of services into rural areas would only be obliged in Denmark, when the population coverage obligation is greater than 88%.

A4.2.5 Framework for judging the success of regulatory and governmental approaches

Our analysis focuses on the success of mechanisms employed in other countries—i.e. coverage obligations attached to spectrum licences. For each of the selected countries, we evaluate the efficacy of these approaches based on the framework described below. Our analysis is limited by the availability of data; not all questions can be answered in all cases.

- **Impact on mobile connectivity**: did the approach accomplish faster roll-out of mobile connectivity, greater coverage of mobile connectivity, or greater quality (e.g. speed) of mobile connectivity? These questions will be explored by comparing MNOs within each country, but it can be difficult to separate from the impact of other factors. For example, a coverage obligation on one

[28] This is based on information from Eurostat.

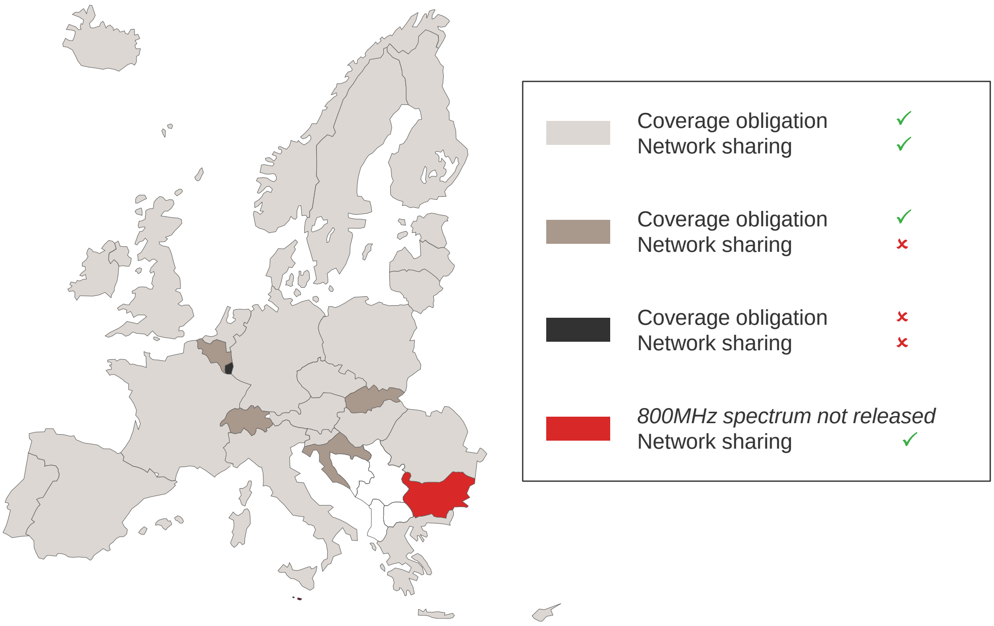
operator may increase the incentive for another operator to roll out greater coverage.

- **Impact on competition**: were regulators or competition authorities concerned about the impact of an approach on competition? Were there any perceived adverse effects on retail or infrastructure competition in the short or long term? What measures were undertaken to counteract these adverse effects?
- **Direct or indirect costs**: we will briefly describe the cost of subsidies in terms of direct cost or lower tax revenue. This is particularly relevant when assessing public subsidies.

In addition to the case studies, we conduct further complementary analysis at the European level to test the robustness of our findings. This analysis enables us to compare how different interventions have been used in different countries, as well as to assess which factors influenced their use. We can also compare countries to understand the effects. However, we do note that owing to the great difference in circumstances between countries (e.g. geo-spatial, existing coverage, competition, spectrum usage, and demand for mobile connectivity), it is not possible to make direct comparisons between them.

We also note that most European countries have some form of network sharing, and that all but one country has imposed coverage obligations on the 800MHz band, as shown in Figure A4.6. This 'small sample' of countries without network sharing or coverage obligations makes it difficult to know for sure what would happen without these approaches.

Figure A4.6 Coverage obligations and network sharing across Europe in the 800MHz band



Source: Oxera.

A4.2.6 Annex structure

The rest of this Annex is structured as follows.

- **Coverage obligations.** Attaching coverage obligations to spectrum licences is a common way for regulators to oblige mobile connectivity to a specified level—we explore how coverage obligations have been used in the five case study countries (section A4.3).

- **Mobile network sharing.** MNOs often share elements of their mobile networks in order to reduce costs and increase coverage—we examine the effectiveness of network sharing on increasing mobile connectivity in the five case study countries (section A4.4)
- **Public subsidies.** Governments can use public subsidies to achieve greater mobile connectivity—we briefly describe how public subsidies have been used in the five case study countries (section A4.5)

A4.3 Coverage obligations on spectrum licensees

This section explores coverage obligations and takes the following structure.

- Section A4.3.1: context for why coverage obligations are effective.
- Section A4.3.2: case study analysis.
- Section 0: European outcomes.
- Section A4.3.4: key observations.

A4.3.1 Context

Coverage obligations allow a regulator to oblige the deployment of coverage from MNOs in both commercially viable and non-commercially viable areas.

Effective competition between MNOs will drive the operators to roll out the optimum level of commercially viable coverage. However, policymakers may wish to increase coverage to beyond the commercially viable levels provided by the MNO (e.g. in areas of low population density). Coverage obligations may also be used by regulators in order to avoid the cherry-picking of areas that are easy to cover (at the expense of other areas) or encourage faster roll-out, bringing the benefits of competition more quickly.

We also note that applying one coverage obligation may be enough to shift the market to a high-coverage equilibrium. This is because the competitive pressure of one MNO offering very high levels of mobile connectivity may incentivise the other MNOs to do the same.

There are many examples of regulators and governments including coverage obligations in mobile spectrum licences, most especially for sub-1GHz bands (owing to their high suitability to providing coverage over a wide area).

Information on such obligations may be relevant for ComReg when it considers how to achieve objectives around mobile connectivity in Ireland going forward.

However, coverage obligations must be tailored to the country-specifics, as noted by the RSPG:[29]

> […] coverage obligations can only be derived as a consequence of national policy objectives and characteristics (i.e. population distribution, geographical morphology, industrial and societal needs) and therefore cannot be harmonised on a EU-level [*sic*].

[29] European Commission (2018), 'RADIO SPECTRUM POLICY GROUP STRATEGIC SPECTRUM ROADMAP TOWARDS 5G FOR EUROPE: RSPG Second Opinion on 5G,' 30 January.

We begin by noting that there are a number of parameters associated with specifying any single ‘coverage obligation’, each of which requires careful consideration. These include:

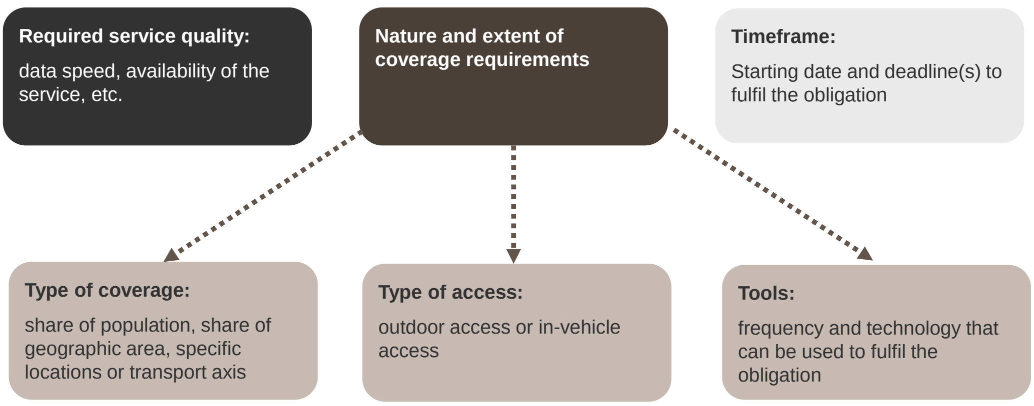
- the nature and extent of coverage requirements (for example: geographic vs population; indoor vs outdoor; 95% vs 99% or other % combinations; frequency[30] and technology to be used);
- the timeframe for achieving the coverage (including single targets, i.e. achieve the final target in five years vs seven years; as well as setting milestones/phasing, i.e. achieve half the coverage in three years and the rest by year seven);
- the required quality or availability of service (e.g. data speeds).

These parameters are shown in Figure A4.7 and do not need to be mutually exclusive (i.e. a coverage obligation could specify both a required population coverage and a required geographic coverage). Not all coverage obligations specify all the parameters of Figure A4.7, but they need to at least specify the timescale and minimum connectivity requirements.

With coverage obligations, the devil is in the detail. For example, high coverage obligations that specify a low quality of service may, in practice, be equivalent to lower coverage obligations with a higher quality of service.

Furthermore, attempting to provide full indoor coverage from a mobile network is likely to require an MNO to operate on a basis that would not be economically sustainable. Modern building materials can reduce signals by up to 40dB in some circumstances,[31] and this can have a significant impact on radio signals as they attempt to penetrate a building. There are other, more appropriate solutions to address indoor coverage, such as WiFi calling and mobile repeaters.

Figure A4.7 Coverage obligations specify a number of parameters



Source: Oxera.

As a number of individual licences may be made available within a given spectrum band in any spectrum release, it is also important to consider whether coverage obligations should be imposed on all spectrum licences in a given band or just one. Coverage obligations could also be split between

[30] It should be noted that the propagation characteristics of the frequency band in question can influence the level of the coverage obligation. For example, a low-frequency band (e.g. 700MHz) may be suitable for a high population coverage obligation, while the same cannot be said for a high-frequency band (e.g. 3.6GHz);
[31] BEREC and RSPG (2017), ‘BEREC and RSPG joint report on Facilitating mobile connectivity in “challenge areas”’, 22 December.

licences, with one operator required to cover some areas and another operator required to cover others (e.g. this was a possibility with the 800MHz auction in Denmark).

Table A4.4 summarises the coverage obligations attached to 800MHz spectrum in the case study countries.

Section A4.3.2 explores the coverage obligations in the case study countries. Where available, we also include regulator plans for coverage obligations on the 700MHz band, as they illustrate each regulator's view on the role of coverage obligations going forward.

Table A4.4 Key characteristics of coverage obligations attached to the 800MHz spectrum in selected countries

	Primary objective (described in general terms)	Preferred spectrum use	Obligation depends on	Obligation defined based on	Licensee(s) with obligation	Frequency that the MNOs can use to meet the obligations
Ireland (2012)	Promote competition, allow the potential for market entry, be in the best interest of consumers, ensure the efficient use of the radio spectrum and prevent cherry picking that could destabilise overall competition	Technology neutral	New vs. existing entrant	Share of population	All operators	800MHz, 900MHz, 1.8GHz, and for up to 50% of the obligation the 2.1GHz
Austria (2013)	Provide improved broadband coverage in communities and municipalities with poor coverage	Technology neutral with preference for new technologies and LTE	New vs. existing entrant, rural areas, 800MHz or all frequencies	Share of population/number of municipalities	Two operators (Telkom Austria and T-Mobile)	800MHz/any frequency
Denmark (2012)	Improve high-speed broadband availability in areas ‘worst affected’ by the current lack of such services	Technology neutral with preference for LTE	Region	Share of household, companies, and holiday house/number of postcodes	Could have been split between operators, although resulted in only one operator with the obligations (TDC)	Any frequency
Finland (2013)	Improve the availability of mobile broadband, especially outside urban areas, and to enable the swift introduction of a national mobile broadband network	Technology neutral with preference for LTE	-	Share of population	All operators	Any frequency
Sweden (2011)	Provide coverage to specific premises with no existing mobile or fixed broadband coverage	Technology neutral with preference for LTE	-	Number of homes and businesses	One operator (Net4Mobility)	800MHz, limited exceptions
UK (2013)	Ensure efficient use of spectrum, maintain competition in the industry and promote widespread availability of services	Technology neutral with preference for LTE	Country vs. national level	Share of population	One operator (O2)	Any frequency

A4.3.2 Case study analysis

Below, we explore the impact of coverage obligations in the case study countries, starting with a description of coverage obligations in Austria.

Austria

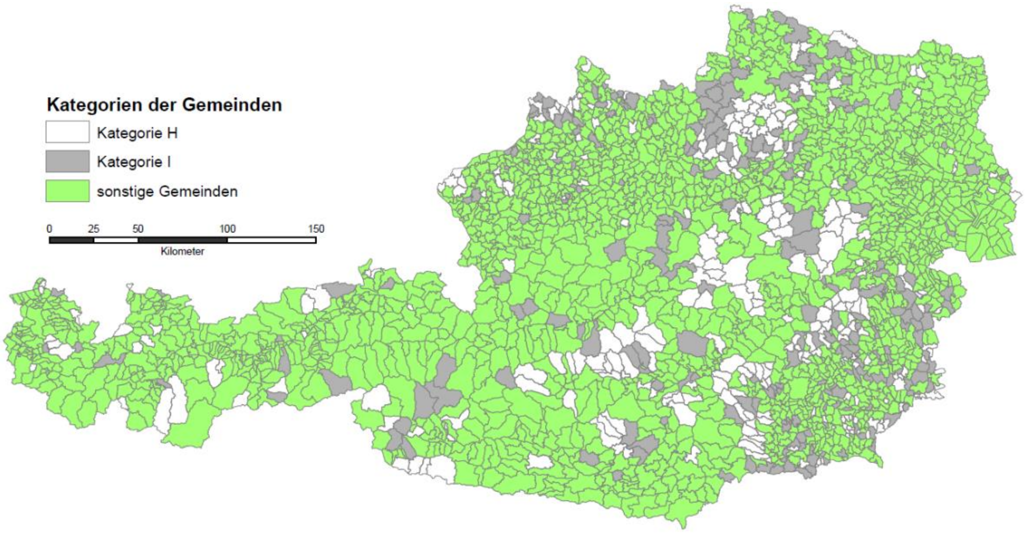
The goal of providing mobile connectivity in rural areas was the predominant concern of the Austrian regulator in the specification of coverage requirements for the 800MHz frequency band.[32] A number of rural regions in Austria did not have access to 3G at the time of the auction. The release of the 800MHz band for MBB was the government's main way of achieving its objective of ensuring that the whole population had Internet access at a speed of at least 25Mbit/s by 2013. This target was subsequently updated, the government aiming for 70% coverage at speeds of 100Mbps by 2018; the government also provided subsidies for broadband network roll-out.[33, 34] Another important objective was ensuring sustainable competition in the mobile market by facilitating access for a new entrant.[35]

The regulator, the Telekom-Control Commission (TKK), conducted a combinatorial clock auction for the award of licences for the 800MHz, 900MHz, and 1.8GHz bands that concluded in October 2013. The assignment of the 800MHz spectrum enabled operators to roll out LTE networks over a large area at relatively low cost (the MNOs had previously gained access to the 2.6GHz band in 2010, which was predominantly used for extra capacity in urban areas). In this section, we focus on the coverage obligations placed on the 800MHz spectrum.

The coverage obligations for the 800MHz band were defined in terms of the percentage of population, plus a number of municipalities and rural areas to be covered. These specific municipalities/rural areas were selected because they had low existing mobile connectivity (most of them had less than 20% indoor coverage and less than 50% outdoor coverage).[36] These respective areas are coloured white and grey in Figure A4.8.

[32] TKK (2013), 'Tender documentation for frequency assignments in the frequency ranges of 800 MHz, 900 MHz and 1800 MHz', 19 March.
[33] European Commission (2014), 'EDPR telecom Factsheet Austria', https://ec.europa.eu/digital-single-market/en/scoreboard/austria, accessed 24 July.
[34] Ibid.
[35] Rundfunk und Telekom Regulierungs-GmbH (2013), 'TKK launches multiband auction 2013: enhancing broadband coverage in rural areas', 18 March.
[36] BEREC and RSPG (2017), 'BEREC and RSPG joint report on Facilitating mobile connectivity in "challenge areas"', 22 December.

Figure A4.8 Coverage obligations in Austria



Note: The specific municipalities/rural areas to be covered are the areas shaded white and grey. The rest of the country is shaded green.

