Modelling the network cost savings to mobile network operators of a change of use of the 700 MHz band

ANNEX 3 TO THE COST BENEFIT ANALYSIS OF THE CHANGE IN USE OF THE 700 MHZ RADIO FREQUENCY BAND IN IRELAND

June 2015

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1 General approach to modelling network cost savings

ComReg is considering the management of spectrum in the 700MHz band[1]. ComReg has commissioned Frontier Economics to assess the likely costs and benefits that would accrue as a result of a change in use of the 700 MHz band to mobile services.

1.1 Network cost savings to mobile of 700 MHz

It is expected that, if released for mobile services, the 700MHz spectrum could be used by a mobile network operator (MNO) to offer LTE services at a lower cost than would otherwise be the case. This report describes the approach we have taken to assess the network cost savings that could accrue to MNOs in the event that they were able to use spectrum in the 700 MHz band.

1.1.1 The addition of 700 MHz spectrum will enable network cost savings

Incremental spectrum holdings enable operators to have more capacity in their Radio Access Network to carry data. This means that to meet a given demand, an operator would require fewer cell sites, enabling network cost savings that can lead to lower costs.

Our analysis has therefore compared the number of base stations that a hypothetical mobile operator would require in order to meet network demand for voice and data in two scenarios. In one scenario it is assumed that the operator has access to 700 MHz spectrum in addition to its other available spectrum holdings (the factual scenario), while in the other scenario it is assumed that it only has access to its other available spectrum holdings (the counterfactual scenario). The difference between the two scenarios (taking into account also the costs of upgrading sites to support the use of 700MHz spectrum in the factual scenario) is the infrastructure savings (i.e. fewer cell sites, base stations etc.) that are enabled by 700 MHz spectrum.

The network cost savings enabled by operators commissioning fewer cell sites as a result of holding incremental 700 MHz spectrum is one estimate of the potential benefit to mobile operators of holding 700 MHz spectrum.

It is also possible that holding 700 MHz spectrum may also have other benefits. To the extent that it is used in heavily loaded cells to increase performance, it may also increase the user performance experienced in those cells, particularly at

1 See ComReg (2014) Management and use of the UHF radio frequency band in Ireland ComReg14/13, and ComReg 14/85.

the periphery of cell coverage.[2] Further there are other additional potential benefits which have not been modelled as part of this exercise, and as such, our quantification of the benefits based solely on network cost savings is conservative.

In addition, it could be expected that in competitive markets, a proportion of the benefits will be passed onto consumers, e.g. in better services, lower prices.

1.1.2 Approach

For both the factual and counterfactual scenarios, the approach to modelling the network cost benefits is as follows.

1. From a 2014 base, the network capacity is modelled for a baseline number of cell sites. These cell sites provide network coverage and a baseline level of network capacity.

2. The model estimates two types of network demand from a 2014 base.

    a. First, network demand that can only be met with lower frequency spectrum (sub 1GHz spectrum), i.e., demand for indoor and deep indoor coverage and rural coverage at the edges of a cell (in the model this is labelled "indoor" demand).

    b. Second, network demand that can be met using any frequency spectrum, i.e. either low or high frequency spectrum (in the model this is labelled "outdoor" demand).

3. The network demand is then distributed across the network into five traffic demand areas, and the model considers whether the "indoor" or "outdoor" demand exceeds the available capacity in each traffic demand area.

4. Where the available capacity is insufficient to meet the network demand, the model determines the required increase in base stations (and thus cell sites) necessary to meet demand.

5. Finally, the model determines the cost of these incremental cell sites.[3]

In the following sections, this paper sets out the approach taken to model the network cost benefits in more detail.

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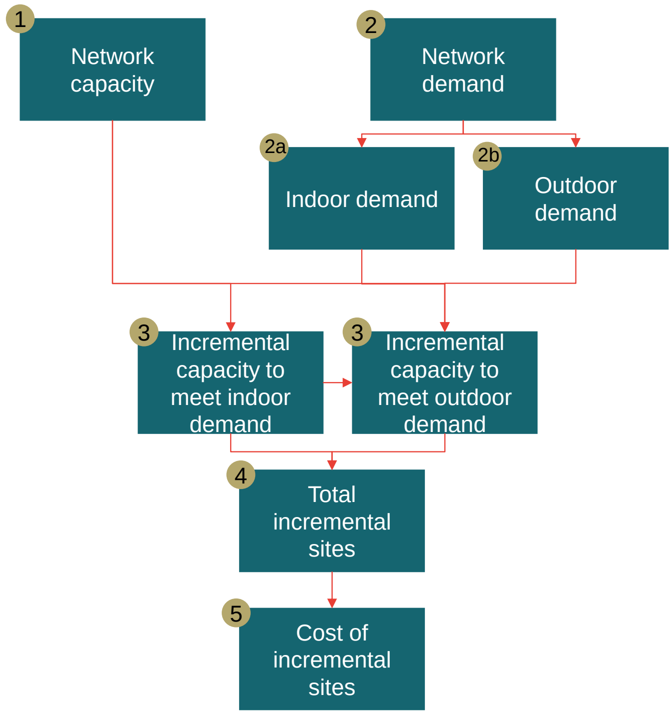
2 See Ofcom 700 MHz band benefits study http://stakeholders.ofcom.org.uk/consultations/700MHz/ ; and

"4G slowing down as more users sign up, says Ofcom study" The Guardian, 2 April 2015. http://www.theguardian.com/technology/2015/apr/02/4g-slowing-down-more-users-sign-up-ofcom

3 Note in the factual scenario the cost of upgrading sites to support the use of 700 MHz is also included.

Figure 1. Schematic of the approach to modelling the need for incremental base stations to meet demand



1.2 Structure of this report

The remainder of this report is structured as follows:

- Section 2 explains how the model estimates network capacity;
- Section 3 explains how the model estimates network demand;
- Section 4 explains how the model estimates the network infrastructure avoided as a result of using 700 MHz spectrum;
- Section 5 explains the cost assumptions used in the model; and
- Section 6 sets out some sensitivities tested in the model.

2 Modelling network capacity

The model begins by estimating the available network capacity for a baseline number of cell sites for both the factual and counterfactual scenarios. This network capacity is then distributed across five different traffic demand areas (see section 3.2.4 below) based on the number of cell sites in each area..

2.1 Assumptions

The model uses information on the mobile market in Ireland to define a set of assumptions for a hypothetical mobile operator. This approach is intended to reflect the characteristics and constraints that are faced by MNOs in Ireland, but abstracts from the specific characteristics of a given operator, which might vary for a number of historic and operator specific reasons. It does this by making assumptions on:

- The number of cell sites the operator deploys.
- The number of operators in the market.
- The amount of spectrum available per operator.
- How spectrum is used for different technologies (2G, 3G and 4G).
- The use of high frequency spectrum.
- The capacity of spectrum when used by different technologies to carry data.
- The technical spectral efficiency of different technologies.
- The number of sectors at each cell site (in the model each site is a three sectors site meaning that that each base station has three antennas).

2.1.1 Number of cell sites

The model assumes a baseline level of 2,200 cell sites. These cell sites provide network coverage and a baseline level of capacity over the period of the model. We note that this number of cells sites is consistent with data provided by operators and is slightly above the 2,000 cell sites noted by eircom[4] and Three[5] in a recent press release of their network sharing arrangement.

[4] http://pressroom.eircom.net/press_releases/article/Three_and_eircom_reach_network_sharing_agreement/

At each cell site, we assume that all available spectrum is deployed, subject to the assumptions on the use of high frequency spectrum as set out in section 2.1.4 below.

2.1.2 Number of operators

The model assumes that there are three identical hypothetical operators in Ireland. This is consistent with the number of MNOs currently in the Irish market. Each hypothetical operator is assumed to have the same traffic demand (i.e. number of subscribers, traffic per device, etc.), the same network capacity (i.e. number of sites, available spectrum, etc.) and the same costs (i.e. costs for site infrastructure, base stations, 700 MHz upgrade etc.).