Source: TKK (2013), 'Multiband auction 800MHz coverage requirements', https://www.rtr.at/en/tk/multibandauktionVersorgungsauflage800MHz, accessed 13 November 2017.

Using a pre-auction, 2 x 10MHz was reserved for a new entrant. This reserved spectrum had less stringent coverage obligations placed upon it. However, no new entrant participated in the pre-auction proceedings, and so this reserved spectrum was therefore offered in the main auction.

The lot structure involved three sub-categories—A1 (one 2 x 5MHz lot), A2 (four 2 x 5MHz lots), and A3 (one 2 x 5MHz lot).

All lots were subject to the following coverage obligations (except the reserve spectrum).

- There must be 1Mbit/s download speeds and 250kbit/s speeds for 25% of the population. This must be achieved using only frequencies in the 800MHz band within three years (four years if new entrant).
- There must be 1Mbit/s download speeds and 250kbit/s upload speeds for 95% of the population. This must be achieved within three years (six years if new entrant), but the operator can use any spectrum band to achieve it.

The reserved spectrum is subject to the same two obligations, with an objective of 10% and 25% coverage within two and four years respectively for the first obligation. The second obligation must be reached within eight years.

In relation to the coverage obligation for municipalities and rural areas, the A3 lot had enhanced rural coverage requirements, while the A1 lot[37] and the four A2 lots had less stringent coverage requirements. Table A4.5 summarises the coverage obligation attached to each lot.

[37] The A1 lot was subject to a higher risk of interference from digital terrestrial television in the 700MHz band.

Table A4.5 Coverage obligation for 800MHz band in Austria

Outdoor end-user data transmission rate	Coverage level[1]	Frequency bands to use	Time from the legal effectiveness of the frequency assignment	
			Existing operator	New entrant
All lots—except reserved spectrum				
Download: 1Mbit/s Upload: 250kbit/s	25%	800MHz	3 years	4 years
Download: 1Mbit/s Upload: 250kbit/s	95%	All	3 years	6 years
A3 lots—and blocks from A1 or A2 if assigned				
Minimum bandwidth	180 identified municipalities	800MHz	1.5 years	3 years
Minimum bandwidth	Another 180 identified municipalities	800MHz	3 years	6 years
A1 or A2 lots				
Minimum bandwidth	90 identified municipalities	800MHz	1.5 years	3 years
Minimum bandwidth	Another 90 identified municipalities	800MHz	3 years	6 years
Reserved spectrum				
Download: 1Mbit/s Upload: 250kbit/s	10%	800MHz	N/A	2 years
Download: 1Mbit/s Upload: 250kbit/s	25%	800MHz	N/A	4 years
Download: 1Mbit/s Upload: 250kbit/s	95%	All	N/A	8 years

Note: [1] 'Coverage level' refers to the share of the population covered. A municipality is considered to be covered by the MNO when at least 50% of the resident population has indoor coverage and 90% of the population has outdoor coverage (with a minimum bandwidth). If one block is assigned in the lot, the minimum bandwidth to achieve both indoor and outdoor coverage is 1Mbit/s for downlink and 0.25Mbit/s for uplink. If two or more blocks are assigned, these numbers must be equal to or higher than 2Mbit/s and 0.5Mbit/s respectively.

Source: TKK (2013), 'Tender documentation for frequency assignments in the frequency ranges of 800MHz, 900MHz and 1800MHz', 19 March.

Regarding the assignment of the lot A3, the MNO must provide coverage to 180 and 360 identified municipalities within one and a half years and three years respectively (three and six years if new entrant). If, in addition to the A3 lot, other frequency blocks of the A1 or A2 category are assigned to the MNO, the increased coverage requirement associated with the frequency block of the A3 category will apply. This criterion must be met using only frequencies in the 800MHz band.

Regarding the assignment of either the lot A1 or A2 category (with the exception of the reserved spectrum), the MNO must provide coverage to 90 and 180 identified municipalities within one and a half years and three years respectively (three and six years if new entrant). This criterion must be met using the 800MHz band only.

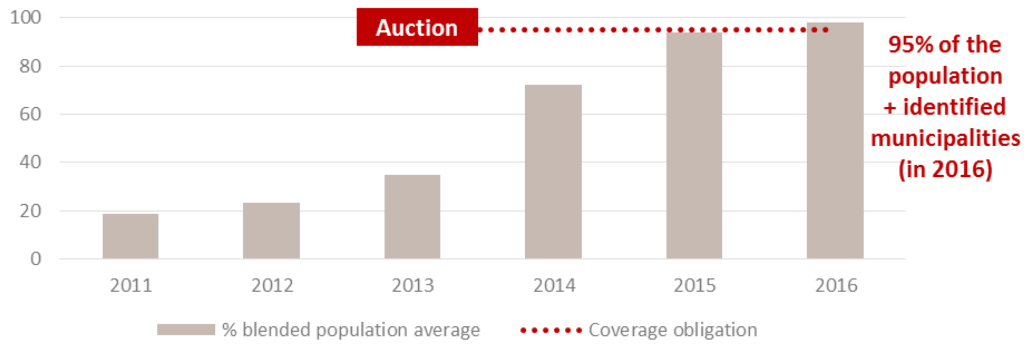
Telekom Austria acquired four blocks (2 x 20MHz) of the 800MHz band—among them block A3, which provides for increased coverage requirements for rural areas. T-Mobile acquired the two other blocks (2 x 10MHz) of the 800MHz band.[38] The third operator, Hutchison, did not win any 800MHz spectrum.

Impact of coverage obligation on mobile connectivity in Austria

The TKK is reviewing the coverage level following the provision of compliance data by the spectrum holders in December 2016.[39] Based on market data in 2015, the regulator highlighted the operators' continuing efforts to roll out fast MBB services to rural areas. By the end of 2015, LTE covered over 95% of the population—see Figure A4.9. The regulator considers that such improvement was primarily driven by competition, while also being an indirect consequence of the obligations to provide coverage imposed as part of the auction.[40]

However, market consolidation (with the merger between Three and Orange in 2012) might also have affected competition and deployment cost sharing, and thus coverage.

Figure A4.9 LTE coverage and deployment mechanisms in Austria



Source: GSMA mobile connectivity index, Eurostat, and Oxera.

In January 2014, Telekom Austria announced that it had used its 800MHz spectrum to extend its LTE coverage to 200 locations, including a number of rural regions never previously covered by its 3G network. At this stage of its deployment programme, Telekom Austria covered around 45% of the population with its 4G network.[41] In June 2016, the firm's LTE network covered over 75% of the country.[42] Also in 2016, Telekom Austria began offering a hybrid fixed-MBB product for connectivity in the home with maximum down/upload speeds of 100Mbps/20Mbps (and the ability to reach 92% of Austrians).[43]

As of November 2017, T-Mobile covers 97% of the Austrian population using LTE.[44] According to the European Commission, in June 2016, the overall level

[38] Rundfunk und Telekom Regulierungs-GmbH (2014), 'Multiband Auction 2013: Comments on essential points of criticism addressed in the high-court proceedings', 18 December.
[39] Rundfunk und Telekom Regulierungs (2017), 'Communications Report 2016: We Stand for Competition and Media Diversity', June.
[40] Rundfunk und Telekom Regulierungs (2016), 'Communications Report 2015', June, p.14.
[41] TeleGeography (2014), 'A1 launches 800 MHz LTE network in 200 locations', 29 January, https://www.telegeography.com/products/commsupdate/articles/2014/01/29/a1-launches-800mhz-lte-network-in-200-locations/, accessed 24 July.
[42] TeleGeography (2016), 'A1 combines VoLTE with Wi-Fi Calling for new Voice Plus service', 17 June, https://www.telegeography.com/products/commsupdate/articles/2016/06/17/a1-combines-volte-with-wi-fi-calling-for-new-voice-plus-service/, accessed 24 July.
[43] TeleGeography (2016), 'A1 combines fixed, mobile technology for new 100Mbps internet offer', 18 July, https://www.telegeography.com/products/commsupdate/articles/2016/07/18/a1-combines-fixed-mobile-technology-for-new-100mbps-internet-offer/, accessed 24 July.
[44] T-Mobile Austria, http://www.t-mobile.at/netz/, accessed 24 July.

of LTE coverage was 99.0% of households, with rural coverage of households at 92.6%.[45]

Denmark

The Danish Business Authority (DBA) conducted the 800MHz band auction in June 2012. The spectrum release aimed to facilitate effective competition and help provide broadband access to everyone at a minimum speed of 100Mbit/s by 2020. Coverage obligations were included in the 800MHz licences to improve high-speed broadband availability in areas with the lowest available mobile connectivity.[46]

The auction introduced an innovative approach to assigning coverage obligations to licensees, by including coverage obligations in all licences but allowing bidders to bid for *regional exemptions* from these coverage obligations.[47]

The spectrum was divided into five lots, with each being subject to a coverage obligation by default. The coverage obligation applied to the 207 postcodes (with the lowest availability of high-speed broadband) in three non-overlapping coverage areas ('regions') specified in the licence. The coverage regions could not be split between licences. Each bidder could bid for exemptions in each of these regions, but the auction outcome ensured that at least one winner in each region would be obliged to meet the coverage obligation. Thus the auction mechanism would efficiently determine whether the overall burden of the coverage obligation would be shared, or if one bidder would take up the obligation in all regions.

In each coverage area specified in the licence, the licensee should ensure 98% geographical outdoor coverage of the land area with 10Mbit/s speeds (excluding forests) and 99.8% outdoor coverage of households, enterprises, and holiday houses. The licensee should also ensure that the minimum coverage rate in each postcode area is 75% of households, enterprises, and holiday houses. The licensees could fulfil the coverage obligation with any frequencies at their disposal by the end of 2015.

Verification of coverage levels was based on documentation provided by the licensee by the end of March 2016, using the methods that it found most suitable.

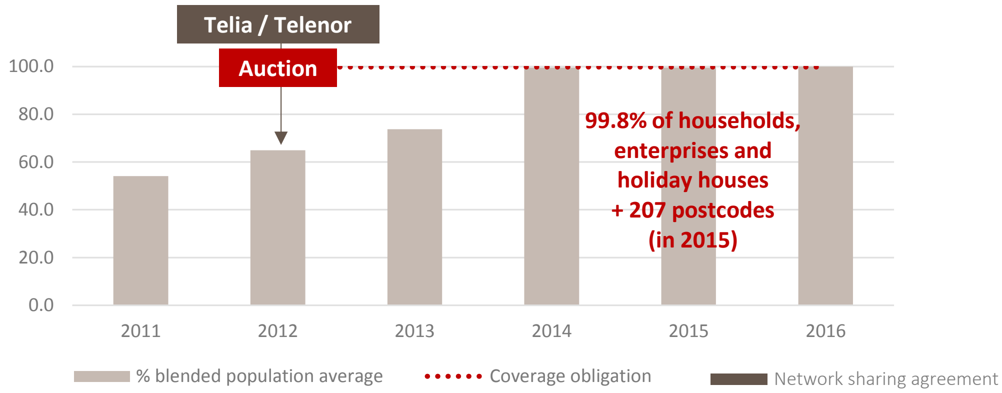
Impact of coverage obligation on mobile connectivity in Denmark

The auction resulted in 2 x 20MHz of 800MHz spectrum going to the operator TDC, and 2 x 10MHz going to the TT-Network (a joint venture between operators Telia and Telenor). The result of the auction meant that TDC bears the coverage obligations across all three regions.[48] Denmark is the only example of our case study countries where a regulator provided a market mechanism through which the coverage obligations could be split between operators, but in this case, one operator still took all three coverage obligations.

[45] European Commission (2017), 'Broadband Coverage in Europe 2016: Mapping progress towards the coverage objectives of the Digital Agenda', 21 September.
[46] European Commission (2016), 'RADIO SPECTRUM POLICY GROUP: RSPG Report on Efficient Awards and Efficient Use of Spectrum', 24 February.
[47] DotEcon (2012), 'Danish 800MHz auction completed', June, www.dotecon.com/news/danish-800mhz-auction-completed/, accessed 24 July.
[48] Ibid.

It would appear that TDC rolled out a 4G network the quickest in Denmark. TDC claimed that its 4G network covered 99.5% of the Danish population and 99% of the landmass (vs the claimed 85% average landmass for other MNOs) at the end of 2016.[49] Indeed, while TDC claimed 98% 4G coverage by the end of 2014, Telenor achieved 4G coverage of 94% only at the end of 2015.[50] This is shown in Figure A4.10 (which also shows that a mobile network sharing agreement was reached in 2012—see section A4.5). TDC is planning to add over 65 mobile sites in 2017 and implement 4G+ upgrade technologies.[51]

Figure A4.10 LTE coverage and deployment mechanisms in Denmark



Source: GSMA mobile connectivity index, Eurostat, and Oxera.

The Danish Energy Agency (DEA), which is now the agency that is responsible for spectrum in Denmark, is currently preparing to consult on the 2018 auction of the 700MHz, 900MHz, and 2.3GHz bands, including on whether to impose coverage obligations.[52]

Finland

The Ministry of Transport and Communications (LVM) concluded the 800MHz auction in October 2013. The aim of the auction was to improve the availability of MBB—especially outside urban areas—and to enable the swift introduction of a national MBB network.

Winning bidders were required to cover 95% of the population in mainland Finland within three years of the start of the licence period. In addition, the regulator determined that one of the licensees had to provide 99% population coverage, while the others were obliged to reach 97% within five years of the start of the licence period. In calculating coverage, connectivity provided using the 1800MHz and 2.6GHz frequency bands would be taken into account. The regulator stated that a reasonable level of indoor coverage should be ensured, but the definition of 'reasonable' in this case is unclear.[53]

The motivation for the coverage obligations was to quicken the pace of roll-out:[54]

[49] TDC Group (2017), 'Annual Report 2016', 9 March.
[50] TDC Group (2015), 'Annual Report 2014', 6 February.
[51] TDC Group (2017), 'Annual Report 2016', 9 March.
[52] Danish Energy Agency (2017), 'Consultancy services and auction software in connection with the 700 MHz, 900 MHz and 2300 MHz auction(s)', Appendix 1.
[53] LVM Ministry of Transport and Communications (2012), 'TAAJUUSPOLIITTINEN PERIAATEPÄÄTÖS', 27 March.
[54] LVM Ministry of Transport and Communications (2012), 'Government resolution on spectrum policy', 27 March.

> Without a coverage condition incorporated in the licences, the established operators would probably not have any great incentive to build a national network quickly enough.

The choice to impose coverage obligations on multiple licences was to ensure that there were competing networks in sparsely populated areas, although the most strict coverage obligation (99%) was only imposed on one licensee to avoid too much network duplication in the most rural areas.[55]

The winning operators for the 800MHz spectrum were DNA, Elisa, and TeliaSonera Finland, the latter achieving the goal of covering 99% of the population by the end of 2018.[56] Each operator won 2 x 10MHz of 800MHz spectrum.

In parallel, Ukko Mobile, which uses the 450MHz frequency band, claimed in late 2014 that its LTE network covered 99.9% of the country's population at launch.[57] While not a major LTE band, this type of low-frequency network may provide useful rural mobile connectivity (albeit with lower data speeds and fewer compatible handsets).

Impact of coverage obligation on mobile connectivity in Finland

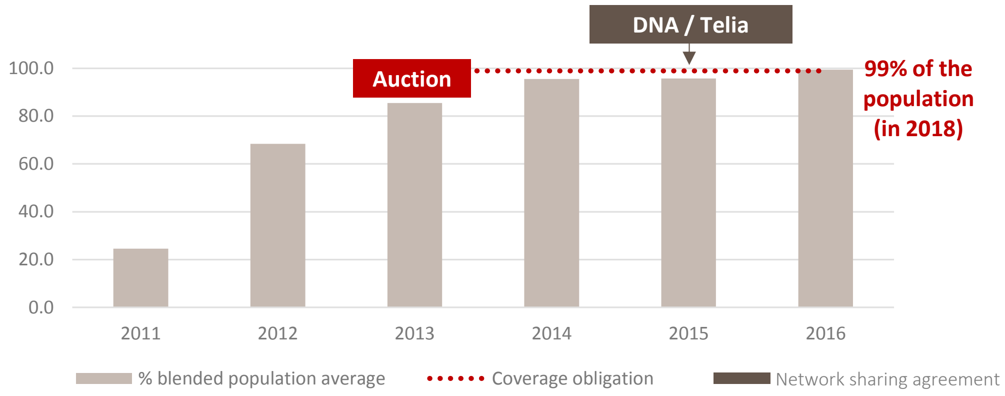
At the end of 2014, the regulator investigated the availability of high-speed broadband subscriptions. The results showed that the availability area of high-speed MBB subscriptions implemented in the mobile network covers as much as approximately 95% of Finland's population.[58]

The LVM judged that the three established MNOs built 4G networks rapidly using the 800MHz spectrum.[59] Currently, the three 4G networks cover about 97% of the population of mainland Finland, although not yet fully the road network in northern and eastern Finland. Despite Finland being one of the most sparsely populated countries in Europe, the population coverage of 4G is amongst the highest in Europe (99.5% in 2016). This is shown in Figure A4.11 (which also shows when a network sharing agreement was reached—see section A4.5).

We note that Finland has a lower proportion of the population living in rural areas than Ireland—meaning that high levels of population coverage are likely to be easier to obtain than in Ireland.

[55] LVM Ministry of Transport and Communications (2012), 'Government resolution on spectrum policy', 27 March.
[56] LVM Ministry of Transport and Communications (2013), 'Spectrum auction results: 4G spectrum to DNA, Elisa and TeliaSonera', 30 October.
[57] TeleGeography (2014), 'Ukko Mobile claims 99.9% LTE-450 coverage at launch', 3 December, https://www.telegeography.com/products/commsupdate/articles/2014/12/03/ukko-mobile-claims-99-9-lte-450-coverage-at-launch/, accessed 24 July.
[58] Finnish Communications Regulatory Authority (2015), 'Availability of high-speed broadband in Finland is good', 18 March, https://www.viestintavirasto.fi/en/ficora/news/2015/availabilityofhigh-speedbroadbandinfinlandisgood.html, accessed 24 July.
[59] LVM Ministry of Transport and Communications (2017), 'Auction of the 700 MHz spectrum', Appendix 2.

Figure A4.11 LTE coverage and deployment mechanisms in Finland



Source: GSMA mobile connectivity index, Eurostat, and Oxera.

The LVM drew the following conclusions regarding the consequences of the 800MHz auction:[60]

- it did not have an impact on the market structure or competition situation in mobile communications services;
- it did not lead to a decline in telecom operators' other business investments;
- it improved the quality and availability of high-speed wireless broadband connections throughout Finland, particularly in sparsely populated areas;
- it did not significantly alter mobile communications prices, resulting in consumers receiving more and better services than before for the same price.

The LVM also auctioned the 700MHz band in 2016, which included coverage obligations. The coverage obligations were set such that the existing MNOs would not incur 'unreasonable additional costs'—the regulator noted that the MNOs were already close to achieving these levels of coverage with their existing networks.[61] The coverage obligations, which also incorporated mobile connectivity using other licensed spectrum bands, were the following.[62]

- There should be 99% population coverage of mainland Finland within three years of the start of the licence period.[63] This includes 'reasonable indoor coverage', which is defined as services that are available indoors without additional cost to users under normal circumstances.
- All the main roads, secondary roads, regional roads, and connecting roads in mainland Finland and the entire rail network should be covered.
- Each MNO's own network must cover at least 35% of the required coverage over the entire population. Network sharing 'in areas beyond an operator's own network is not limited in any way' because such agreements enable better coverage in rural areas.

Sweden

[60] Ibid.
[61] Ibid.
[62] Ministry of Transport and Communications (2016), 'Invitation for applications for frequency band allocation—Telecom operating licences for the spectrum 703–733 MHz and 758–788 MHz', https://www.lvm.fi/lvm-site62-mahti-portlet/download?did=214984, accessed 24 July.
[63] Ibid.

The Swedish Post and Telecom Agency (PTS) assigned licences for the 800MHz band in March 2011. The government's broadband strategy is that 'all households and businesses should have good opportunities to use electronic public services and other services via broadband'. The coverage obligation targeted those homes and businesses identified as lacking both fixed and MBB connectivity.

The PTS divided the frequency band into six 2 x 5MHz blocks, including a condition on coverage and roll-out on one 2 x 5MHz block (FDD6 block).[64] Bidding for the FDD6 block was designed to take place within the same auction system and in the same way as bidding for the other blocks, with the only difference being that bidders would compete for FDD6 through making binding offers in coverage investments. The amount of the coverage bid would not be paid to the PTS in auction proceeds, but rather spent on improving coverage. Bidders could switch bids between FDD6 and the other blocks throughout the entire auction.

The reserve price on the licence with coverage obligations was SEK150m, ensuring that the winner had to spend at least €17m on coverage. In addition, the maximum coverage bid was SEK300m (€34m), and any bids above SEK300m was to be considered as auction proceeds.[65]

The coverage requirement stated that a licensee shall cover all homes and businesses identified by PTS, but the recovery of roll-out costs would be limited to the amount bid on coverage (€17m–€34m, with an annual adjustment for inflation).[66]

The identification of locations to be covered by the licensee took place annually from 2011, listing homes and businesses that did not have access to 1Mbit/s connectivity and requested coverage. This way, the regulator was able to implement a dynamic coverage obligation based on needs in rural areas and to ensure that operators would allocate financial resources for this.

For recovery of roll-out costs from the coverage investment bid, PTS considered a location to be covered if the licensee:

- rolls-out a network appropriately and cost effectively (see below);
- provides access to data communications services in at least one room in the end-user's permanent home or fixed place of business;
- provides mobile connectivity of at least 1Mbit/s (or a higher data rate stipulated by the government) over the period.[67]

The cost-effectiveness criteria aims to ensure that the licensee uses the money promised for coverage in the intended way as the roll-out costs are to be deducted from the promised amount of the coverage investment bid. By 'appropriate and cost-effective roll-out', the PTS meant a roll-out at justified

[64] Swedish Post and Telecom Agency (PTS) (2010), 'Open invitation to apply for a licence to use radio transmitters in the 800 MHz band', 13 December.
[65] Exchange rates as of summer 2017.
[66] The part of the licensee's bid in coverage that remains each year, after deducting the licensee's annual roll-out costs, shall be adjusted upwards with inflation using the Consumer Price Index.
[67] A bit rate of 1Mbps means (i) that the bit rate amounts to at least 1Mbps at some point in time in a day; (ii) that the average rate amounts to at least 750kbps in a day, and (iii) that the average rate for four consecutive hours when the speed is at its lowest amounts to at least 500kbps.

and reasonable costs.[68] The PTS assessed what was appropriate and cost-effective on the basis of the licensee's own preconditions.[69]

The licensee had to provide coverage along the following schedule until the roll-out cost reached the amount promised for coverage (including inflation adjustment):

- at least 25% coverage of any premises on the list by 31 December 2012;
- at least 75% coverage of any premises on the list by 31 December 2013;
- all the premises on the list from 2014 onwards.

The licensee was to satisfy the coverage roll-out requirements using the 800MHz band. In some specific cases (e.g. lack of basic infrastructure), the licensee may be able to use other frequency bands and other technologies if it is clearly less costly to do so.[70]

The PTS assigned two 800MHz frequency blocks (2 x 10MHz) to Net4Mobility for SEK769m (€86m), including the block with the coverage obligation (FDD6).71 Net4Mobility is a joint venture between Telenor and Tele2 in Sweden (for more information, see section A4.5). The purchase was financed equally by both parties, with SEK469m (€52m) paid to the state in addition to SEK300m (€34m) to be used to build infrastructure in rural areas. TeliaSonera and Hutchinson each purchased 2 x 10MHz for SEK854m and SEK431m respectively.

Impact of coverage obligation on mobile connectivity in Sweden

Sweden has high levels of LTE coverage. The European Commission estimates rural coverage, as of June 2016, to be 100% of the population.[72] Net4Mobility attained 99% population coverage in 2013, and Telia reached the same coverage level in 2014, despite not purchasing the 800MHz license with the coverage obligation.[73, 74] Swedish MNOs seem to have been successful in increasing rural mobile connectivity, with rural 4G coverage increasing from 7% to 71% in 2011–12.[75] In terms of coverage of landmass, 69% of the country had 4G network coverage that provided 10Mbit/s broadband speed in 2015 (up from 40% in 2013).[76, 77]

We note that like Finland, Sweden has a lower proportion of its population living in rural areas than Ireland—meaning that providing high levels of

[68] PTS (2010), 'Open invitation to apply for a licence to use radio transmitters in the 800 MHz band', 13 December, Appendix A: licence conditions etc. for PTS decision to assign licenses.
[69] Costs for covering a permanent home or a fixed place of business may only be deducted once during the roll-out, except in cases where PTS has identified the home or place of business once more due to an increase in the level for functional access to the Internet. The cost of maintaining the coverage established (e.g. the cost of operating and servicing the network) is not covered.
[70] For the 250 homes and places of business that are most costly to cover through roll-out, the licensee may take into account coverage provided by using infrastructure in other frequency bands , if such roll-out is clearly less costly than a roll-out in the 800 MHz band. For the 20 most expensive homes and places of business, the licensee may also take into account coverage provided by using satellite solutions if such roll-out is clearly less costly.
[71] PTS (2011), 'Results from the Swedish 800 MHz auction', 4 March.
[72] European Commission (2017), 'Study on broadband coverage in Europe 2016', 21 September.
[73] Tele2 (2016), 'Full Year and Fourth Quarter 2015 Report', 23 March.
[74] TeliaSonera (2014) 'Annual Report 2014', 11 March.
[75]GSMA Intelligence, (2015), 'Rural coverage: strategies for sustainability', July.
[76] PTS (2015), 'Rapid expansion of mobile broadband according to PTS survey', 3 February.
[77] PTS (2017), 'Seven out of ten have high-speed broadband as a consequence of continues fibre roll-out', 20 March.

population coverage is likely to require less percentage geographic coverage than in Ireland.

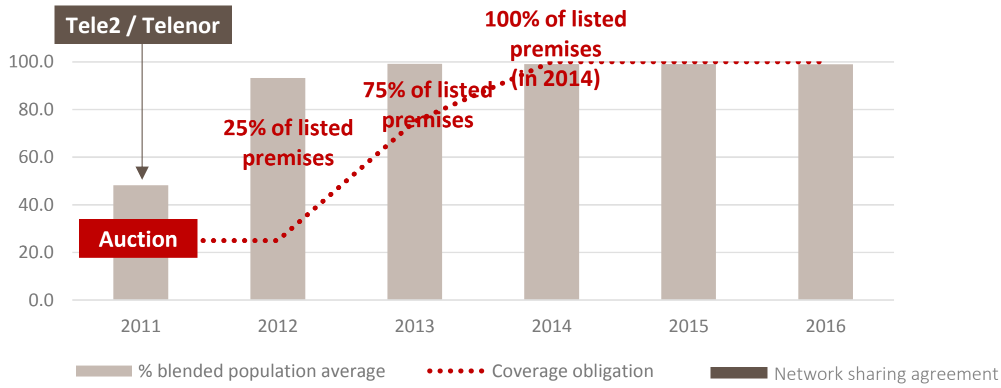
Following the auction, 4G availability increased rapidly. In December 2012, the PTS assessed that the coverage requirements for the 800MHz band had already led to 4G coverage for 120 homes and businesses that were previously unable to access broadband. At that time, 4G population coverage reached 90% across Sweden, up from 56% in 2011.[78]

In 2012, the PTS identified 628 homes and businesses that would be offered coverage.[79] The PTS required Net4Mobility to cover 471 addresses (i.e. 75% of 628) by the end of 2013.[80] In 2015, the PTS reported that Net4Mobility had failed to meet the coverage obligations as defined in their licences.[81] As the MNO failed to fulfil this requirement, the PTS defined a clear schedule for future coverage obligations—at least 50 addresses were to be covered by June 2015, another 50 addresses by September 2015, and another 65 addresses by November 2015. In its 2015 statistics report, the PTS considered that the coverage requirement had so far resulted in broadband coverage of at least 1Mbit/s for more than 300 of the households and business locations identified by the PTS as being unable to access broadband subscriptions through other means.[82]

It would therefore appear that the coverage obligations may have been too onerous for Net4Mobility. This might be because the specific addresses in the coverage obligations were set dynamically by the PTS on an annual basis following the auction, or it might be because of other practical considerations, such as the roll-out time required for Net4Mobility (a joint venture between Tele 2 and Telenor) proving to be too onerous.

Net4Mobility 4G network now covers areas where 99% of the population live and claims to be the largest network.[83]

Figure A4.12 LTE coverage and deployment mechanisms in Sweden



Source: GSMA mobile connectivity index, Eurostat and Oxera.

[78] GSMA (2015), op. cit.
[79] PTS (2012), 'Broadband arrives in 120 homes and companies thanks to the PTS coverage provision', 18 December.
[80] PTS (2014), 'PTS submits Net4Mobility to meeting coverage requirements in the 800MHz band', 14 January.
[81] Ibid.
[82] PTS (2015), 'Rapport av uppdrag att samla in statistik om tillgången till mobile kommunikationsnät', 11 May.
[83] Tele2 (2016), 'Tele2 and Telenor to build a common 5G network', 16 December, http://www.tele2.com/Documents/Cision/documents/2016/20161216-tele2-and-telenor-to-build-a-common-5g-network-en-0-2408324.pdf?epslanguage=en, accessed 24 July.

The PTS has proposed to also apply coverage obligations on the 700MHz band (although the auction process has been delayed and the PTS may amend these proposals).[84] The PTS proposed to set the coverage obligation on one of the five 2 x 5MHz frequency blocks (FDD5). The proposed obligation would follow a similar structure to the 800MHz obligations, with at least SEK100 million to be invested in providing coverage. The coverage obligation would first target areas where consumers live and work but have no mobile voice coverage, and then similar areas that may have mobile voice coverage but lack MBB coverage. The targeted speed is faster than the 800MHz obligation, at 10Mbps.[85]

The UK

Ofcom auctioned the 800MHz band in February 2013 and attached coverage obligations to one of the 2 x 10MHz licences. This was won by O2.[86] This licence requires O2 to provide 2Mbit/s indoor[87] mobile connectivity (90% of the time) for at least 98% of the UK population, including at least 95% of the population in each of the UK's nations—England, Scotland, Wales, and Northern Ireland.[88] The deadline for this coverage was the end of 2017. O2 could meet both obligations using any frequency or technology available at its disposal. Ofcom anticipated that this would be likely to lead to outdoor coverage of areas within which 99.5% of the UK population lives. The other 800MHz licences were won by Vodafone (2 x 10MHz), EE (2 x 5MHz) and Three (2 x 5MHz).

Ofcom was aware of the risks of setting a coverage obligation that was too onerous:[89]

> We set out our view that such an obligation (i) should guarantee that a future mobile broadband service would be provided to a significant number of citizens and consumers and on a reasonable timescale, and (ii) balanced the costs and benefits and addressed risks of regulatory failure arising from a poorly specified obligation or unintended consequences such as distorting investment decisions or deterring new entry.

Ofcom concluded the following.

- A coverage obligation was required to ensure a relatively quick roll-out of 4G services.
- Population coverage of 98% was chosen because it was achievable—it reflected existing 2G coverage (95%) and the impact of the government's investment in improving coverage under the Mobile Infrastructure Project.[90] An MNO would be able to achieve 95% coverage by upgrading its 2G sites

[84] The PTS postponed the 700MHz auction due to issues around clearing the spectrum for mobile and issued a preliminary consultation about the process going forward in June 2017. See PTS (2016), 'Open invitation for applications for a licence to use radio transmitters in the 700MHz band', 1 July; PTS (2017), 'Consultation prior to updated preliminary study report 700 MHz', 28 June.
[85] PTS (2015), 'Feasibility Study Report 700 MHz Pre-study before work on allocation of 694-790 MHz', 14 April.
[86] Ofcom (2013), 'Ofcom announces winners of the 4G mobile auction', 20 February, https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2013/winners-of-the-4g-mobile-auction, accessed 24 July.
[87] Due to the difficulties associated with testing indoor coverage, Ofcom decided that the coverage obligation would be tested at outdoor locations but taking account of a specified building penetration loss to indoor locations. The verification methodology actually calculates achieved service based on predictions of coverage and interference from the relevant licensee's site portfolio.
[88] Ofcom (2012), 'Assessment of future mobile competition and award of 800 MHz and 2.6 GHz', Statement, 24 July.
[89] Ofcom (2012), 'Second consultation on assessment of future mobile competition and proposals for the award of 800 MHz and 2.6 GHz spectrum and related issues', 12 January.
[90] DCMS, 'Broadband Delivery UK', https://www.gov.uk/guidance/broadband-delivery-uk, accessed 24 July.

to 4G (which was less costly than building new sites). The extra 3% population coverage (to reach 98%) was expected to be less costly than otherwise because of the Mobile Infrastructure Project.