2.1.3 Available spectrum per operator

The spectrum available to the hypothetical operator reflects both the existing mobile spectrum bands currently assigned in Ireland, and the spectrum bands that may be made available in the future as set out in **Figure 2**.

It is assumed that all available spectrum is equally assigned to three hypothetical operators using a minimum block size of 2 x 5 MHz. Further, it is assumed that specific spectrum bands are used for specific technologies, and that some spectrum bands get re-farmed from one technology to another technology over the period of the model. The technology used in each spectrum band in 2015 is consistent with the use of spectrum by the MNOs in Ireland and with the licences issued by ComReg[6].

In the 900 MHz band it is assumed that 2 x 5MHz is used to provide UMTS services and 2 x 5MHz is used for GSM services.[7] It is assumed that a thin layer of GSM services continue to be provided to support a proportion of voice services in Ireland[8] and legacy services including Machine to Machine (M2M) applications.

In the 1800 MHz band it is assumed that 2 x 5MHz is used to provide GSM services and 2 x 20 MHz is used to provide LTE services. In the 2100 MHz

5 http://press.three.ie/press_releases/three-and-eircom-reach-network-sharing-agreement/

6 See current GSM, 3G and Liberalised Use Licences available on ComReg Spectrum Licensing website (http://www.comreg.ie/radio_spectrum/licensing.541.html).

7 The requirement that spectrum is assigned equally across the three hypothetical operators with a minimum block size of 2 x 5 MHz means that 1 block of 2 x 5 MHz in the 900 MHz band is not included in the model.

8 This is consistent with the voice traffic profile assumptions proposed in Mobile Termination Rate (MTR) model in Ireland – See section 4.1.3 of ComReg 15/19a http://www.comreg.ie/_fileupload/publications/ComReg1519a.pdf

band, it is assumed that spectrum is used to provide LTE services from 2023 onwards.[9]

It is assumed that other spectrum in higher frequency bands will become available over time[10] (see Table 2 below). For the purposes of the model, the quantum of spectrum in each band is expressed as the equivalent of paired spectrum using Frequency Division Duplex (FDD) operation mode.

Table 1. Assumed spectrum per operator (paired MHz) - Future available high frequency spectrum

Spectrum band	Available spectrum	Operation Mode	FDD equivalent (industry)	FDD equivalent (per operator)
1.4GHz	40 MHz	SDL	20 MHz	5 MHz
2.3GHz	100 MHz	TDD	50 MHz	15 MHz
2.6GHz	70 MHz	FDD	70 MHz	20 MHz
2.6GHz	50 MHz	TDD	25 MHz	5 MHz
3.6 GHz	200 MHz	TDD	100 MHz	30 MHz

SDL refers to supplemental downlink. Supplemental downlink uses unpaired spectrum and provides only downlink capacity for mobile services.

TDD refers Time Division Duplex; FDD refers to Frequency Division Duplex.

In total, the future available high frequency spectrum is assumed to provide 75 MHz of paired spectrum for LTE per hypothetical operator. As set out in **Figure 2**, it is assumed that this spectrum is gradually added to the network to provide additional capacity.

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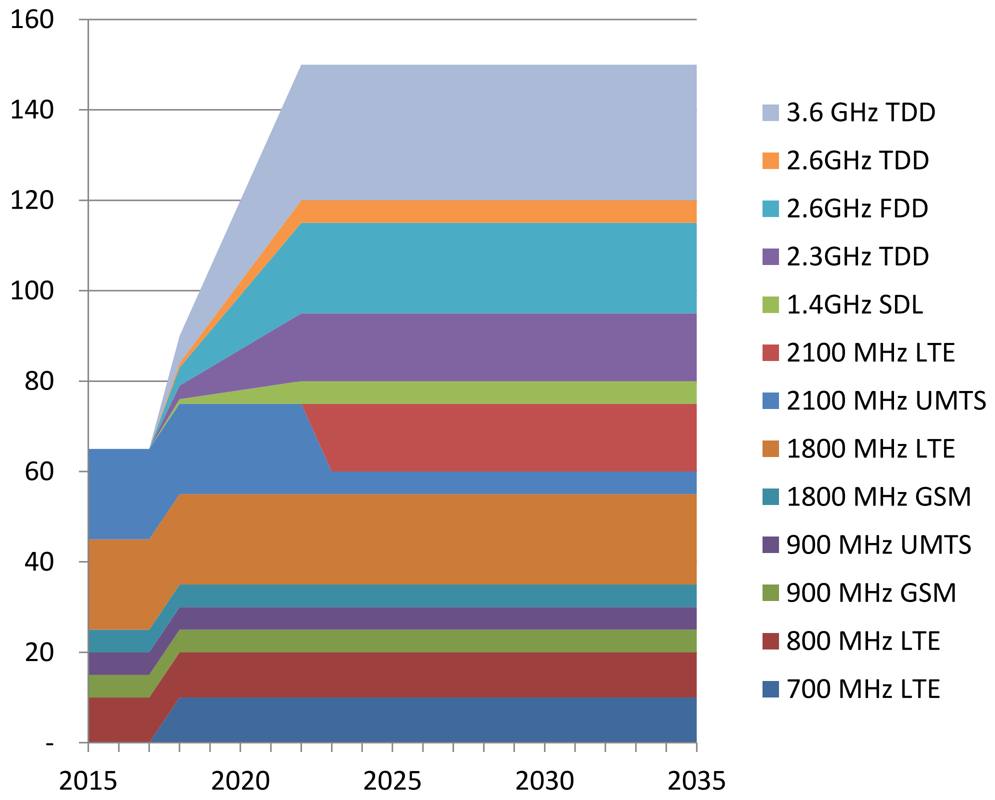
9 Three of the four 3G licences in Ireland expire in 2022.

10 The potential other spectrum bands are broadly consistent with ComReg's proposals in ComReg consultation 14/101 http://www.comreg.ie/_fileupload/publications/ComReg14101.pdf

Figure 2. Assumed spectrum per operator (paired MHz or equivalent of paired MHz)



Source: Frontier

2.1.4 The use of high frequency spectrum

The model assumes that in certain areas (e.g. rural areas[11] or areas with low traffic demand) high frequency spectrum is less likely to be used than sub 1GHz spectrum given its propagation characteristics which mean that its coverage range is much lower than low (sub 1GHz) spectrum.

To reflect the likelihood that high frequency spectrum will be less likely to be used in certain areas, we down-weight the capacity available from high frequency spectrum in the two traffic demand areas (see section 3.2.4 below) with the lowest traffic demand.

Specifically it is assumed that:

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11 In rural areas networks are configured to provide sufficient coverage and the resulting capacity may in many cases be more than is required to meet network demand in such areas.

- In traffic demand area 4, which contains 20% of cells and carries 34% of network traffic, it is assumed that only 85% of the cells use high frequency spectrum.
- In traffic demand area 5, which contains 70% of cells and carries 35% of network traffic, it is assumed that only 50% of the cells use high frequency spectrum.

2.1.5 The capacity of spectrum when used by different technologies to carry traffic

The capacity of a sector within a cell is dependent on the amount of spectrum used, the technology deployed and the efficiency of the technology at carrying the data.

GSM

The parameters used to model the GSM network capacity[12] are set out in **Table 2**.

Table 2. GSM capacity parameters

	parameter
Carrier size (MHz)	0.20
Reuse factor	10.00
MHz per carrier	2.00
Channels per carrier	8.00
Channel - Erlang Conversion Factor	0.80

Notes: Frontier Economics assumptions. The assumptions are consistent with the assumptions used in ComReg's MTR model proposals; see ComReg document 15/19a.

UMTS and LTE services

The parameters used to model UMTS and LTE network capacity is set out in **Table 3**.

As technology standards are improved and refined, so the effective capacity of different technologies improves. This report refers to the improvement of capacity with improvements in technology as "technical spectral efficiency".

12 GSM data is not included or modelled in the model.

The technical spectral efficiency of UMTS and LTE was examined in Ofcom's decision on the costs and benefits of a change in use of 700 MHz spectrum[13]. The technical spectrum efficiency assumptions used in this model are consistent those used in the Ofcom study with the exception that in the case of LTE spectrum, the forecast spectrum efficiency improvements have a lag of two years. This reflects the fact that even where new LTE releases are deployed in the network, there may be a lag in the user adoption of handset technology with the latest LTE releases, which would in turn reduce the effective capacity of the cell.

Table 3. UMTS and LTE technical spectral efficiency (Mbps per MHz)

	2015	2016	2017	2018	2019	2020	2025	2030	2035	2040
UMTS	1.41	1.5	1.715	1.93	2.14	2.14	2.14	2.14	2.14	2.14
LTE	1.57	1.57	2.3	2.875	3.45	3.685	4.44	4.814	4.92	4.944

Voice channels per MHz, 3G = 12; 4G = 50[14]

2.1.6 Assumptions on effective efficiency of different technologies

In order to convert the theoretical network efficiency of each technology into a network capacity, a number of adjustments are made to account for real-world effects. These assumptions are set out below and are consistent with the assumptions used in models elsewhere[15].

Traffic mix adjustment

The traffic mix adjustment adjusts the estimated capacity to reflect the fact that the available downlink data rate in a cell will not be available to all users, as some users will not be close enough to the base station to get a sufficiently good signal. In addition it reflects the fact that the available downlink rate is not likely to be used to the full extent by the applications of some users as some applications will only require a lower data rate throughput. The Traffic Mix adjustment reduces the effective efficiency of different mobile technologies to 65% of the theoretical level.

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13 Section 3.2.3, Figure 3.8 and 3.9, of "Assessment of the benefits of a change in the use of 700 MHz spectrum" Analysys Mason (2014), http://stakeholders.ofcom.org.uk/binaries/consultations/700MHz/annexes/benefits_700MHz.pdf

14 See for example http://mobilesociety.typepad.com/mobile_life/2009/11/how-many-voice-calls-can-you-squeeze-into-1-mhz.html,

15 ComReg MTR model proposals (ComReg 15/19a) and the Ofcom 700 MHz modelling work.

Loading adjustment

The loading adjustment reflects the fact that in reality, cells are not fully loaded to their theoretical maximum capacity. This is to ensure a reasonable quality of service and that network stability requirements are met. Furthermore, cells can be upgraded or new cells installed when cell loading is less than the theoretical maximum. The Loading Mix adjustment reduces the effective efficiency of different mobile technologies to 75% of the theoretical level.

Network overheads

The network overheads adjustment reflects the fact that a certain amount of network capacity is required to provide network signalling and overheads (i.e. in addition to the capacity required to carry data required by users). The Network Overheads adjustment reduces the effective efficiency of different mobile technologies to 75% of the theoretical level for GSM technologies, 77% of the theoretical level for UMTS technologies, and 80% for LTE technologies.

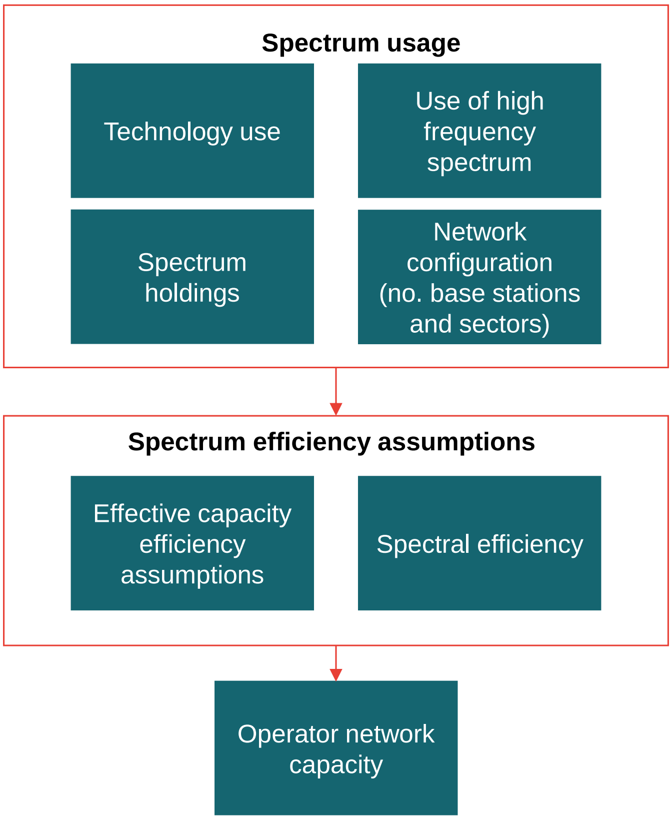
2.1.7 3 sector sites

It is assumed that all cell sites are 3 sector sites. This is consistent with the majority of sites currently deployed in Ireland.

2.2 Approach to modelling the network capacity

The approach to modelling the network capacity is summarised below in Figure 2.

Figure 3. Approach to modelling network capacity



Network capacity is separately modelled for sub 1GHz spectrum and for higher frequency spectrum. This is because the model estimates the demand for "indoor" demand which can only be met with sub-1GHz spectrum, and "outdoor" demand which can be met with any spectrum band.

2.2.1 Network Capacity per traffic demand area

In order to model the capacity of the network the model separately estimates the capacity in each traffic demand area for each technology.

The total capacity of each technology in each traffic demand area is a function of:

- the number of cells in each traffic demand area in section 3.2.4, multiplied by the number of sectors per cell (which is assumed to be three);
- the capacity per sector as explained below; and
- the effective efficiency factors described in section 2.1.62.1.6.

Additionally, in the case of capacity derived from high frequency spectrum, the proportion of equipment using high frequency spectrum in each traffic demand area is also taken into account.

Capacity per sector - GSM Technology

The capacity per sector for GSM is measured as the number of channels per sector, which is a function of the:

- spectrum used for GSM as set out in section 2.1.3 multiplied by
- the MHz per carrier for 2G services multiplied by the number of channels per carrier as set out in **Table 2** above.

The capacity is converted into Erlangs using the *channel to Erlang* factor in **Table 2** above.

Capacity per sector - UMTS and LTE Technology

The capacity per sector for UMTS and LTE is measured as Mbps per sector which is a function of the spectrum used for UMTS and LTE as set out in 2.1.3 above, multiplied by the UMTS and LTE technical Spectral Efficiency (Mbps per MHz) as set out in **Table 3** above.

2.2.2 The availability of 700 MHz spectrum

700 MHz spectrum is intended to be rolled out in each traffic demand area at the same rate and on a gradual basis. Roll out occurs following the 700 MHz availability date and where the network capacity (using the other available spectrum holdings) is insufficient to meet demand. In each year that this occurs for a given traffic demand area, the 700 MHz spectrum is assumed to be rolled out to augment the available capacity.

The roll out is at increments of 25% (i.e. 25%, 50%, 75% and 100%), where incremental roll out occurs in a given year where there is insufficient capacity to meet demand in the traffic demand area (i.e. during the rollout period, if capacity is sufficient to meet demand no further roll out is assumed to occur until a year where capacity is insufficient to meet demand).

3 Modelling demand

Section 3.1 below describes the approach to modelling network demand and section 3.2 summarises the assumptions used.

3.1 Approach to modelling network demand

The model estimates the network demand in the following way:

1. The demand per subscriber is calculated based on assumptions of penetration of devices (standard mobile phones, smartphones, mobile broadband and other types of connected devices) per population, the usage (voice and data) of each mobile device, the proportion of devices which are capable of using each technology, and the proportion of traffic (data or voice) which is carried on each technology.