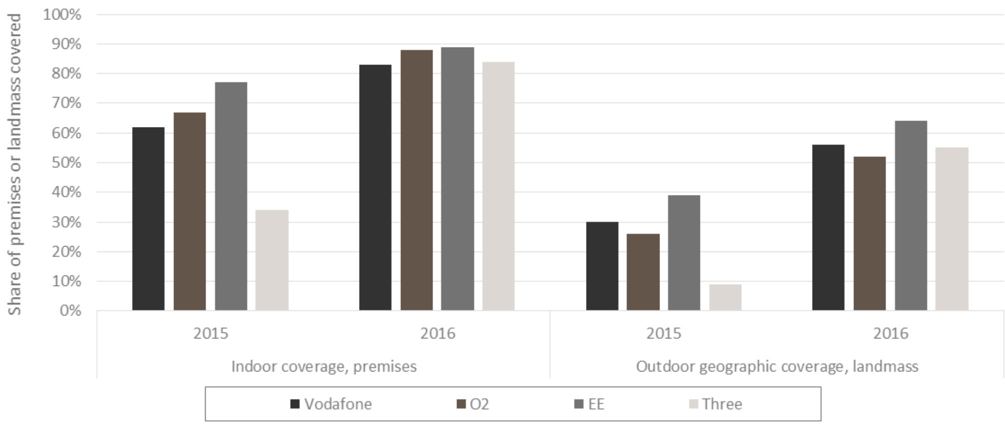
- The requirement of one MNO to provide coverage to 98% would be enough to spur competition so that the other MNOs would match that level of coverage.
- The target date may not have been feasible for a new entrant, but other elements of the auction design should mean that this does not matter (i.e. some spectrum was reserved for a fourth MNO, Three, or a new entrant).

Impact of coverage obligation on mobile connectivity in the UK

In 2012, O2 and Vodafone announced network sharing plans to deliver a 4G service faster than if they operated independently (see section A4.5)—which explains why O2 and Vodafone have broadly similar levels of 4G coverage.[91] In November 2013, O2 announced that its 4G network covered 25% of the UK's population.[92] In April 2014, it covered a third of the population indoors and 41% of the population outdoors.[93]

Competition between MNOs supports the extension of coverage, with several MNOs having indicated their intention to match O2's obligation.[94] For example, EE currently provides greater coverage than O2 and has announced its objective to cover 95% of the country by 2020, compared to its 2016 coverage of 60% landmass.[95] Figure A4.13 illustrates operators' LTE coverage in 2016 in the UK.

Figure A4.13 4G coverage in the UK by MNO (2015 and 2016)

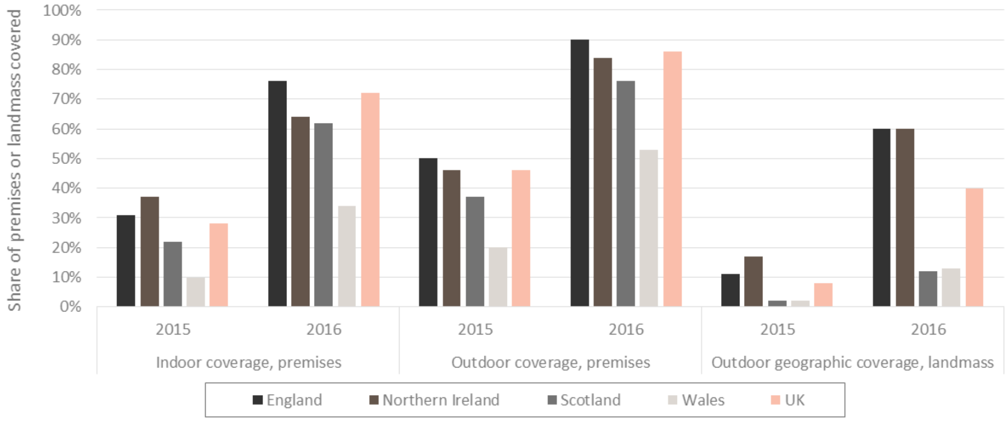


Source: Ofcom (2016), 'Connected Nations 2016', 16 December.

[91] TeleGeography (2012), 'Vodafone UK and Telefonica UK to merge network infrastructure', 7 June, https://www.telegeography.com/products /commsupdate/articles/2012/06/07/vodafone-uk-and-telefonica-uk-to-merge-network-infrastructure/, accessed 24 July.
[92] TeleGeography (2013), 'O2 UK LTE coverage reaches 25% of population', 12 November, https://www.telegeography.com/products/commsupdate/articles/2013/11/12/o2-uk-lte-coverage-reaches-25-of-population/, accessed 24 July.
[93] TeleGeography (2014), 'O2 UK reveals 4G network now offers coverage of 41% of population', 14 April, https://www.telegeography.com/products/commsupdate/articles/2014/04/14/o2-uk-reveals-4g-network-now-offers-coverage-of-41-of-population/, accessed 24 July
[94] Ofcom (2016), 'Connected Nations 2016', 16 December.
[95] TeleGeography (2016), 'EE to increase geographic 4G coverage to 95% of the UK', 25 April, https://www.telegeography.com/products/commsupdate/articles/2016/04/25/ee-to-increase-geographic-4g-coverage-to-95-of-the-uk/, accessed 24 July.

Reports from the European Commission and the British Infrastructure Group indicate coverage difficulties for MBB in the UK. The former estimated UK overall coverage in June 2016 to be near 99.5% of premises, with rural coverage at 95.3% of premises.[96] It should be noted that according to data from Which? and OpenSignal, although mobile download speeds are consistent across the UK, the ability of consumers to access 4G coverage differs widely.[97] For example, mobile users in London can access 4G coverage 69.7% of the time, while 35.4% of mobile users can have such access in Wales. Figure A4.14 illustrates 4G network coverage differences across nations.

Figure A4.14 4G coverage in the UK by nation (2015 and 2016)



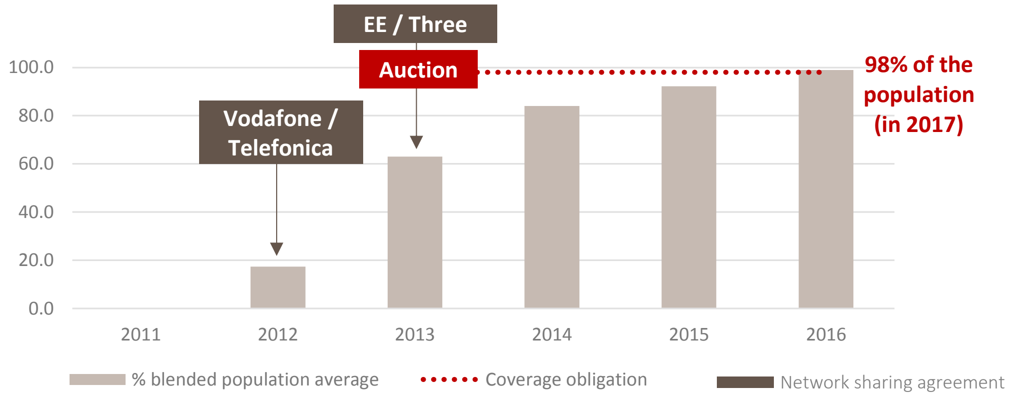
Source: Ofcom (2016), 'Connected Nations 2016', 16 December.

In February 2015, Ofcom varied the licences of the UK's four MNOs to improve coverage after the MNOs made voluntary agreements with the government to improve mobile connectivity across the UK.[98] Ofcom imposed a 90% voice and text geographic coverage obligation to be reached by the end of 2017, as well as addressing specific concerns such as black spots.[99] The government decision to accept voluntary commitments from the MNOs came after consulting on other alternative approaches to improving mobile connectivity, including national roaming or the creation of a multi-operator MVNO.[100]

Overall UK 4G coverage is shown in Figure A4.15 (which also shows two network sharing agreements—see section A4.5).

[96] European Commission (2017), 'Broadband Coverage in Europe 2016: Mapping progress towards the coverage objectives of the Digital Agenda', 21 September.
[97] British Infrastructure Group (2016), 'Mobile Coverage: A good call for Britain?' October.
[98] Department for Digital, Culture, Media & Sport (2014), 'Government secures landmark deal for UK mobile phone users', 18 December, https://www.gov.uk/government/news/government-secures-landmark-deal-for-uk-mobile-phone-users, accessed 24 July.
[99] TeleGeography (2015), 'Ofcom imposes 90% geographic coverage commitment', 3 February, https://www.telegeography.com/products/commsupdate/articles/2015/02/03/ofcom-imposes-90-geographic-coverage-commitment/, accessed 24 July.
[100] Department for Digital, Culture, Media & Sport (2015), 'Tackling Partial Not-Spots in Mobile Phone Coverage', 12 March.

Figure A4.15 LTE coverage and deployment mechanisms in the UK



Source: GSMA mobile connectivity index, Eurostat, and Oxera.

In March 2018, Ofcom consulted on coverage obligations for the 700MHz band, which will be auctioned in 2019.[101] Ofcom proposed that there would be three coverage obligations, each of which would need to be accomplished within three years of the spectrum being awarded:

- indoor coverage to 60% of premises currently without any mobile coverage (this is attached to one licence);
- outdoor coverage of 92% of the total UK landmass (likely to be more than 90% of the rural landmass), with minimum levels specified for each nation (this is attached to two licences).

In September 2019, Ofcom published technical advice to Government on further options to improve mobile coverage, following a request from Government earlier this year.[102] This advice uses a snapshot of mobile coverage data from January 2018 and provides technical analysis of options to improve mobile coverage, such as public subsidy, rural wholesale access (commonly known as rural roaming), infrastructure sharing and planning reform.

A4.3.3 European outcomes

This section summarizes the role played by coverage obligations in a selection of European countries.

All 800MHz band auctions in Europe included a coverage obligation, except in Luxembourg. Oxera analysed the outcome of coverage obligations included in the 800MHz licence in 11 European countries for which information was readily available.[103] Sweden is the only case study country excluded from this analysis as the coverage obligation is defined in terms of postcodes rather than population, making comparison more difficult.

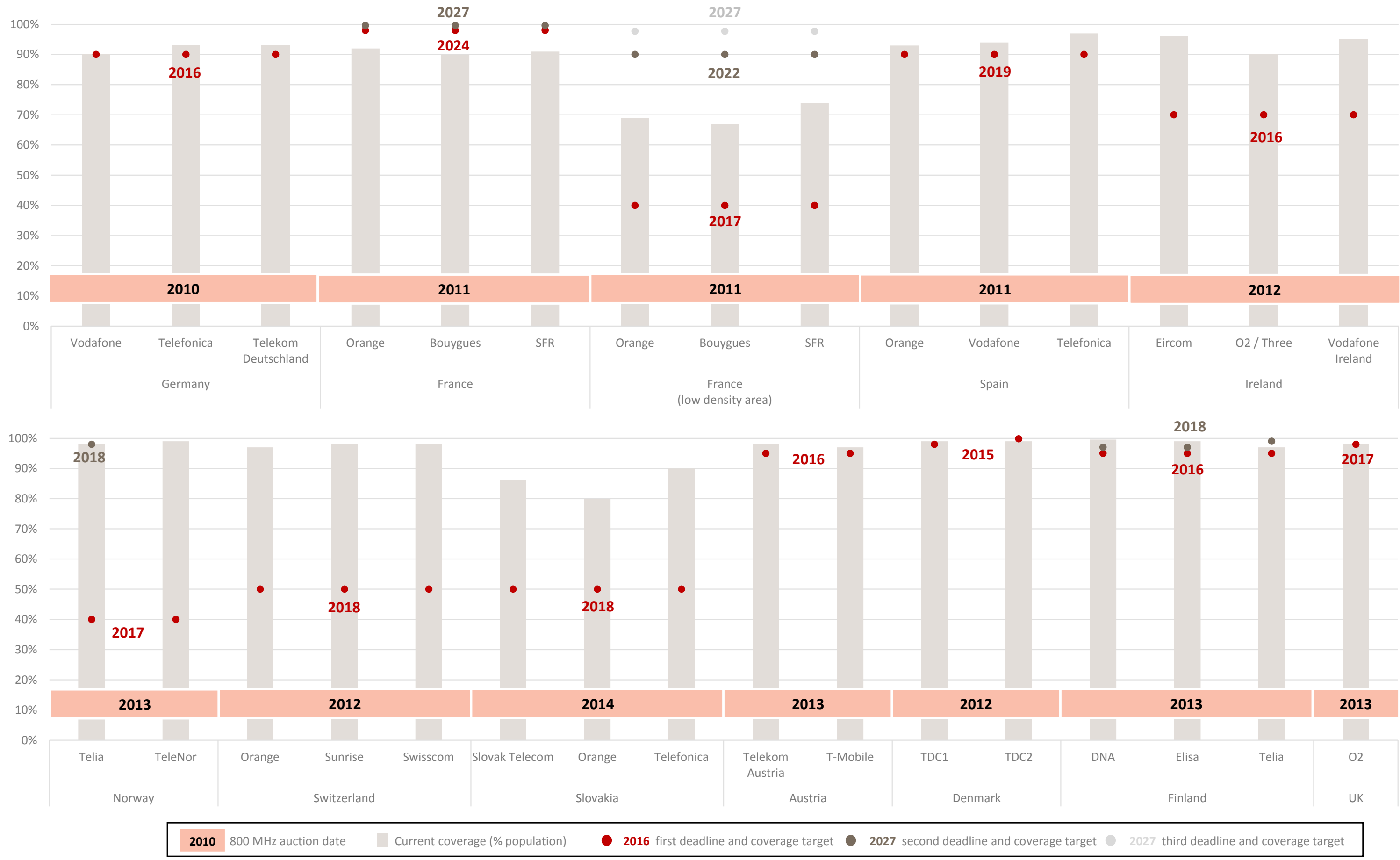
Figure A4.16 shows coverage requirements and actual 4G coverage (in terms of population) by MNO in the selected countries (only including those MNOs that faced coverage obligations). The chart demonstrates that most MNOs have already achieved the required coverage under the obligation before the deadline imposed by the regulator. Several MNOs that have not yet reached

[101] Ofcom (2018), ‘Improving mobile coverage: Proposals for coverage obligations in the award of 700MHz spectrum band’, 9 March.
[102] Ofcom (2018), ‘Further options for improving mobile coverage, Advice to Government’ 14 September
[103] Austria, Denmark, Finland, France, Germany, Ireland, Norway, Slovakia, Spain, Switzerland, and the UK.

their deadlines are currently also on course to fulfil the obligation ahead of their deadlines. The data is from the websites of regulators and MNOs.

The data indicates that coverage obligations are likely to be effective in obliging MNOs to increase the coverage of mobile connectivity. It also suggests that even in the absence of strict coverage obligations, it may be in an MNO’s interest to attain high levels of population coverage. For example, many of the MNOs shown in Figure A4.16 have exceeded their obligations. Well-specified obligations can complement this by ensuring that MNOs do not neglect areas that are less profitable, such as rural areas.