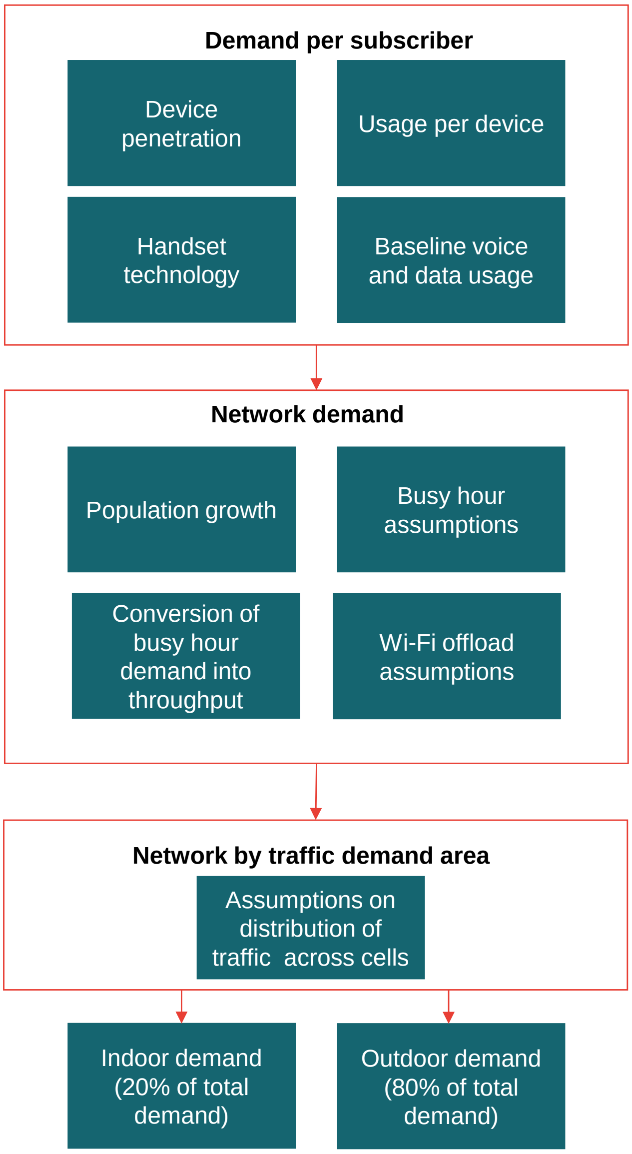
2. The network demand depends on the population and its growth, and assumptions on how networks are configured to meet busy hour demand.

3. The network demand is distributed into five traffic demand areas to reflect the heterogeneous distribution of traffic in the network which results in some sites being more heavily loaded than others.

4. In each traffic demand area, the demand is calculated separately for both "indoor" and "outdoor" demand.

This is represented in **Figure 4** and discussed in more detail below.

Figure 4. Schematic showing network demand



3.1.1 Traffic demand

The traffic demand is a function of:

- the number of subscribers with a given device (standard mobile phones, smartphones or mobile broadband and other types of connected device) in each year, and

- the usage (voice or data) per device which is based on the current usage[16] and assumptions of projected increases in usage as set out in section 3.2.1 below.

3.1.2 Modelling network demand

Demand is modelled for each technology. The total annual demand for traffic is expressed as volume throughput during busy hour periods measured in Erlangs (in the case of voice traffic) and Mbps (in the case of data traffic).

Conversion of voice and data traffic into network demand

Voice and data traffic is modelled by technology, 2G, 3G or 4G. The network demand by technology depends on assumptions on:

- the stock of devices by technology as described in section 3.2.2; and
- how voice and data traffic is carried on the RAN.

How voice traffic is carried on the RAN

Voice traffic originates on mobile handsets. In the case of 2G only mobile handsets, this traffic can only be carried on the 2G RAN.

In the case of voice traffic that originates on handsets with tri or dual technology functionality a proportion of this traffic is assumed to be carried on the RAN of the older technologies (GSM or UMTS). This is to model the slow adoption of Voice over LTE ('VoLTE') and the continued reliance on older circuit switching voice technology. This adjustment forces a certain amount of voice traffic to be carried on the older technologies.

The proportion of traffic that originates on a UMTS or LTE enabled device and is assumed to be carried on the GSM or UMTS network is set out in **Table 4** below. In the early years of the model a greater proportion of LTE enable device voice traffic is pushed to the older technologies, and gradually this reduces over time.

16 Information from ComReg's Quarterly Report for Q4 2014 (ComReg 15/27) http://www.comreg.ie/_fileupload/publications/ComReg1527.pdf

Table 4. Proportion of Voice Traffic generated on dual or tri-mode handsets that is carried over Older Technologies

	2015	2020	2025	2030	2040
Proportion of 3G enabled handset voice traffic carried on GSM network	25%	25%	25%	25%	25%
Proportion of LTE enable handset voice traffic carried on UMTS or GSM network	100%	61%	27%	12%	2%

Data traffic

Data traffic is assumed to originate from 3G and 4G handsets only (i.e. smartphones) and from mobile broadband and other connected devices

3.1.3 Traffic modelled for "indoor" demand and "outdoor" demand

It is assumed that 20% of traffic can only be carried on sub 1GHz spectrum. This is for two reasons.

- In urban areas, the propagation characteristics of spectrum means that a proportion of demand can only be met using low frequency spectrum for in-building and deep in-building coverage.
- In rural areas which are more sparsely populated, low frequency spectrum is required to provide coverage at the edge of cells, and to penetrate buildings and other objects.

This traffic is labelled "indoor" demand. The model assumes that 20% of demand is assumed to be "indoor" demand, and 80% of demand is assumed to be "outdoor" demand which can be carried on any spectrum band.[17]

3.2 Assumptions

Demand for mobile network services is a function of a number of assumptions. These are explained below.

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17 The assumption is consistent with the assumption used by Ofcom in its estimate of the network cost savings as a result of incremental 700 MHz spectrum being made available for mobile services.

3.2.1 Voice and data base levels and growth

Voice and data volumes from ComReg's Quarterly Report of Q4 2014 are used to determine the network demand for 2014 from which we then project forward.

For 2014, the model assumes a data usage (GBs) per month of 1.32 GBs per smartphone device and 6.62 GBs per mobile broadband device. For voice, the model assumes 207.2 voice traffic minutes per month.

The projected growth in voice and data traffic is based upon recent trends in data traffic growth and device penetration for Ireland. The growth in voice and data traffic is determined from:

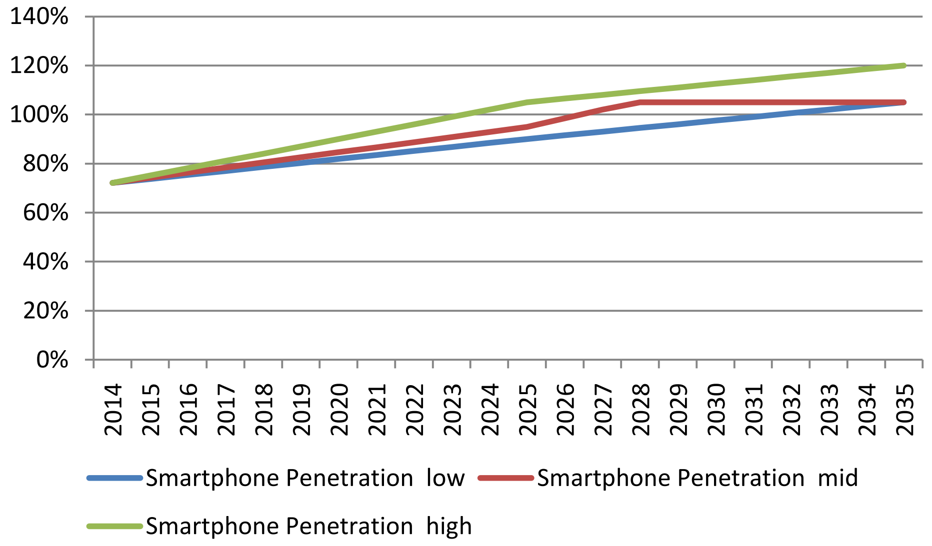
- Population growth. Population growth is as provided by the Central Statistics Office (CSO) Ireland[18].
- The growth in penetration of mobile devices (whether standard mobile phones, smartphones or mobile broadband and other types of connected device).
- The growth in voice and data use per device.

Device penetration

Smartphone penetration is assumed to grow in line with **Figure 5**.

18 ` Population projections M2F1_2011.

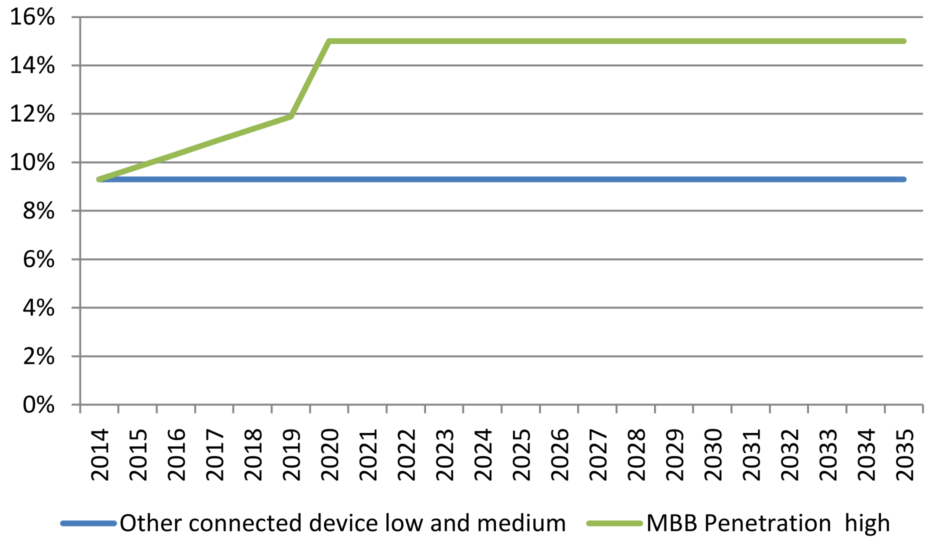
Figure 5. Smartphone penetration



Source: Frontier

Other connected device penetration is assumed to grow in line with **Figure 6**.

Figure 6. Other connected device penetration



Source: Frontier

Voice demand is a function of "standard" mobile penetration. Standard mobile penetration currently is at 106% in Ireland. In the base scenario penetration is expected to stay at this level for the forecast period.

Smartphone penetration is currently 74.2% and is projected to reach almost the same level as standard mobile penetration by 2028. This may be a conservative assumption, since other forecasters have projected higher rates of smartphone device penetration. For example Real Wireless project that by 2030 smartphone penetration in the UK will reach 227%.[19] However in another UK projection, Analysys Mason project that penetration will increase to 100% by 2035[20].

Mobile broadband and other connected device penetration is expected to remain constant at the current rate of 9.8%. This may be a conservative assumption. While the current assumption is based on penetration of mobile broadband devices in Ireland which is reducing slightly, this may be an imperfect proxy for a wider group of connected devices which could include portable devices such as tablets, or other types of connectivity, for example as mobile services are provided in cars. Growth in penetration of these devices may increase significantly in coming years. Real Wireless project that in the UK tablet and laptop mobile connectivity will increase to 95% and 109% respectively by 2030[21]; and Analysys Mason project that mobile broadband device penetration will increase to 25% by 2035. [22]

Data use per device

The base case for growth in voice and data traffic is set out in **Table 5**.

Voice traffic per device is expected to increase slightly in coming years. Underlying this assumption is two opposing trends. First the growth in the use of OTT services for the provision of voice traffic is likely to lead to a decline in the volume of voice traffic per device. On the other hand, the continued migration of fixed traffic to mobile networks might gradually increase the volume of voice traffic per device. In our mid case we assume that voice traffic increases slowly until 2023 then does not change.

Data use per mobile device in Ireland has been growing rapidly in recent years, driven partly by the growth in the use of video traffic over mobile networks.

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19 Real Wireless (2013), *"Techniques for increasing the capacity of wireless broadband networks: UK 2012-2030"* http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

20 Analysys Mason (2014) Figure B.3. http://stakeholders.ofcom.org.uk/binaries/consultations/700MHz/annexes/benefits_700MHz.pdf

21 Real Wireless (2013), *"Techniques for increasing the capacity of wireless broadband networks: UK 2012-2030"* http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

22 Analysys Mason (2014) Figure B.3. http://stakeholders.ofcom.org.uk/binaries/consultations/700MHz/annexes/benefits_700MHz.pdf

Mobile data usage volumes (including smartphone and mobile broadband traffic) increased by 82.7% in the year to Q4 2014.[23] Mobile broadband traffic has grown by 24% in the last twelve months and smartphone data traffic has grown by 128% in the last twelve months

In the base case the modelling assumes that annual data usage per smartphone device gradually reduces from an assumed 2015 growth rate of 75% to 20% annual growth by 2020, and continues to fall more gradually from that point. The growth rate in data traffic per mobile broadband and other connected device is assumed to fall from an assumed 2015 growth rate of 40% and then continue to reduce to 15% in 2020, and then to reduce more gradually.

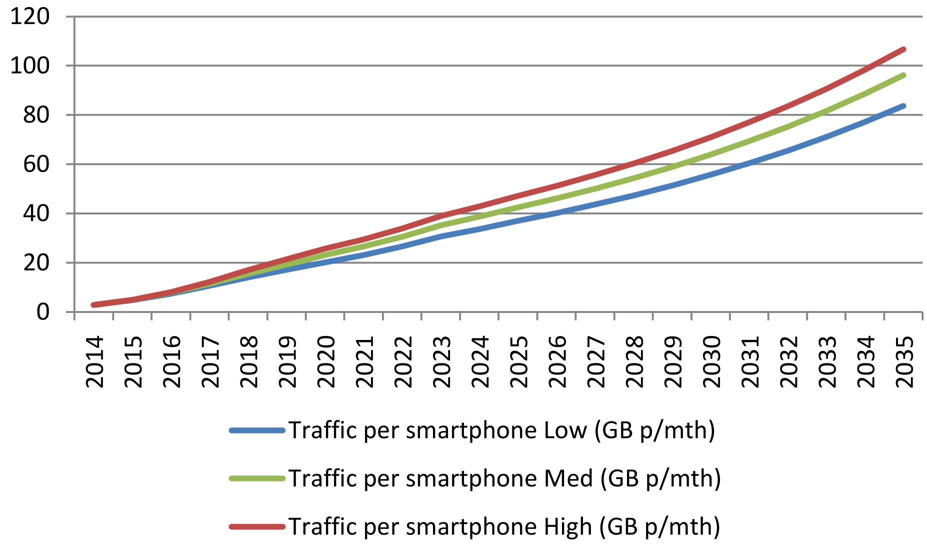
Table 5. Annual growth in traffic per device (mid case)

	2015	2020	2025	2030	2040
Standard mobile	2.0%	1.0%	-	-	-
Mobile broadband and connected devices	75.0%	20.0%	10.0%	8.5%	8.5%
mobile subscribers	40.0%	15.0%	10.0%	7.7%	6.9%

Data traffic per smartphone device is set out in **Figure 7**.