Figure A4.16 Coverage obligations attached to 800MHz licence and actual 4G coverage by operators in selected countries (using most recent available coverage data from operator websites, typically 2016–17)



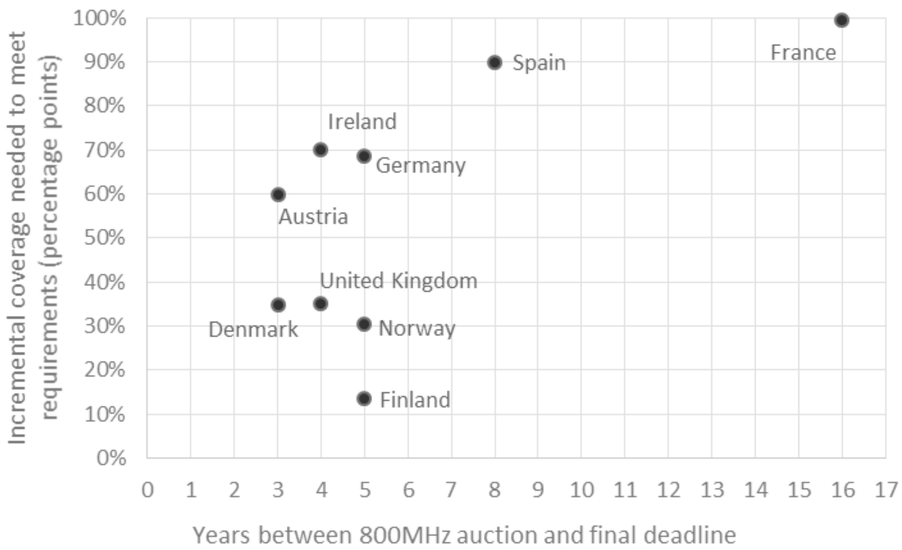
Note: Excluding operators without 800MHz coverage obligations. Regarding Denmark, TDC1 refers to the TDC coverage obligation/outcome in terms of area; TDC2 refers to the TDC coverage obligation/outcome in terms of households, enterprises, and holiday houses. Regarding Norway, Telia merged with Tele2 in 2014.

Source: Oxera, websites of regulators and MNOs, GSMA, European Commission. Accessed June–November 2017.

Coverage requirements across these countries are not equally demanding (allowing more years to achieve the required coverage is less onerous, as it gives MNOs more time to build their networks and spread the cost of doing so over more years).

Figure A4.17 shows that an obligation can run between three years (Austria and Denmark) and 16 years from the auction date (France), and require an additional coverage from 13 percentage points (Finland) to nearly 100 percentage points (France).[104] Note that this incremental additional coverage differs from the total population coverage (most countries set this at over 90%).

Figure A4.17 Diversity of coverage obligations across European countries in terms of additional coverage and deadlines



Note: The analysis includes data for Austria, Denmark, Finland, France, Germany, Ireland, Norway, Spain, and the UK on the most demanding coverage obligation in each country. Switzerland and Slovakia were not included due to lack of (or inconsistency in) data on coverage in the year of the auction.

Source: Oxera and regulators' websites, GSMA connectivity indicator, Eurostat.

In most cases, countries chose to attach a coverage obligation of at least 90% of the population (along with additional requirements). Most MNOs have met (or are on the way to meeting) their 800MHz coverage obligations. These coverage obligations seem achievable for MNOs, particularly where the roll-out is sufficiently long and the obligation itself is not excessive.

However, there is a risk that excessive obligations will not be met by MNOs. Regulators should assess coverage obligations to ensure that any such obligations are objectively justified and proportionate with respect to ensuring the efficient use of the radio spectrum and that such obligations are achievable. For example, Net4Mobility failed to meet the coverage obligations agreed with the regulator and defined in their licences, as the obligations were too onerous for it.

[104] Note that although licence deadlines are MNO-specific, we did not have the data on coverage per MNO. Hence, we have the overall country average as a proxy.

A4.3.4 Key observations

While mobile coverage obligations are very often used by European regulators, the reasons and forms of them vary considerably across countries.

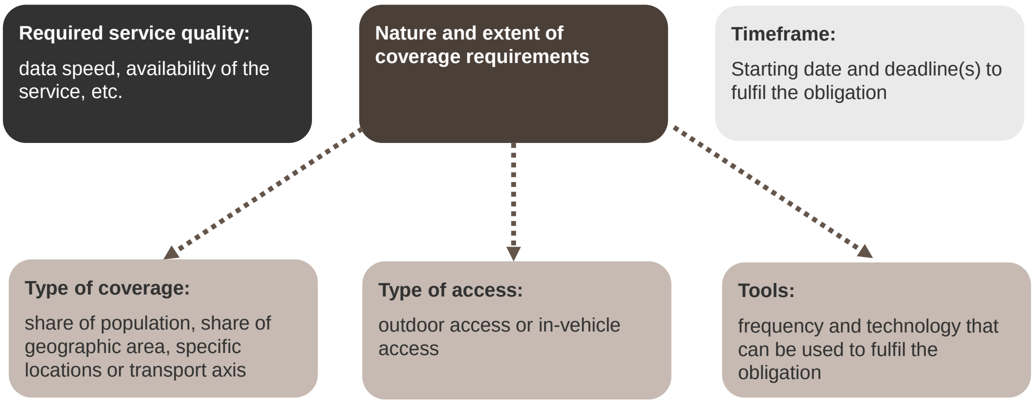
For instance, some countries adopt coverage obligations to promote investment in areas that are not commercial, while others employ them to ensure a minimum level of national coverage is provided or to increase the speed of roll-out. Many countries implement coverage obligations to achieve some combination of these, or even all three.

Oxera's analysis of coverage obligations in the case study countries leads to the following observations.

- **Coverage obligations are generally employed and designed in order to achieve specific objectives**—for example, facilitating new entrants (e.g. Austria) or increasing the availability of mobile connectivity in coverage black spots (e.g. Austria, Denmark and Sweden).
- **Coverage obligations on 800MHz spectrum licences have promoted the roll-out of 4G, including in rural areas**—most MNOs achieve their coverage obligations although they may also have achieved them without coverage obligations. Typically, regulators imposed a target of above 90% of the population. Some regulators also specified particular regions (e.g. Austria) or postcodes (e.g. Denmark) that were required to be covered.
- **Coverage obligations can be set to oblige the roll-out of coverage in specific areas**—where specific areas are targeted, these are normally specified in advance and based on specific criteria (e.g. Austria, Denmark), although some degree of dynamism[105] could be built into the obligation (e.g. Sweden).
- **Coverage obligations can be set to increase the speed of roll-out**—in areas in which the MNO may already find it commercially viable to build a network (e.g. the UK).
- **Appropriately specifying the obligation in detail (see Figure A4.18) is critical to the achievement of its objectives**—for example, in Ireland, where 37% of the population lives in rural areas,[106] a population coverage requirement greater than 63% would, in effect, oblige an MNO to provide services in rural areas in order to meet the licence obligation. In addition, specifying a high population coverage target in Ireland would require an MNO to extend mobile connectivity to significant parts of the country's landmass. For example, the simulation results (see section 5 of the main report) for a MBB 30Mbit/s service indicates that 90% population coverage would equate to 28% landmass coverage, whereas 99% population coverage would equate to a doubling of the landmass coverage to 59%.[107]

[105] In Sweden, PTS included a dynamic coverage obligation in the 800MHz auction of 2011 to oblige one licensee (Net4Mobility—a JV between Tele 2 and Telenor), to cover all homes and business identified by PTS. The identification of locations to be covered took place annually from 2011 and in this way, PTS implemented a dynamic coverage obligation based on specific needs in rural areas (i.e. no access to 1Mbit/s and requested coverage). In 2012, PTS identified 628 homes and companies businesses that would be offered coverage and this required Net4mobile to cover 472 addresses (i.e. 75% of 628) by the end of 2013.
[106] Census 2016, available from the Central Statistics Office, www.cso.ie, accessed 24 July.
[107] World Bank database, www.data.worldbank.org, accessed 24 July.

Figure A4.18 Coverage obligations specify a number of parameters



Source: Oxera.

- **It may not be necessary to attach coverage obligations to all of the licenses in an award**—if the MNO with the obligation rolls out coverage with the aim of meeting the target by the deadline, competition may incentivise other MNOs to deploy at a similar speed (e.g. Sweden, the UK). However, this may not have occurred in Denmark, where the MNO with the coverage obligation rolled out quicker than the others.
- **It is possible to design coverage obligations such that different areas of coverage can be assigned to different MNOs in an award**—this approach was successfully used in Denmark, although the end result of the auction was that the coverage obligation was placed on one MNO.
- **Setting the details of coverage obligations needs careful consideration**—due to risk of the obligations being set too high for some bidders or of them not being met in the future (e.g. Sweden).[108]
- **Regulators should (and are often legally obliged to) assess coverage obligations to ensure that any such obligations are objectively justified and proportionate**—with respect to ensuring the efficient use of the radio spectrum and that such obligations are achievable.[109]
- **Coverage obligations can be designed so that they do not deter new entrants**—for example, Austria would have applied different coverage obligations to new entrants, had any won spectrum.
- **A coverage obligation is usually static in time**—it does not adjust to the emergence of more pressing needs in terms of mobile connectivity (as it is defined in advance of the auction). Sweden is an exception to this; the regulator identified new homes and places of businesses to be covered as part of the obligation on an annual basis. However, the MNO in charge of

[108] In Sweden, Net4Mobility (a JV between Tele 2 and Telenor) failed to meet the coverage obligations as defined in their licenses, and the PTS defined a clear schedule for its future coverage obligations. It would therefore appear that the coverage obligations may have been too onerous for Net4Mobility. This might be because the specific addresses in the coverage obligations were set dynamically by the PTS on an annual basis following the auction or other practical considerations, such as the roll-out time required for Net4Mobility being too onerous for it.
[109] Most operators have met (or are on the way to meeting) their 800MHz coverage obligations, indicating that these coverage obligations seem achievable for operators, particularly where the roll-out is sufficiently long and the obligation itself is not excessive.

the mandatory coverage struggled to meet the coverage obligation, perhaps due to the dynamic requirements.

Overall, the benefits generated by the coverage obligations in each country highlight how the **coverage obligations should be designed around each country's characteristics—there is no 'one size fits all'**.

Next, we explore public subsidises.

A4.4 Public subsidies

This brief section summarises the public subsidies that have been used in the case study countries, and it is structured as follows:

- context, section A4.4.1;
- case study analysis, section A4.4.2;
- key observations, section A4.4.3.

A4.4.1 Context

Where the fixed costs of providing a service (i.e. sites, base stations, access to power, or other basic infrastructure) are large relative to the size of the market (i.e. potential demand is low and dispersed), MNOs may be unable to supply the service profitably or only able to do so at very high prices. When this problem arises, affected consumers may not have access to services. If the costs of providing mobile connectivity are outweighed by the benefits, then there would be a market failure (i.e. the market is not maximising total welfare, leading to an inefficient outcome). This market failure could be ameliorated through government intervention (subsiding the costs).

Not every market imperfection justifies public intervention. In many cases, intervening can create competitive distortions. Public subsidies usually occur in specific target areas, due to difficult geographic conditions and/or low density of the population and where MNOs do not plan to roll out such infrastructure in the near future. The implementation of any such schemes is subject to compatibility with State aid rules.

A4.4.2 Case study analysis

Below, we explore the use of public subsidies to increase mobile connectivity in the case study countries.

Austria

The Austrian government is targeting full coverage of ultrafast broadband by 2020, including rural and mountainous areas.[110] The government has implemented various schemes based on the proceeds from the 4G spectrum auction of 2013, known as 'the Broadband billion'.[111]

From 2015 onwards, several State aid programmes were implemented with the aim of bridging the digital gap between urban and rural areas. For example, the 'Access' programme is a funding instrument to stimulate investments in the extension of broadband access. The 'Backhaul' programme focuses on the

[110] The Austrian government's aim is to achieve 70% ultra-fast broadband coverage (defined as 100Mbps downstream) by 2018, coupled with 99% ultra-fast broadband coverage for all Austrian households by 2020.
[111] European Commission (2017), 'Digital Single Market Country Information—Austria', 22 June, https://ec.europa.eu/digital-single-market/en/country-information-austria, accessed 24 July.

modernisation of existing backhaul facilities to provide NGA network with sufficient capacity.[112] The funding programme is aimed at network investors willing to close the digital gap in poorly accessible areas. It supports the upgrade of existing connections based on copper, mobile radio base stations, and local coaxial networks by using fibre technology.

Denmark

The Danish government's primary focus has been on the roll-out of high-speed network infrastructure based on private investments, with public funding reserved for areas with poor broadband coverage. For example, State aid was introduced in 2013 for the island of Bornholm; later, the Broadband Fund (2016–19) was established as a nationwide aid measure. The latter programme encourages local municipalities and associations to aggregate citizen's demand to apply for financial assistance collectively.

The fund consists of a total of DKK200m (€27m) spread over four years, 2016 to 2019. This new initiative enables MNOs to construct networks where it has been previously commercially unviable to operate.[113] The allocation of the money is technology-neutral, which means that MNOs can use any technology to provide a better coverage.

The government has also used funding from the European Investment Bank (EIB) to support for 3G and 4G mobile connectivity in Denmark.[114] As the scheme also applied to Sweden, it is described below.

Finland

In 2015, the EIB helped improve the quality of mobile connectivity in Finland and Estonia through a €150m loan to support Elisa's investment in 4G LTE networks.[115] The project includes the replacement of all existing 3G nodes with multi-purpose nodes to increase the efficiency of the Finnish mobile networks. Elisa will invest the proceeds in underserved rural areas in particular.

In Finland, the EIB is expecting that this initiative will increase 4G coverage to 98% of the population (from 50%) and 3G high-speed data services coverage from 75% to 85% by the end of the project.[116]

Sweden

The Swedish government used funding from the EIB to support 3G mobile connectivity in Sweden.[117] In 2004, the EIB provided a loan of SEK1.8bn (€197m) to a Swedish industrial company, Investor AB for the construction of a 3G UMTS mobile connectivity project in Sweden and Denmark. This project was undertaken by a joint venture between Hutchison Whampoa and Investor

[112] Bundesministerium für Verkehr, Innovation und Technologie (2015), 'Breitband Austria 2020—Backhaul', December.
[113] Nexia International, 'Nordic Broadband City Index: How cities facilitate a digital future' November.
[114] European Investment Bank (2004), 'EIB support for 3G Mobile Communications Network in Sweden and Denmark', 21 April, http://www.eib.org/infocentre/press/releases/all/2004/2004-033-support-from-the-eib-for-3g-mobile-communications-network-in-sweden-and-denmark.htm, accessed 24 July.
[115] European Investment Bank (2015), 'EIB fosters high-speed mobile broadband services in Finland and Estonia', 6 October, http://www.eib.org/infocentre/press/releases/all/2015/2015-218-eib-fosters-high-speed-mobile-broadband-services-in-finland-and-estonia.htm, accessed 24 July.
[116] European Investment Bank (2016), '2015 Annual Report on EIB operations inside the EU: With the three pillar assessment methodology.'
[117] European Investment Bank (2004), 'EIB support for 3G Mobile Communications Network in Sweden and Denmark', 21 April, http://www.eib.org/infocentre/press/releases/all/2004/2004-033-support-from-the-eib-for-3g-mobile-communications-network-in-sweden-and-denmark.htm, accessed 24 July.

AB. The aim was to combine local market knowledge from Investor and 3G network experience from Hutchison.

In 2014, the EIB provided another SEK1.8bn (€193m) loan to Hutchison for the upgrading and expansion of its mobile network in Sweden and Denmark.[118] The operator rolled out the new 4G mobile network and upgraded the 3G mobile network in both countries.

The UK

The UK government targeted 95% coverage of 24Mbit/s connectivity by the end of 2017 through either fixed or MBB.

In 2013, the government introduced the Broadband Delivery UK (BDUK) scheme to support the development of fixed broadband and mobile networks.[119] This funding aimed to develop mobile coverage by combining central and local sources.[120]

As part of this programme, the central government invested £150m (€177m) to improve quality and coverage of mobile phone and basic data network services in 600 black spots. It also encouraged local authorities to match this funding using their own budget and external resources.

However, the implementation phase experienced several issues, such as the lack of accurate data on where the remote areas were, difficulties with planning permission, and local opposition. In February 2016, the government admitted that the programme was not a success as only a fraction of the planned budget was handed out and only 16 masts were erected in two years.[121] By the time the programme closed in March 2016, the government expected 60 masts to be erected (10% of the initial target).