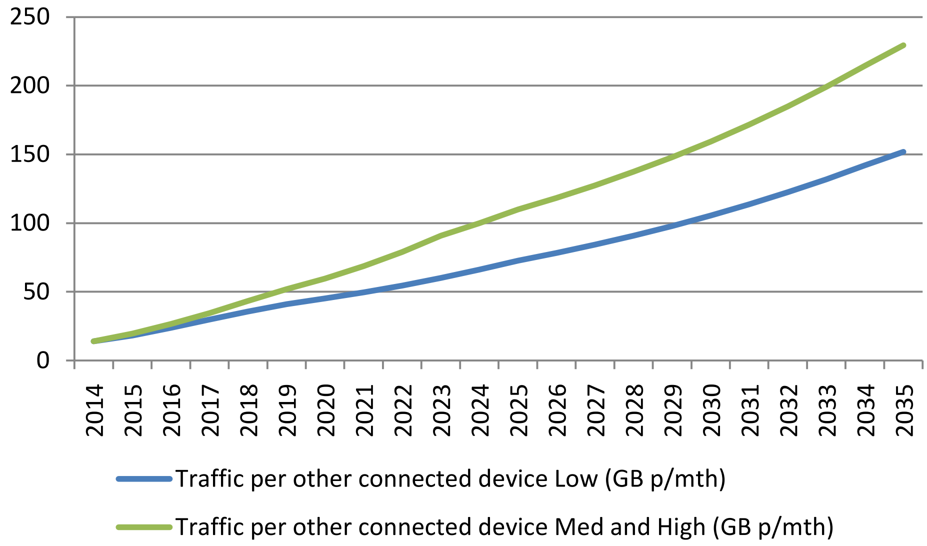
23 ComReg 15/27. Figure 4.3.1.

Figure 7. Data traffic per smartphone device (GB p/mth)



Data traffic per other connected device is set out in **Figure 7**.

Figure 8. Data traffic per other connected device (GB p/mth)



Wi-Fi offload assumptions

The actual required capacity of mobile networks also depends on how much traffic is actually offloaded via Wi-Fi onto fixed broadband networks. The model assumes that the proportion of device traffic that will be offloaded onto fixed networks increases over time. This reflects the assumption that mobile networks will attempt to actively manage capacity by offloading traffic onto fixed networks as well as a greater use of public Wi-Fi networks. Data was not available on the use of Wi-Fi offloading in Ireland. The model has therefore adopted the same base year assumption as was used by Ofcom in its assessment of the network cost savings as a result of the release of 700 MHz spectrum.

Table 6. Wi-Fi offload

	2015	2020	2025	2030	2040
Proportion of traffic offloaded onto fixed networks	53%	55%	58%	60%	65%

3.2.2 Stock of devices

Voice and data traffic is modelled by device technology based on the stock of devices by technology. The stock of devices is assumed to be either: single mode (i.e. 2G only); dual mode (i.e. 2G and 3G); or tri-mode (i.e. 2G 3G and 4G). The proportion of active SIM cards according to each technology (i.e. 2G, 3G and 4G) described in ComReg's Quarterly Report is used to estimate the stock of devices by technology.

The stock of devices depends on:

- the starting stock of devices (mobiles, smartphones and mobile broadband and other connected devices);
- the rate of device replacement; and
- the technology of replacement devices.

Over time the stock of devices gradually migrates to accommodate 2G, 3G, and 4G technologies in one device.

Starting stock of devices

The starting stock of devices is set out in **Table 7**.

Table 7. Assumptions on the starting stock of devices

	Mobiles and Smartphone	Mobile broadband
Single Mode (2G only)	22%	0
Dual Mode (2G, 3G)	67%	90%
Tri Mode (2G, 3G, 4G)	11%	10%

Source: Figure 4.2.6 ComReg 15/27 Quarterly Data Report 12/03/15 and Frontier Assumption

The rate of device replacement

The rate of device replacement is driven by rapidly evolving technology and the fact that many devices are provided as part of fixed term 12, 18 or 24 month contracts. The rate of device replacement is assumed to be 50% per year for mobiles and smartphones and 33% for mobile broadband.

The technologies of replacement devices

100% of replacement devices are assumed to be LTE enabled by 2017 rising from 50% in 2015.

3.2.3 Busy hour traffic

The network is dimensioned based on the average traffic volume in the eight busy hours each day, across each working day. The estimate of busy hour traffic is based on data collected to support ComReg's MTR modelling (and is therefore consistent with the MTR model)[24]. That report notes that 77.6% of voice traffic occurs on 244 busy-days, and that the average 3G/LTE daily busy hour traffic in each of the eight busy hours amounts to 7.8% of total daily traffic. Therefore, the model assumes that 48.5%[25] of traffic is carried in the eight busy hours of the 244 busy days.

3.2.4 Distribution of Traffic in the network

The voice and data traffic that has been derived for the network as a whole is distributed to the traffic demand areas, according to the traffic distribution assumptions as set out in **Table 8**.

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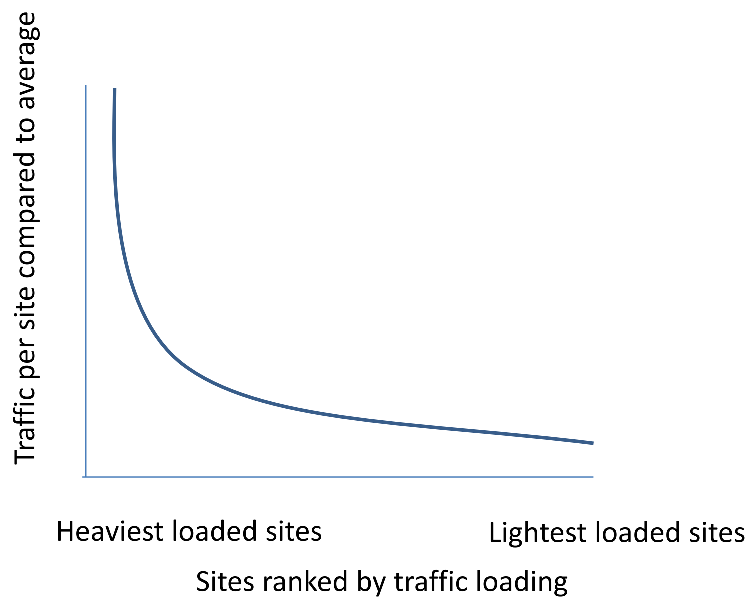
24 See: ComReg (2015) MTR Model Specification Document for Ireland http://www.comreg.ie/_fileupload/publications/ComReg1519a.pdf

25 i.e. 77.6% x 7.8% x 8.

Distribution of capacity across the different traffic demand areas

The model assumes that network demand is heterogeneously distributed across different cells such that some cells are "heavily loaded" and some cells are more "lightly loaded".

Figure 9. Illustration of traffic distribution by site



This is in line with studies which have suggested that the distribution of traffic is typically heterogeneous across cell sites[26].

The assumption on the distribution of traffic is set out in **Table 8**. In the heaviest loaded group of cells (traffic demand area 1) the model assumes that 5% of network demand is carried on 1% of cells. Whereas in the lightest loaded group of cells (traffic demand area 5) we assume that 35% of network demand is carried on 70% of cells.

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26 Analysys Mason (2013) THE INCREMENTAL VALUE OF CAPACITY SPECTRUM. http://www.analysysmason.com/About-Us/News/Newsletter/The-incremental-value-of-capacity-spectrum/ ;
Plum (2013) The impact of 2.1 GHz spectrum deprival on mobile consumers and operators https://www.hkt.com/staticfiles/PCCWCorpsite/Press%20Release/2013/Sep/Plum%20press%20briefing%20spectrum%20deprival%20impacts.pdf ; and
Coleago (2014) Will Wi-Fi relieve congestion on cellular networks? http://www.gsma.com/spectrum/wp-content/uploads/2014/05/Wi-Fi-Offload-Paper.pdf

Table 8. assumptions on traffic distribution

Traffic Demand Area	Percentage of cells	Percentage of demand
1.	1%	5%
2.	4%	13%
3.	5%	13%
4.	20%	34%
5.	70%	35%

Frontier assumptions

This distribution is based on Frontier Economics assumptions .

4 Estimating the reduction in infrastructure required as a result of 700MHz spectrum

The model estimates the reduction in RAN infrastructure that is required if the hypothetical mobile operators also hold 700 MHz spectrum. It does this in the following way:

- For each year the model estimates the incremental number of base stations over the baseline level of 2,200 sites that is required to meet demand.
- It does this in a scenario for an operator with 700MHz spectrum, and without 700 MHz spectrum.
- The cost difference between the number of sites required in each scenario, minus the 700 MHz upgrade costs associated with using the 700 MHz spectrum, represents the network cost savings that is enabled by 700 MHz spectrum.

4.1 Estimating base station requirements

The model estimates the base station requirements to meet demand in the following way.

4.1.1 Base stations to meet "indoor" demand

For each technology in each traffic demand area:

- The model subtracts the "indoor" demand from the sub 1GHz capacity.
  - If this is positive, there is a ***surplus of "indoor" sub 1GHz capacity*** and no further base stations are required to meet "indoor" demand. The surplus "indoor" sub 1GHz capacity can be used to meet "outdoor" demand.
  - If this is negative there is a ***deficit of "indoor" sub 1 GHz capacity***.
- The model estimates the number of base stations required to meet the **"indoor" sub 1GHz capacity deficit,** (using network capacity assumptions as set out in Chapter 2) such that the deficit is eliminated.

4.1.2 Base stations to meet "outdoor" demand

For each technology in each traffic demand area:

- The model subtracts the "outdoor" demand from the sum of supra 1GHz capacity and any surplus "indoor" sub 1GHz capacity.

- If this is positive there is a surplus of spectrum required to meet the "outdoor" demand. No further base stations are required to meet the "outdoor" demand.
- If this is negative then there is an initial deficit in "outdoor" capacity.

- The model estimates the number of incremental base stations required to meet the initial deficit in "outdoor" capacity for a given technology.
  - Where incremental base stations are required to meet "indoor" demand, it is assumed that these base stations also use high frequency spectrum. The resulting throughput capacity (from high frequency spectrum on incremental sub-1GHz base stations) is netted off against the initial deficit in "outdoor" demand to estimate the "outdoor" capacity deficit.
  - If the high frequency capacity from incremental "indoor" demand base stations is sufficient to eliminate the initial "outdoor" demand deficit, then no further base stations are required.
  - If the high frequency capacity from incremental "indoor" demand base stations ***does not*** eliminate the initial "outdoor" demand deficit, the then model estimates the number of incremental base stations required to meet "outdoor" demand assuming that all available spectrum can be used (both sub-1GHz and high frequency spectrum) and given assumptions about the infrastructure requirements to meet a given throughput.

4.2 Total site infrastructure requirements

The model estimates the number of base stations required in each traffic demand area by summing the total number of incremental "indoor" and "outdoor" base stations (which are required to meet demand over the assumed baseline level of capacity provided by 2,200 sites) that are required for a given technology.

The total site infrastructure requirements in each traffic demand area is the highest of the number of incremental 2G, 3G, and 4G base stations required[27].

The difference between the number of total site infrastructure required in the scenarios with and without 700 MHz spectrum represents the infrastructure savings that could be achieved as a result of incremental 700 MHz spectrum being made available for mobile.

[27] For example if the model projects the following infrastructure requirements: 5x2G base stations, 6x3G base stations, and 7x4G base stations, then the model projects the total number of sites (including base stations) required is 7.

5 Estimating the avoided costs realised by MNOs having access to 700 MHz spectrum

5.1 Introduction

The model estimates the costs of incremental site infrastructure required to meet demand. This is based on a cost of site build, RAN equipment and backhaul. It includes both capex and opex costs. It also assesses the costs of rolling out 700 MHz spectrum in those cell sites where there is demand for 700 MHz spectrum.

These costs are then expressed in terms of Net Present Value (NPV), using a discount rate of 8.63%. This discount rate is based on ComReg's assessment[28] and is equivalent to a pre-tax real WACC of 6.76%, assuming an inflation rate of 1.75% (the Bank of Ireland target rate).

Costs and benefits are assessed in a fixed period up to 2035.

5.2 Costs assumptions

The model estimates the costs incurred in installing new base stations to meet demand. The costs include the capex and opex costs of new sites, RAN equipment and backhaul.

5.2.1 Cost categories

The cost categories for capex and opex are set out below.

Capex

Capex costs are set out for the model in **Table 9**.

[28] See: http://www.comreg.ie/_fileupload/publications/ComReg14136.pdf

Table 9. Capex costs

	Cost €k	Asset life
Site	88	8
RAN equipment	35	8
700 MHz upgrade costs	7.5	8

Site costs and RAN equipment cost data sourced from ComReg as set out in MTR Model Specification Document for Ireland. (ComReg 15/19a)

700 MHz upgrade costs of €7.5k are assumed to cover cost of installation of a new 700 MHz carrier. This is equivalent to the cost assumption used in the Ofcom assessment of benefits of a change in use (£6000 per 700 MHz carrier) assuming an exchange rate of €1.25 / £.

Capital costs are annualised in the model given the pre-tax real WACC to discount costs, where the annualised payment is given by the formula below for the annualised capex cost of asset *i*, given its asset life and the relevant discount rate (WACC).

$$Annualised\ payment_i = Capexi \quad \times \frac{WACC}{\left(1 - \left({}^{1}/_{1+WACC}\right)\right)^{Asset\ life_i}}$$

Opex

Annual opex is assumed to be 20% of the unit capex costs. This is based on the assumption used in ComReg's MTR model[29]. The indirect mark-ups represent costs such as power consumption, device cooling and maintenance tools; costs incurred in provisioning the network elements modelled and supporting the network. A report for ComReg noted that a "*comparison of the simple average implied ratio of opex to capex in Portugal, Sweden and UK presented in Table 26 and Table 27 generate results of 16%, 23% and 20% respectively.*"[30]

The assumption is higher than the similar assumption used by Ofcom in its modelling of the cost savings of 700 MHz, where annual opex was assumed to be 10% of unit capex[31].

29 See ComReg 15/19a MTR Model Specification Document for Ireland page 73.

30 Ibid.

31 Analysys Mason (2014) Assessment of the benefits of a change of the 700 MHz band to mobile.

Backhaul

Annualised backhaul costs are based on the average backhaul capex costs and an associated opex which is 20% of the capex cost. The costs are a weighted average of the elements that are used for providing backhaul across the 1,325 modelled sites in the ComReg MTR model. These are set out in **Table 10**. The annualised weighted average cost of backhaul is €17k per site.

Table 10. Backhaul costs

Element	Quantity of elements	Capex €	Asset life	Annual-ised Capex cost	Opex (20%)	Total Annual-ised cost
Abis (BTS_BSC)	241	41,948	8	6,960	8,390	15,350
IuCS (RNC_MGW)	3	94,304	8	15,647	18,861	34,508
IuCS (RNC_MSC/VLR)	2	94,304	8	15,647	18,861	34,508
Iur (RNC_RNC)	2	94,304	8	15,647	18,861	34,508
Iub (NB_RNC)	1,688	41,948	8	6,960	8,390	15,350
Nb (MGW_MGW)	3	94,304	8	15,647	18,861	34,508
A (BSC_MGW)	4	94,304	8	15,647	18,861	34,508
Mc (MSS/VLR_MGW)	3	94,304	8	15,647	18,861	34,508

Source: ComReg 15/19a, Figures 21, 24 and 25. Backhaul costs for 1,325 sites assuming a pre-tax real WACC of 6.76%

5.2.2 Site sharing

Site sharing is assumed to reduce the site acquisition and build costs. The model assumes that two of the three operators share 100% of their sites.

The model estimates the average cost per site for all operators.

This is, in effect, equivalent to applying an adjustment to the site build costs and associated opex of 66%.