In 2014, a new £10m (€12m) fund was made available to help superfast broadband reach remote communities via alternative technology providers, including those using 4G to deliver fixed wireless connectivity.[122]

A4.4.3 Conclusion

There are an increasing number of public subsidy schemes that aim to promote mobile connectivity. These can be large or small, depending on their scope, and can subsidise one (or more) MNOs or, indeed, infrastructure providers.

Governments can provide a public subsidy to an MNO through either direct funding or tax breaks (VAT exceptions, etc.). Public subsidies can also vary in their specificity—they can either define areas (that the MNO decides how to cover), or they define the precise location of subsidised sites to be built.

The case study countries have all deployed public subsidies to encourage greater mobile connectivity. These schemes vary in scope, ranging from

[118] European Investment Bank (2014), 'EIB fosters high-speed mobile broadband services in Sweden and Denmark', 4 April, http://www.eib.org/infocentre/press/releases/all/2014/2014-079-eib-fosters-high-speed-mobile-broadband-services-in-sweden-and-denmark.htm, accessed 24 July.
[119] Department for Digital, Culture, Media, and Sport, 'Broadband Delivery UK', https://www.gov.uk/guidance/broadband-delivery-uk, accessed 24 July.
[120] European Commission (2017), 'Digital Single Market Country Information—United Kingdom', 22 June, https://ec.europa.eu/digital-single-market/en/country-information-united-kingdom, accessed 24 July.
[121] Hansard (2016), 'Mobile Infrastructure Project', 10 February.
[122] Department for Digital, Culture, Media & Sport (2014), 'New Broadband Chief as final 5% of most remote areas in Britain tackled', 15 January, https://www.gov.uk/government/news/new-broadband-chief-as-final-5-of-most-remote-areas-in-britain-tackled, accessed 24 July.

schemes targeted at improving backhaul to those aimed at building specific base stations in black spots. The mechanisms also vary, with loans from the EIB used in some countries. When designing a public subsidy, it is important to consider the factors described in Figure A4.19.

Figure A4.19 Parameters of public subsidies

Type of funding:	Beneficiary:	Target:	Tools:
subsidies, grant, loan	one vs. several operators, a joint-venture	flexibility vs. specific network elements (e.g. backhaul)	frequency and technology that can be used

Source: Oxera.

Public subsidies, however, come with risks for government. In particular, governments need to ensure compliance with the State aid rules, which may require a formal State aid notification to the European Commission.

The next section explores the impact of mobile network sharing (including spectrum sharing) on coverage.

A4.5 Mobile network sharing

This section explores mobile network sharing. We henceforth take spectrum sharing to be a category of mobile network sharing.

A4.5.1 Context

Mobile network and/or spectrum sharing can, in certain instances, help to achieve greater mobile connectivity, as certain MNOs, where appropriate, can share the costs of building and running mobile networks (i.e. CAPEX and OPEX).

Such cost reductions can speed up network roll-out and extend final network coverage to areas that would otherwise be unprofitable to serve on a stand-alone basis. This is because less potential revenue is needed to build a site if the costs of that site have been shared with another MNO.

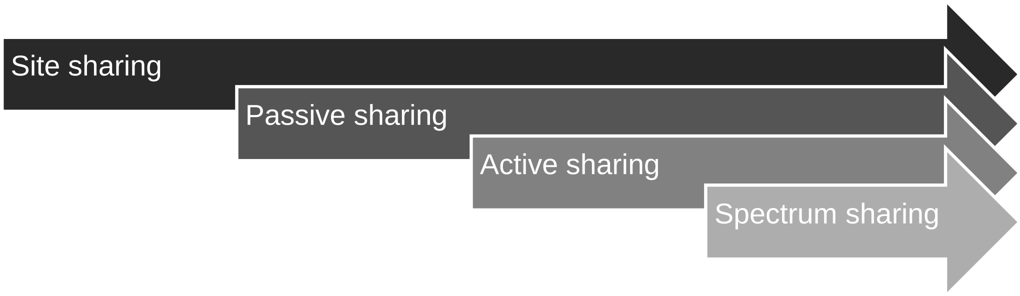
Different degrees of network sharing

There are different levels of infrastructure sharing, as shown by Figure A4.20. Greater degrees of network sharing can increase the cost savings, but they can also raise competition issues/concerns—if, for example, it is believed that such sharing would negatively affect competition and lead to higher prices and/or reduced quality for consumers.[123] Such issues should be judged on a case-by-case basis.

Even though there are potential competition problems, network sharing agreements can be observed in many member states, as shown by the case study analysis. There is a continuum between the degrees of network sharing with grey areas between the categories—significant variation exists in the exact nature of passive or active sharing—but Figure A4.20 provides a useful taxonomy with which to start.

[123] European Commission (2008), 'Consolidated version of the Treaty on the Functioning of the European Union—Part Three: Union policies and internal actions—Title VII: Common rules on competition, taxation and approximation of laws—Chapter 1: Rules on competition—Section 1: Rules applying to undertakings—Article 101 (ex Article 81 TEC)', Official Journal 115 , 09/05/2008 P. 0088—0089.

Figure A4.20 Different degrees of mobile network sharing



Source: Oxera.

Network sharing typically occurs between two MNOs, but it can involve multiple MNOs. The four degrees of network sharing are as follows, although the precise scope for differentiation should be judged on a case-by-case basis.[124]

- **Site sharing**—MNOs share sites but not the physical infrastructure on the sites, such as masts or cabinets. This reduces certain costs (e.g. site rental costs might be split between the operators). The core network and spectrum are not shared, resulting in significant scope for service differentiation between the sharing MNOs. Much of the ability of MNOs to differentiate their services comes from having separate core networks.
- **Passive sharing**—MNOs share sites and the physical infrastructure (masts, cabinets). The sharing of some operating costs, such as the cost of air conditioning cabinets, is also often shared under passive sharing. Antennas are sometimes shared under passive sharing. Passive sharing typically reduces costs through lower CAPEX (e.g. site build costs) and lower OPEX (e.g. lower electricity and maintenance costs). The core network and spectrum are not shared, resulting in significant scope for service differentiation between the sharing operators.
- **Active sharing**—also known as 'MORAN sharing',[125] where MNOs share active network equipment in addition to passive network sharing. Active network equipment typically includes antennas, the radio station, and any other network equipment directly involved in the transportation of data traffic on the site. Active sharing reduces CAPEX (less equipment needs to be installed) and OPEX (lower electricity and maintenance costs). The core network and spectrum are not shared, resulting in significant scope for service differentiation between the sharing MNOs.
- **Spectrum sharing**—MNOs share spectrum in addition to active network sharing. Spectrum sharing, also known as spectrum pooling, is where MNOs do not separately utilise their own spectrum holdings. Spectrum sharing reduces the cost of building and running the networks and also enables the operators to use wider spectrum blocks. Wider spectrum blocks result in greater speeds and capacity (although this may be offset by the greater number of customers, especially in urban areas). Spectrum sharing may also be more commercially attractive in areas where the parties have similar levels of traffic (or else one operator may benefit more from the pooling of spectrum resources than the other). Spectrum sharing need not

[124] This study focuses on existing network sharing arrangements, but the opportunities for mobile network sharing may increase with the development of 5G (for example, network slicing and infrastructure as a service). See LS Telecom for NIC (2016), '5G Infrastructure Requirements in the UK', 12 December, p. 96.
[125] Multi-operator radio access network sharing.

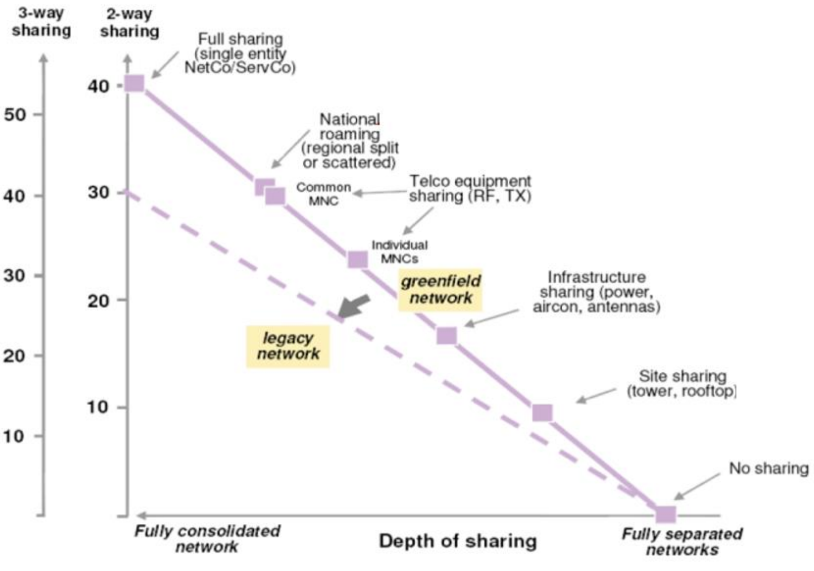
involve core network sharing, and where the core network is not shared, there is greater scope for service differentiation between the MNOs.[126] However, in some cases, the reduced scope for differentiation from shared spectrum can lead to regulatory concerns (e.g. the Austrian regulator's concerns about spectrum sharing, see section A4.5.2).

Network sharing agreements can be based on different types of geographic split. For example, an active network sharing agreement between two MNOs could split the country in half, with each MNO running the network in half the country. Alternatively, a site sharing agreement between two MNOs could be based on each MNO sharing their existing sites, with both MNOs running nationwide networks. In general, network sharing agreements can be limited to certain areas of a country, as long as those areas are well-defined and are large enough to generate the savings required to make sharing commercially viable.[127]

The likelihood of a network sharing agreement being commercially viable depends on the extent to which the MNOs involved have similar spectrum holdings, networks, or roll-out ambitions, and whether the MNOs use the same equipment vendors. In the case of spectrum sharing, it may be more commercially attractive in areas where the parties have similar levels of traffic (or else one MNO may benefit from the pooling of spectrum resources more than the other).

The magnitude of cost savings from network sharing are highly context-dependent and are a function of existing network design.[128] Figure A4.21 gives one MNO's estimates of the cost savings from network sharing.

Figure A4.21 Cost savings from network sharing (% of costs)



Note: The savings are generally less for legacy networks due to the cost of decommissioning existing sites and more limited opportunities to share features and functionalities.

[126] Models of spectrum sharing are sometimes called multi-operator core network (MOCN) sharing, as they can involve sharing of certain core network elements.
[127] Active network sharing agreements also often seek to minimise the length of boundaries between those areas run by different MNOs. When a user crosses a boundary (from part of the network run by one operator, to the part of a network run by another operator) there is a 'handover' from one network to the other. These handovers tend to reduce the quality of mobile connectivity experienced by the user.
[128] Kibilda, J., Kaminski, N. J. and DaSilva, L. A. (2017), 'Radio Access Network and Spectrum Sharing in Mobile Networks: A Stochastic Geometry Perspective', 6 February.

Source: Vodafone (2009), 'Network sharing in Europe', June. Cited in BEREC and RSPG (2011), 'Report on infrastructure and spectrum sharing in mobile/wireless networks', June.

Next, we explore why network sharing can attract the attention of regulation and competition authorities.

Regulatory concerns with network sharing

While network sharing can help reduce costs, they can also raise potential competition concerns. Therefore, any assessment of a network sharing arrangement requires a case-by-case consideration, taking into account the specifics of the arrangement and other relevant factors (e.g. market-specific factors).[129]

Regulatory concerns around network sharing usually relate to one or both of the following.

- **Reducing the ability/incentives of MNOs to differentiate their network quality—**to what extent would the network sharing reduce the scope for offering different network quality? As discussed above, in general site sharing, passive sharing, and active sharing allow for service differentiation (particularly as the core network is not shared).
- **Sharing of commercially sensitive information between competitors—** could network sharing allow for sharing of commercial secrets? For example, would the network sharing arrangement involve MNOs getting prior warning of investment plans? The concern is that this may act to reduce network investment (in the absence of competitive pressure from MNOs not party to the network sharing agreement) or facilitate collusion. This concern can be addressed by adopting an appropriate corporate governance mechanism for the network sharing agreement with, for example, the entity implementing the network sharing agreement acting as an independent company.

In order to assess these concerns, reports from the likes of BEREC/RSPG provide some helpful guidelines on the sort of criteria that should be considered when assessing possible distortion of competition from network sharing agreements. As stated by the BEREC/RSPG, these criteria: '[…] do not, however, constitute a "checklist" which can be applied mechanically. Each case must be assessed on the basis of its own facts.' Such criteria include the following:[130]

- whether sharing agreements are unilateral (one MNO agrees to provide access to another), bilateral (two MNOs agree to provide mutual access), or multilateral (several MNOs agree on terms on which they will provide access to each other)—there may be a concern if all MNOs in a market share the same network, as they would then face limited external competitive pressure to improve the network;
- the geographic scope of the sharing agreement (one site, several, or all sites in a certain region or the territory of a member state, international);

[129] Through the lens of ex post competition law (i.e. the framework laid out by Article 101 of the TFEU).
[130] BEREC and RSPG (2011), 'Report on infrastructure and spectrum sharing in mobile/wireless networks', June, p. 9–10.

- the impact on the competitive situation in the concerned markets before and after the sharing agreement (does the agreement affect important competition parameters such as coverage, prices, and network quality?);
- whether the MNOs involved in the sharing agreement keep their independent control over the radio planning and the freedom to add sites;
- whether the MNOs are enabled to conclude similar agreements with other parties (no exclusivity clauses);
- whether it is ensured that the exchange of information between the parties is limited to what is strictly necessary for the purpose of the sharing agreement and does not extend to the exchange of confidential business information;
- whether the MNOs retain the ability to differentiate themselves in terms of prices and quality and variety of services;
- whether the independence of a MNO is prejudiced (where the emphasis would be on avoiding collusive behaviour).

The BEREC/RSPG conclude that antitrust enforcement is likely to focus on assessing whether the parties involved in an infrastructure sharing agreement keep their independent control over important competition parameters and remain full competitors in all aspects. Furthermore: [131]

> In their assessment, competition authorities will probably also have to balance anti-competitive concerns, if any, with positive effects on competition, as for instance increased incentives for network roll-out and more competition on services.
>
> Nowadays, in almost all European countries sharing is encouraged, provided that this is not detrimental to competition, on the grounds of, inter alia, efficient use of resources, environmental and health protection issues and coverage.

Despite the potential regulatory concerns, we note that some form of network sharing (active and passive) takes place in all five case study countries. The form of sharing that is perhaps the most contentious (in terms of its implications for competition) is spectrum sharing, which occurs in three out of five of the case study countries.

According to Huawei, active sharing is the most common form of sharing across Europe:[132]

> In Europe, the region with most shared networks this far, MORAN is used in most cases. The main reasons for this are restrictions on spectrum sharing and operators' preference for keeping some degree of independence on RAN level. MOCN [spectrum sharing with a shared core network] is the preferred solution in particular in the Nordic countries. One reason for this could be that the regulators in the Nordic countries have the view that as long as there is full competition between the operators in the retail side of the business, there is no need to restrict the extent of network infrastructure and spectrum sharing.

We also note many European regulators have taken actions to facilitate the functioning of network sharing arrangements. For example, the Swedish regulator allowed the MNOs to transfer spectrum rights to a joint venture, and the UK regulator granted specific powers to a joint venture in order to reduce

[131] BEREC and RSPG (2011), 'Report on infrastructure and spectrum sharing in mobile/wireless networks', June, p. 11.
[132] Huawei Technologies Co., LTD (2015). 'Network Consolidation Cooperation for Business Success', p. 8.

obstacles to network roll-out. Similar to Ireland, joint bidding for spectrum at auction was allowed by the Danish and Swedish regulators.

A4.5.2 Case study analysis

Network sharing agreements in the five case study countries exhibit differences that go beyond the distinctions between active and passive sharing. In particular, countries like Sweden and Denmark have seen auctions where MNOs have jointly bought spectrum through a third entity (e.g. a joint venture).

Furthermore, where sharing agreements exist, they may not be the same for all mobile network technologies. For example, the MBB Network Limited (MBNL) arrangement in the UK between EE and Three involves active sharing of 2G and 3G technologies but passive sharing of 4G technology. Table A4.6 summarises some of these differences for the case study countries.

Table A4.6 Mobile network sharing in case-study countries

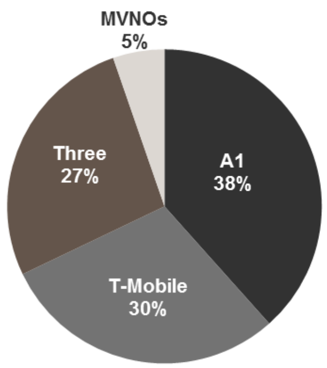
	# of MNOs	Joint bidding for 800MHz	Passive sharing	Active sharing (2G, 3G)	Active sharing (4G)	Spectrum sharing
Austria	3	×	✓	✓	×	×
Denmark	4	✓	✓	✓	✓	✓
Finland	3	×	✓	✓	✓	✓
Sweden	4	✓	✓	✓	✓	✓
UK	4	×	✓	✓ (for both agreements)	✓ (one of the two agreements)	×

Source: Oxera.

Austria

Following the acquisition of Orange by Three (owned by Hutchison), Austria has three MNOs—Three, T-Mobile Austria, and Telekom Austria (A1). A1 is the largest MNO, with 38.4% of the market, followed by T-Mobile, with 29.5%, and Three, with 26.8%.[133] The remaining market share is made up of MVNOs, including Lycatone and Vectone, as shown in Figure A4.22.

Figure A4.22 Retail mobile market shares in Austria



Source: Regulatory Authority for Broadcasting and Telecommunication (2016), 'RTR Telekom Monitor Annual Review 2016'.

[133] Regulatory Authority for Broadcasting and Telecommunication (2016), 'RTR Telekom Monitor Annual Review 2016'.

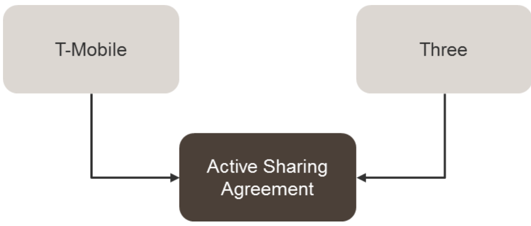
Under Article 8 (Part 2) of the Austrian Telecommunications Act, owners or other authorised users of an antenna masts or high-voltage masts must permit joint use by public communications network operators, fire brigades, rescue services, and police authorities where technically feasible. As stated by the European Commission:[134]

> In Austria, there are no statutory requirements or licence conditions which would mandate MNOs to share sites. There is, however, a right under Section 8(2) of the TKG for an MNO to require another MNO to share individual sites on request, which can only be refused on grounds of a lack of technical or commercial feasibility. The requesting MNO has to pay a fee of EUR 30 000 for the initial 8 years of sharing, with an additional fee depending on the dimension of the antenna. Whilst site sharing is encouraged by the authorities, with several regional authorities requesting MNOs to increase their site sharing ratio and to deconstruct redundant greenfield masts, any request for site sharing between MNOs will, however, be subject to the various planning, landlord and other approvals.

The TKK approaches each network sharing agreement on a case-by-case basis and has set out guidelines for assessments in a position paper.[135] This outlines that 'the TKK generally assumes that mutual spectrum sharing does not ensure sufficient competitive differentiation between the cooperation partners', but adds that spectrum sharing would be permitted 'in exceptional cases in those areas where coverage is desirable, but not reasonable from a business standpoint for technical or economic reasons', such as road tunnels. The TKK also clarifies that one MNO cannot use the frequencies of another in order to meet its coverage obligations—spectrum sharing would only be allowed 'in those areas which go beyond the minimum required coverage level'.[136]

There is an active sharing arrangement between T-Mobile and Three, allowing T-Mobile to offer 3G to its customers in rural areas while enabling Three to access the 2G networks of T-Mobile.[137]

Figure A4.23 Mobile network sharing agreements in Austria



Source: Oxera.

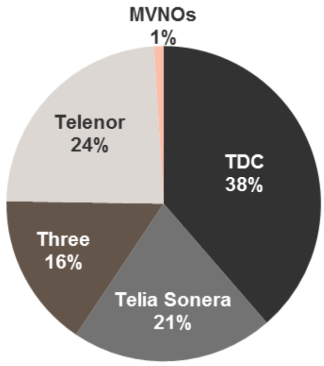
There is no evidence of network sharing agreements covering LTE services in Austria.

Denmark

[134] European Commission (2012), 'Case No COMP/M.6497—HUTCHISON 3G AUSTRIA/ORANGE AUSTRIA', 12 December.
[135] TKK (2011) 'Position Paper on Infrastructure Sharing in Mobile Networks', 4 April 2011.
[136] Ibid.
[137] CMS (2014), 'CMS Network Sharing Study 2014: The 4G race—catching up or falling behind?', September.

Denmark's market has four MNOs—TDC, TeliaSonera, Three and Telenor. As of June 2016, the incumbent TDC held 38% of the retail mobile market, followed by Telenor, TeliaSonera, and Three.[138] This is shown in Figure A4.24.

Figure A4.24 Retail mobile market shares in Denmark

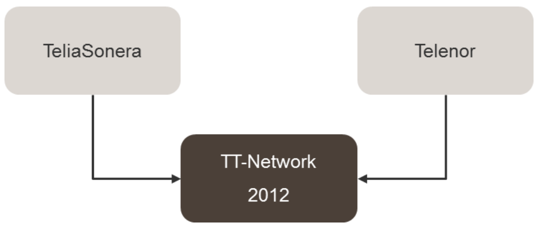


Source: Telenor Group (2016), 'Telenor Denmark Update'.

In 2012, TeliaSonera and Telenor jointly bid for spectrum under the entity TT-Network, purchasing 2 x 10MHz of 800MHz spectrum at the lower end of the band for DKK111m (€15m). The remaining 2 x 20MHz was purchased by TDC for DKK628m (€84m).

The auction also allowed participants to bid for regional exemptions from coverage obligations of providing average download access speeds of 10Mbps outdoors in three regions identified by the regulator. TT-Network won these exemptions in all three regions—the coverage obligations were borne entirely by TDC.

Figure A4.25 Mobile network sharing agreements in Denmark



Source: Oxera.

TT-Network is an active network sharing agreement that involves both RAN and spectrum pooling in the 800MHz and 1.8GHz bands. It covers 2G, 3G, LTE, and potentially LTE-A technology, covering the entire Danish landmass. There is no sharing of core networks under this agreement.

The Danish Competition Authority (DCC) found that the proposed arrangement would be beneficial for consumers through increased coverage and efficiency (despite competition concerns).[139] The two MNOs offered commitments that addressed each of these concerns, leading to the DCC approving the sharing agreement. More detail is provided in Table A4.7.[140]

[138] Telenor Group (2016), 'Telenor Denmark Update', 29 February.
[139] Danish Competition and Consumer Authority (2012), 'Radio Access Network sharing agreement between Telia Denmark A/S and Telenor A/S', 29 February, https://www.en.kfst.dk/nyheder/kfst/english/decisions/20120229-radio-access-network-sharing-agreement-between-telia-denmark-and-telenor/, accessed 7 August 2017.
[140] European Competition Network (2012), 'Denmark: Network Sharing Agreement in Danish Mobile Telecommunications Sector', May.

Table A4.7 Competition concerns and commitments over TT-Network

	Concern	Commitment
1	The agreement may increase the risk of a collusive outcome on the wholesale market for mobile telephony and mobile broadband in Denmark.	The parties will accept all requests from wholesale customers to buy mobile telephony and mobile broadband on customary and market conditions.
2	The tariff structure initially chosen by the parties to recover the joint venture's costs from the parties may change the underlying cost structure of the Radio Access network compared to the situation before the agreement in a way that converts fixed costs into variable costs. This can reduce the parties' incentives to compete and attract new customers.	The parties will pay the commonly owned joint venture for its supply of Radio Access capacity according to a tariff structure that at all times reflects the underlying cost structure of the Radio Access network.
3	The parties may obtain a joint amount of frequency resources that in the long term significantly exceeds that of the competing operators.	In the future, the parties (TeliaSonera and Telenor) are obliged to buy frequency licenses in common (through the joint venture).
4	The parties will reduce the number of antennas and masts in their common Radio Access network, which may create coverage problems for competitors that rent antenna positions on the parties' masts.	The parties are obliged to sell or let the antenna sites that prove to be superfluous to any interested player on the market.
5	The agreement increases the risk of exchange of commercially strategic information that exceeds the sharing of data necessary for the joint production of the goods subject to the network sharing agreement.	The parties adopt a set of limitations as to who can be appointed as member of the Board, as part of the Management and as employees of the joint venture, as well as to the information that may be exchanged within the joint venture and between the joint venture and the parties, etc. The joint venture shall at any time and upon request from the DCCA forward copies of the information exchanged within the Board or between employees in the joint venture and a party.
6	The agreement reduces competition on significant parameters such as coverage and the development and spread of new technology (LTE, LTE-Advanced). This is due to the fact that these parameters are solely defined in the Radio Access network. The agreement implies that the parties' respective Radio Access networks are integrated and the parties' mobile coverage and supply of mobile technologies will thus become identical.	While not a commitment, the parties did give the DCC sufficient proof that this last concern did not constitute grounds for action.

Source: Danish Competition and Consumer Authority (2012), 'Radio Access Network sharing agreement between Telia Denmark A/S and Telenor A/S', and European Competition Network (2012), 'Denmark: Network Sharing Agreement in Danish Mobile Telecommunications Sector', ECN Brief May 2012.

Impact of network sharing on mobile connectivity in Denmark

The European Commission measures coverage as of June 2016 to be close to 100%. TDC claimed that it had reached 70% coverage by the end of 2013 and 98% by the end of 2014.[141] Compared to TDC, TT-Network seems to have

[141] TDC 2014 annual report.

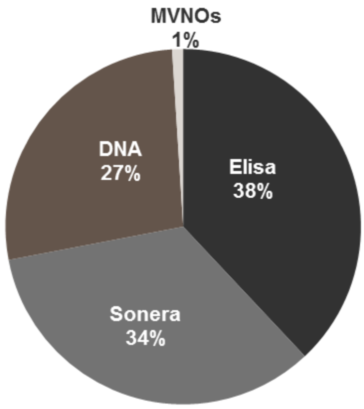
achieved slower roll out speeds, reaching 94% 4G population coverage at the end of 2015.[142] The cause of this slower 4G roll-out by TT-Network is not clear.

The Danish auction for 800MHz spectrum is an interesting example of the interactions between auction design, coverage obligations, and sharing agreements. The number of bidding candidates was reduced by TT-Network's joint bid. The auction results also suggest non-linearities in the valuation of spectrum, with TT-Network paying DKK111m (€14.9m) for the 2 x 10MHz block with no coverage obligations and TDC paying DKK628m (€84.4m), almost six times that, for a 2 x 20MHz block with coverage obligations in all the 207 postcodes identified by the regulator. This is possibly a combination of TDC's desire to avoid the bottom band while simultaneously securing a contiguous block of spectrum. Three, the fourth MNO, won no spectrum in this auction.

Finland

The Finnish mobile market is characterised by three MNOs who collectively hold more than 98% of the retail market, as shown in Figure A4.26.[143] Elisa is the leader, with 38% mobile retail market share.

Figure A4.26 Retail mobile market shares in Finland



Source: Communications Regulatory Authority (2017), 'Market shares of mobile subscriptions.'

Unlike in Sweden and Denmark, the MNOs in Finland did not bid jointly for spectrum in the 800MHz auction. A sharing agreement called 'the Finnish Shared Network', was formed after the auction between DNA and Sonera.

The two operators made commitments[144] to the Finish Competition and Consumer Authority (FCCA), before the network sharing agreement was approved, namely that the operators would:

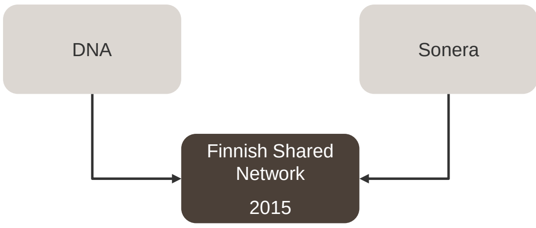
- offer virtual and service operators access to their national networks and rent out mast and equipment location sites to competitors;

[142] TeleGeography (2014), 'Telenor Denmark outlines LTE plans for 2015', 17 November, https://www.telegeography.com/products/commsupdate/articles/2014/11/17/telenor-denmark-outlines-lte-plans-for-2015/, accessed 24 July.
[143] Finnish Communications Regulatory Authority (2018), 'Market shares of mobile subscriptions', 7 March, https://www.viestintavirasto.fi/en/statisticsandreports/statistics/2013/marketsharesofmobilesubscriptions.html, accessed 24 July.
[144] Finnish Competition and Consumer Authority (FCCA) (2015), 'FCCA´s decision ensures consumers benefit from network partnership between DNA and Sonera', 5 November, https://www.kkv.fi/en/current-issues/press-releases/2015/5.11.2015-fccas-decision-ensures-consumers-benefit-from-network-partnership-between-dna-and-sonera/, accessed 24 July.

- restrict information exchange; and,
- be able to bring their preferred network features or additional capacity to the joint network (therefore being able to offer competing services).

The fact that the network only covers half of the country was considered as a relevant factor in FICORA's decision. FICORA was also required to facilitate network sharing by making changes to the operator's licences.[145]

Figure A4.27 Mobile network sharing agreements in Finland



Source: Oxera.

The Finnish Shared Network covers 50% of Finland's landmass. Specifically, the agreement helps increase coverage in the sparsely populated Northern and Eastern parts of the country, where 15% of the country's population lives.[146] The agreement takes the form of RAN sharing, and two blocks of 2 x 10MHz spectrum in the 800MHz band is pooled. This helps the MNOs increase 4G coverage, speed, and capacity, while the core network is excluded from the agreement. Sharing is not mandated by the Finnish regulator.[147]

Impact of network sharing on mobile connectivity in Finland

FICORA estimated that LTE coverage in July 2015 had reached 95% of the country's population, with the European Commission estimating 4G coverage at 100% in June 2016, with rural LTE coverage also at 100%.[148, 149]

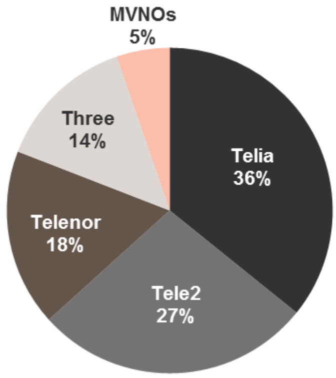
It is perhaps too early to fully judge the success of the Finnish Shared Network, as construction was only completed at the end of 2016. However, the MNOs have cited efficiency savings in delivering higher speeds as a motivation behind the network.

Sweden

Sweden's mobile market has four MNOs, providing services to 95% of all customers in the country. As shown in Figure A4.28, Telia is the largest MNO, with 35.8% of the market, followed by Tele2, Telenor, and then Three.[150] The rest of the retail market is made up of MVNOs.

[145] FICORA (2015), 'FICORA Annual Report 2015'.
[146] Although, as noted in section 6, the road network in these areas is not yet fully covered.
[147] Finnish Communications Regulatory Authority (2013), 'Mobile network coverage', https://www.viestintavirasto.fi/en /internettelephone/functionalityoftelephoneandbroadbandsubscriptions/mobilenetworkcoverage.html, accessed 24 July.
[148] Finnish Communications and Regulatory Authority (2015), 'The Taajuustalkoot (Free Frequency Help) service removes disruptions caused by 4G networks in antenna television', https://www.viestintavirasto.fi/en/tvradio/broadcastingandreception/terrestrialtv/interferencecausedbythe4gnetwork.html, accessed 24 July.
[149] European Commission (2017), 'Broadband Coverage in Europe 2016: Mapping progress towards the coverage objectives of the Digital Agenda', 21 September.
[150] PTS (2016), 'Swedish Telecommunication Report 2016'

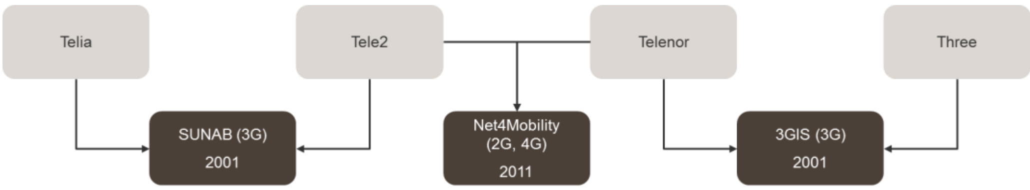
Figure A4.28 Retail mobile market shares in Sweden



Source: Post and Telecom Authority (2016), 'Swedish Telecommunication Report 2016'.