5.2.3 Inflation

It is assumed that inflation is zero in real terms for all categories of spend except site build, where a 2% p/a inflation is assumed (in real terms). This assumption is intended to reflect the inflation in cost of acquiring land for building base stations.

6 Sensitivity testing assumptions

6.1 Introduction

The model makes a number of assumptions in order to estimate the network cost savings that arise as a result of operators being able to use 700MHz spectrum. Given that there is a degree of uncertainty in some of the assumptions in the model we have sensitivity tested plausible changes to the key assumptions to understand the impact that a variation in each assumption has on the results of the model under the base case (mid demand), high and low demand scenarios.

Table 11. Key assumptions

Assumption	Base case
Number of Sites;	2,200
Traffic Demand Forecasts	Medium
Technical spectrum efficiency assumptions;	Two year lag on available technology
Other incremental high frequency spectrum- availability and speed of roll-out.	Assume all high frequency spectrum is available
The use of high frequency spectrum	Assume high frequency spectrum is not used in 15% of sites in traffic demand areas 4 and 5
The percentage of traffic that is "indoor" traffic	Assume 20% of traffic is only met with sub 1GHz spectrum
Costs	Central estimate of costs expressed in 2015 prices[32]

6.1.1 Traffic Demand Forecasts

The medium case assumes that traffic demand is as set out in the medium scenario. We also sensitivity test high and low demand scenarios as set out in the main report.

The results of the model (**Table 12**) indicate that the greater the traffic demand, the greater the benefit of incremental 700 MHz spectrum.

32 Costs are uplifted from the base year of 2014 to 2015 prices using the assumption of forecast 2015 inflation from the Bank of Ireland of 0.7% (see: http://www.centralbank.ie/publications/Documents/Quarterly%20Bulletin%20No.%202%202015.pdf).

Table 12. Traffic demand forecasts sensitivity €m

	Base assumptions
Low demand	50
Base (mid demand)	89
High demand	150

Given the significance of this sensitivity, for all subsequent sensitivity tests we in combination test each assumption with the low, medium and high demand.

6.1.2 Number of Sites

The central assumption assumes that each hypothetical operator uses 2,200 sites. This is similar to the number of sites used by Vodafone and is slightly above the 2,000 cell sites noted by eircom and Three in their 2014 press release of their network sharing arrangement. We also sensitivity test 1,800 sites and 2,400 sites.

The results of the model (**Table 13**) indicate that the lower the number of sites, the greater the benefit of incremental 700 MHz spectrum.

Table 13. Number of cell site sensitivities €m

	Base (2200)	1800	2400
Low demand	50	68	42
Base (mid demand)	89	112	79
High demand	150	175	138

6.1.3 Technical spectrum efficiency assumptions

Technological advances increase the technical efficiency of mobile technologies (e.g. LTE) that use spectrum. We use assumptions on technical spectral efficiency from Ofcom on projected spectral efficiency with the exception that in the case of LTE spectrum, we lag the efficiency assumptions by two years to reflect handset technologies.

We also sensitivity test technical efficiency assumptions where it is assumed that efficiencies are achieved two years faster and two years slower.

The results of the model (**Table 14**) indicate that the slower the adoption of the technical spectrum efficiencies, the greater the benefit of incremental 700 MHz spectrum.

Table 14. Spectrum efficiency advances sensitivity €m

	Base	2 year lag	2 year early
Low demand	50	55	47
Base (mid demand)	89	99	84
High demand	150	165	143

6.1.4 Other incremental high frequency spectrum- availability

The model assumes that other incremental high frequency spectrum (1.4GHz, 2.3 GHz, 2.6 GHz and 3.6 GHz bands) becomes available for use in 2018, i.e. the base case for 700 MHz.

We also sensitivity test the scenario where no other incremental high frequency spectrum is released and where it is released in 2020.

The results of the model (**Table 15**) indicate that no incremental high frequency spectrum leads to lower value for 700 MHz spectrum[33]. If there is a two year delay in the availability of the high frequency spectrum this marginally increases the value of 700 MHz mobile spectrum.

[33] 700 MHz has a lower benefit when the operator has less high frequency because high frequency spectrum is much less fungible than 700 MHz spectrum since it can't be used to provide indoor coverage or large scale rural coverage. Where an operator's spectrum holdings are weighted to higher frequency spectrum the effective average capacity per MHz of its spectrum holdings is lower than where its spectrum holdings are weighted to lower frequency spectrum (since lower frequency spectrum is more fungible). Hence where an operator meets demand with spectrum holdings that are weighted to high-frequency spectrum, incremental 700 MHz spectrum is very beneficial, since 700 MHz is more efficient at meeting demand, than the operator's existing spectrum holdings. Whereas where operator's meet demand with spectrum holdings that are weighted to lower-frequency spectrum, incremental 700 MHz spectrum is relatively less beneficial since the operator's existing spectrum holdings are already more "efficient". For this reason over the course of the assessment, incremental 700 MHz spectrum is more beneficial where an operator deploys capacity using existing spectrum holdings which are weighted to higher frequency spectrum.

Table 15. Availability of high frequency spectrum €m

	Base	No incremental high frequency spectrum	2 year delay in high frequency spectrum
Low demand	50	38	51
Base (mid demand)	89	61	89
High demand	150	108	151

6.1.5 The use of high frequency spectrum

The model assumes that in certain areas (e.g. rural areas[34] or areas with low traffic demand) high frequency spectrum is less likely to be used than sub 1GHz spectrum given its propagation characteristics which mean that its coverage range is much lower than low (sub 1GHz) spectrum.

We also sensitivity test alternative assumptions as detailed in **Table 16** below which assume lower use of high frequency spectrum.

34 In rural areas networks are configured to provide sufficient coverage and the resulting capacity may in many cases be more than is required to meet network demand in such areas.

Table 16. Description of assumptions in base and alternative sensitivity

Traffic demand area	Proportoin of demand	Base	Low use of high frequency spectrum
Type 1-3	31% of demand	100%	60%
Type 4 areas	34% of demand	85%	60%
Type 5 areas	35% of demand	50%	50%

Making a lower assumption in on the proportion of cell sites that use high frequency spectrum marginally lowers the NPV of the base case by €9m (**Table 17**)[35].

Table 17. Sensitivity test of lower use of high frequency spectrum €m

	Base	Alternative assumption on use of high frequency spectrum
Low demand	50	45
Base (mid demand)	89	80
High demand	150	131

6.1.6 The percentage of traffic that is "indoor" traffic

It is assumed that 20% of traffic can only be carried on sub 1GHz spectrum. This is for two reasons.

- In urban areas, the propagation characteristics of spectrum means that a proportion of demand can only be met using low frequency spectrum for in-building and deep in-building coverage.

35 See footnote 33 for the intuition behind this result.

- In rural areas which are more sparsely populated, low frequency spectrum is required to provide coverage at the edge of cells, and to penetrate buildings and other objects.

Given the uncertainty in the percentage of traffic that can only be carried by sub 1GHz traffic we also sensitivity test 18% and 22%.

The results of the model (**Table 18**) indicate that a lower assumption on the proportion of demand that can only be met with sub-1GHz spectrum reduces the base case by €20m. Whereas a higher assumption on the proportion of demand that can only be met with sub-1GHz spectrum increases the NPV by €22m.

Table 18. sensitivity of the proportion of demand that is met with sub-1GHz spectrum €m

	Base (20%)	18%	22%
Low demand	50	37	64
Base (mid demand)	89	69	111
High demand	150	122	179

6.2 Summary of sensitivity testing

In the above sensitivity testing, plausible changes to the key assumptions are tested to understand the impact that a variation in each assumption has on the results of the model under the base case (mid demand), high and low demand scenarios. We have not measured the cumulative sensitivity of every possible combination of low assumptions occurring simultaneously since this is a very unlikely scenario.

Sensitivity testing assumptions

Sensitivity testing assumptions

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