There are three network sharing agreements in Sweden, of which two are for 3G services—3GIS (between Three and Telenor) and SUNAB (a joint venture between Telia and Tele2). In 2009, Net4Mobility, a 50/50 joint venture between Tele2 and Telenor, was announced with the mission of assisting the roll-out of LTE services in Sweden. Both SUNAB and Net4Mobility were approved by the national competition authority at the time.[151]

Figure A4.29 Mobile network sharing agreements in Sweden



Source: Oxera and Markendahl, Ghanbari and Molleryd (2013), 'Network Cooperation Between Mobile Operators—Why And How Competitors Cooperate?'.

Net4Mobility is an active network sharing agreement in the 800MHz, 900MHz, 1.8GHz, and 2.6GHz bands, involving both 2G and 4G technology. There is active RAN sharing as well as some spectrum pooling.[152] Following the approval by the competition authority for the Net4Mobility joint venture in 2010, Net4Mobility won 800MHz spectrum in 2011. In 2012 the Swedish regulator, the PTS, permitted Tele2 and Telenor to transfer their licences in the 2.6GHz band and some of their licences in the 900MHz band to Net4Mobility. The PTS identified that Net4Mobility would help provide better coverage and greater capacity. The PTS saw no reason to prohibit the transfer of licences from taking place on grounds of either competition or the risk of lower spectrum efficiency, adding that it would give consumers better access to both GSM and LTE services.[153]

In 2011, Tele2 and Telenor jointly bid for spectrum under the Net4Mobility entity in the 800MHz auction. Net4Mobility won 2 x 10MHz for SEK469m (€52.5m), along with a further coverage commitment to spend an additional SEK300m (€34m). Telia, the country's largest operator, and Three, the smallest, also purchased 2 x 10MHz each for SEK854m (€96.5m) and

[151] Cullen International (2017), 'Mobile network sharing: facilitating deployment of mobile broadband', 6–7 April.
[152] Analysys Mason (2014), 'Network sharing: winning approaches and strategies'.
[153] PTS (2012). 'PTS allows assignment of radio licenses to Net4Mobility', https://www.pts.se/sv/Nyheter/Radio/2012/PTS-medger-overlatelse-av-radiotillstand-till-Net4Mobility/, accessed 24 July.

SEK431m (€48.7m) respectively. Telia's licence did not come with a coverage obligation, and the disparity in bids could reflect each MNO's evaluation of the net costs of coverage obligations.

Another possibility regarding the disparity of bids is the 'Edge Effect', where the dynamics of the auction process used by Sweden make the central block purchased by Telia more valuable for strategic reasons, as it increases the probability of purchasing spectrum in a continuous band.[154] While Three's licence also did not include coverage obligations, there were technical usage restrictions to prevent interference with television channels.

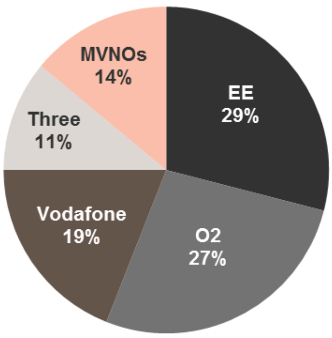
Impact of network sharing on mobile connectivity in Sweden

Sweden has high levels of 4G coverage, and Net4Mobility provides 99.9% population 4G coverage (May 2017)[155] (see section A4.3.2). However, in 2015, PTS reported that Net4Mobility had failed to meet some of the coverage obligations as defined in their licences.[156] It would therefore appear that the coverage obligations may have been too onerous. This might be because the coverage obligations were set dynamically on an annual basis following the auction, or it might be due to other practical considerations, such as the roll-out time required for Net4Mobility (a joint venture between Tele 2 and Telenor) being too onerous. As set out in section A4.2.4, the PTS provided a new schedule for coverage upon the failure of Net4Mobility to meet some of the original obligations.

The UK

The UK has four MNOs that control around 85% of the market, as shown in Figure A4.30. EE is the largest MNO, with 29% of all retail subscriptions, followed by O2 (including their wholly owned MVNO service, GiffGaff), Vodafone (including their wholly owned MVNO service, Talkmobile), and then Three. The remaining 14% of the market is held by MVNO's, including Tesco Mobile, Virgin Mobile, Lycamobile and Lebara.[157]

Figure A4.30 Retail mobile market shares in the UK

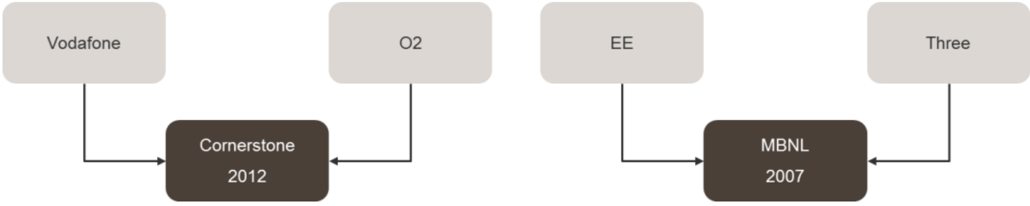


Source: Ofcom (2016), 'The Communications Market 2016'.

[154] ComReg (2011), 'Award of 800MHz, 900MHz and 1800MHz Spectrum—Further Update Report on Benchmarking', 24 August.
[155] Telecompaper (2017), 'Net4Mobility grid covers 90% of Sweden, 99.9% of population', 11 May, https://www.telecompaper.com/news/net4mobility-grid-covers-90-of-sweden-999-of-population--1195584, 24 July.
[156] PTS (2015), https://www.pts.se/sv/Nyheter/Radio/2015/PTS-forelagger-Net4Mobility-om-att-uppfylla-tackningskrav-i-800-MHz-bandet/, accessed 24 July.
[157] Ofcom (2016), 'The Communications Market 2016'.

The United Kingdom has two network sharing arrangements—Cornerstone, which is between Vodafone and O2, and MBNL, which is between EE and Three.

Figure A4.31 Mobile network sharing agreements in the UK



Source: Oxera.

The Cornerstone arrangement has both active and passive elements, with the companies agreeing to share RAN and consolidate the existing sites and passive infrastructure through a joint venture. Under the agreement, each operator is responsible for roughly 50% of the country's landmass and population. Vodafone covers the West of England, Wales, and South London, while O2 covers the East of England, Northern Ireland, Scotland, and North London. Unlike Sweden, the active sharing component of this arrangement is limited to RAN sharing with no sharing of spectrum.[158] As of July 2017, Cornerstone was 79% complete, and it was expected to be 99.9% complete by the end of December.[159]

The Office for Fair Trading (OFT) assessed the proposed Cornerstone agreement in 2012 and decided not to refer it to the Competition Commission as it would not lead to a substantial lessening of competition.[160] In 2017, Ofcom made it easier for Cornerstone to build infrastructure by granting it 'Code powers'.[161] These powers mean that Cornerstone may:

- construct and maintain infrastructure on public land (streets) without needing to obtain a specific street works licence to do so;
- benefit from certain immunities from the Town and Country Planning legislation;
- apply to the Court in order to obtain rights to execute works on private land in the event that agreement cannot be reached with the owner of that land.

The MBNL arrangement between Three and EE involves active RAN 3G sharing and passive (but not active) 4G sharing.

Only one licence in the 800MHz spectrum auction of 2013, purchased by O2, stipulated a coverage obligation (2Mbit/s indoor for 98% of the population by the end of 2017).[162]

[158] OECD Committee on Digital Economy Policy (2015), 'Wireless Market Structures and Network Sharing', 8 January.
[159] TeleGeography, (2017), 'Vodafone UK and O2 UK expect to have finished mast sharing project by 2018', 10 July, https://www.telegeography.com/products/commsupdate/articles/2017/07/10/vodafone-uk-and-o2-uk-expect-to-have-finished-mast-sharing-project-by-2018/, accessed 24 July.
[160] Office for Fair Trading (2012), 'Anticipated joint venture between Vodafone Limited And Telefónica UK Limited', ME/5556/12. The OFT's decision on reference given on 28 September 2012. Full text of decision published 11 October 2012.
[161] Ofcom (2017), 'Proposal to apply Code Powers to Cornerstone Telecommunications Infrastructure Limited', 25 May, https://www.ofcom.org.uk/consultations-and-statements/category-3/cornerstone-code-powers, accessed 24 July.
[162] Ofcom (2015),' Ofcom varies mobile operators' licences to improve coverage', 2 February, https://www.ofcom.org.uk/about-ofcom/latest/media/media-releases/2015/mno-variations, accessed 24 July.

Impact of network sharing on mobile connectivity in the UK

Ofcom estimates that current coverage for all four of the UK's operators is at similar levels. It is not clear that the coverage obligation has resulted in O2 having greater population coverage than the other MNOs (see Table A4.8), although O2 may have greater coverage than it would have done in the absence of the coverage obligation. It is not clear which of the Cornerstone or MBNL agreements resulted in the quickest 4G roll-out. It is also unclear which agreement led to the greatest cost savings, but in general we would expect that active sharing generates to greater cost savings than passive sharing (which one would then expect to be passed on, at least in part, to consumers).

Table A4.8 LTE population coverage in the UK (2016)

	Vodafone	O2	EE	Three
Indoor LTE coverage	83%	88%	89%	84%
Outdoor geographic LTE coverage	56%	52%	64%	55%

Source: Ofcom (2016), 'Connected Nations 2016', 16 December.

The European Commission estimates UK overall coverage to be 99.5% of premises and rural coverage to be 95.3% of premises.[163]

4G coverage is also influenced by the pre-existing levels of infrastructure, which may have varied between the operators. EE was able to roll out its LTE network more quickly than its rivals by using existing spectrum before the auction of the 800MHz band.[164] This allowed it to establish an early advantage.

A4.5.3 European outcomes

This section summarizes the role played by mobile network sharing in Europe beyond the case study countries.

Four EU 28 countries did not have any 4G network sharing agreements implemented prior to or during 2016: Belgium, Croatia, Luxembourg, and Slovakia.

Oxera analysed the outcome of 4G mobile network sharing in seven European countries for which information was readily available.[165] All the 4G network sharing agreements in the seven countries are between two MNOs. Sweden is the only case study excluded from this analysis as the coverage obligation is defined in terms of postcodes rather than population, making a comparison more difficult.

It is difficult to tell from Figure A4.32 whether MNOs that take part in mobile network sharing have greater coverage than they would have done otherwise. In some countries, the members of network sharing agreements have higher 4G coverage than other MNOs (e.g. Germany), while in other countries they do not (e.g. Denmark).

One observation we can make from the figure is that the members of a network sharing agreement do not always have the same level of 4G coverage (for example, EE and Three in the UK). This suggests that mobile network sharing does not necessarily remove competition over mobile coverage between the

[163] European Commission (2017), 'Broadband Coverage in Europe in 2016: Mapping progress towards the coverage objectives of the Digital Agenda', September.
[164] Financial Times (2014), 'Vodafone and O2 make progress on 4G', https://www.ft.com/content/d1f2827c-1d84-11e4-b927-00144feabdc0?mhq5j=e2, accessed 24 July.
[165] Austria, Denmark, Finland, France, Germany, Ireland, Spain, and the UK.

members of an agreement. However, it is hard to draw any firm conclusions based on this information.

Figure A4.32 4G mobile network sharing agreements and 4G coverage by MNOs in selected countries (using most recent available coverage data from MNO websites, typically 2016–17)

Note: Regarding Denmark, TDC1 refers to the TDC coverage obligation/outcome in terms of area; TDC2 refers to the TDC coverage obligation/outcome in terms of households, enterprises and holiday houses. We note that in Spain, the Yoigo/Telefonica sharing agreement has been recently replaced with an agreement between Yoigo and Orange. We also note that the terms of the sharing agreements in France have changed due to regulatory intervention. The network sharing in Germany between Telefonica and Deutsche Telekom was expanded to incorporate LTE technology in 2012. The network sharing agreement between Orange and Free in France does not cover 4G technology.

Source: Oxera, websites and reports of regulators and MNOs, GSMA, European Commission. Accessed June–November 2017.

A4.5.4 Key observations

Mobile network sharing is a commercial, operator-driven decision that is motivated particularly by the potential to save significant costs.

The likelihood of a network sharing agreement being commercially viable depends on the extent to which the MNOs involved have similarly sized assets (e.g. spectrum holdings, networks) or similar roll-out ambitions, and whether the MNOs use the same or compatible equipment vendors.

Spectrum sharing is a form of mobile network sharing. In the case of spectrum sharing, we note that it is likely to be more commercially attractive in areas where the parties have similar levels of traffic (or else one operator may benefit from the pooling of spectrum resources more than the other).

While there are obvious benefits to network sharing, these need to be balanced against possible competition distortions that could arise, such as reduced scope for differentiation and decreased incentives to invest in increasing capacity.

Network sharing agreements can vary considerably in nature and scope, and the market circumstances and competitive landscape will dictate the extent to which different forms of sharing will deliver benefits. In short, the costs and benefits of network sharing agreements need to be assessed on a case-by-case basis.

In some circumstances (and where appropriate), regulators or competition authorities have taken actions to provide ex ante approval for sharing arrangements in accordance with competition law. For example, the Danish Competition Authority required commitments from the MNOs before approving the creation of the TT-Network joint venture.

In line with ex post competition law assessment, ComReg has set out its current thinking on collaboration between wireless operators:[166]

> Recalling that there are many forms of collaboration and, further, that the benefits and drawbacks of each collaboration will depend on the specifics of the proposed collaboration, ComReg maintains that it cannot have a firm view on spectrum rights sharing (or pooling) and network sharing other than that it would look more favourably on agreements that would not unduly restrict competition and would deliver demonstrable benefits that are shared with end-users.
>
> Further, ComReg remains of the view that interested parties should be in a position to identify for themselves the types of potential issues and concerns (e.g. competition law) that could be raised by a proposed collaboration agreement.

On balance, Oxera agrees that this case-by-case approach would be the best way to move forward.

In terms of regulatory actions on network sharing as set out in the case study countries, regulators have taken decisions in accordance with relevant legislation that facilitate the functioning of the sharing arrangement. For example, the Swedish regulator allowed the MNOs to transfer spectrum rights to the joint venture, and the UK regulator granted specific powers to a joint venture in order to reduce obstacles to network roll-out. Similar to Ireland, joint

[166] ComReg (2017), 'Radio Spectrum Management Strategy 2016 to 2018', 21 June, para. 7.21–7.22.

bidding for spectrum at auction was allowed by both the Danish and Swedish regulators.

There is currently one passive network sharing agreement, Mosaic (between Eir and Three), in Ireland, while Vodafone has a standalone network. During the 2014 Three/O2 merger, Vodafone stated that it was 'very keen' to have a network sharing agreement in Ireland, which was seen by the European Commission as evidence that Eir continued to have a choice over which other MNO it would share its networks with.[167] However, following a merger commitment to the European Commission, Eir and Three agreed to a strengthened Mosaic agreement. Furthermore, Vodafone Ireland and H3G Ireland terminated their network sharing agreement in 2014.

[167] European Commission (2014), 'Case No COMP/M.6992 HUTCHISON 3G UK/TELEFONICA IRELAND: Merger Procedure Regulation (EC) 139/2004', Article 8 (2) Regulation (EC) 139/2004, 28 May, para. 1,009–1,010.

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