analysys mason

Report for ComReg

Specification for the proposed new MTR model (v1.0D)

6 March 2018

Ian Streule, Matthew Starling

Ref: 2007874-102B

www.analysysmason.com

Contents

Analysys Mason Limited
St Giles Court
24 Castle Street
Cambridge CB3 0AJ
UK
Tel: +44 (0)1223 460600
cambridge@analysysmason.com
www.analysysmason.com
Registered in England No. 5177472

1 Introduction

The Commission for Communications Regulation (ComReg) commissioned Analysys Mason Limited (Analysys Mason) to develop a cost model for the purposes of understanding the costs of providing mobile voice call termination (MVCT) services in Ireland. This wholesale market corresponds to Market 2 as set out in the European Commission (EC) Recommendation 2014/710/EU.[1] This market can be price-regulated through the setting of a mobile termination rate (MTR). This cost model developed by Analysys Mason can be used to set such a price and is referred to as the "MTR model".

Analysys Mason and ComReg agreed a process for delivering the cost model, which ComReg will use to inform its potential regulation (and potentially pricing) of MVCT. This process gives industry stakeholders the opportunity to contribute at various points during the project. The first phase of the project was to gather demand, network and cost information from mobile service providers (MSPs) in Ireland.

As part of a separate project, Analysys Mason has developed a separate report on the key principles and methodologies that should underpin the cost modelling and subsequent pricing of both MVCT and fixed voice call termination (FVCT) in Ireland. This MTR model specification document takes these MVCT modelling principles and methodologies as a starting point and describes the modelling implementation that has been developed in line with these principles. The proposed new MTR model (v1.0D) accompanies this document released for consultation with industry stakeholders. The remainder of this document describes the proposed new MTR model and is structured as follows:

- Section 2 summarises the background to this modelling work
- Section 3 sets out the conceptual principles underlying the proposed new MTR model
- Section 4 describes the market-related calculations
- Section 5 describes the demand-related calculations
- Section 6 describes the network design calculations
- Section 7 describes the expenditure calculations
- Section 8 describes the depreciation calculations
- Section 9 describes the display of results in the proposed new MTR model.

The report also includes two supplementary annexes. Annex A provides a list of the acronyms used and what each stands for. Annex B summarises the sources of the inputs in the proposed new MTR model.

Note: Where confidential data has been presented in this report, it is indicated using the scissor symbol '✂'. A redacted version of this report has also been prepared, suitable for publication, with the confidential data removed.

[1] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014H0710.

2 Background to the proposed new MTR model

This section summarises the background to the modelling work, as follows:

- Section 2.1 describes the motivation for developing the proposed new MTR model
- Section 2.2 provides an overview of the flow of information in the proposed new MTR model
- Section 2.3 sets out the basic operation of the proposed new MTR model.

2.1 Motivation

ComReg has an existing MTR model (the 'previous MTR model') that has been used to set a time series of regulated prices for wholesale MVCT for the period September 2016 to December 2018. This model and pricing decision are set out in ComReg's decision D02/16, published in February 2016.[2]

In 2016, ComReg appointed Analysys Mason firstly to provide 'Economic Consultancy Services in relation to FTRs and MTRs – Pricing Principles and Methodologies' and secondly to 'Update/Amend Existing Pricing/Costing Model(s) for Mobile Termination Rates (MTRs) in Ireland'.

Analysys Mason was required to assess all relevant price control models/methodologies relating to MTRs and recommend preferred options. Whilst Analysys Mason has proposed no changes to the general approach to modelling the costs of MVCT at this time, we are of the opinion that there are still particular aspects of the modelling process that will need to be reviewed and updated to ensure that the proposed new MTR model reflects the latest service and technological developments in the Irish market e.g. 4G Long Term Evolution ('LTE' technology). Having considered the extent and implications of these developments on the form and structure of the model proposed, we have concluded that the most appropriate approach is to construct a new MTR model specifically for this process (the 'proposed new MTR model').

The previous MTR model captured 2G and 3G radio technologies and modelled certain aspects of the network (such as backhaul assets) at a high level. Incorporating 4G, voice-over-LTE (VoLTE) and more detailed backhaul modelling would have required extensive redevelopment of the previous MTR model. We also concluded that the modelling period should be extended beyond 2030 given that deployment of 4G networks would only have commenced in 2013.

We therefore requested that ComReg obtain data from MSPs on all their radio technologies (2G, 3G and 4G) and core technologies in use, in order to develop a new MTR model. ComReg issued a Section 13D Information Request in September 2016, in accordance with ComReg's formal powers to request additional information from MSPs. As well as incorporating other updates relating to demand and equipment prices, the proposed new MTR model can identify greater economies of scale from more extensive integration of the core and last-mile access (LMA) networks across the

2 See http://www.comreg.ie/csv/downloads/ComReg1609.pdf.

different radio technologies deployed and allows the quantification of efficiencies arising from the deployment of 4G and voice-over-LTE (VoLTE) technologies.

2.2 Overview of information flows

Analysys Mason has developed a new MTR model for ComReg, to provide cost-based information for future MVCT regulation in Ireland. This bottom-up model has been developed using demand and network parameter information submitted by Market 2 stakeholders in Ireland, combined with estimates and calculations performed by Analysys Mason.

The three broad types of input that feed into the proposed new MTR model calculation relate to demand volumes, network design and costs, as shown in Figure 2.1 below.

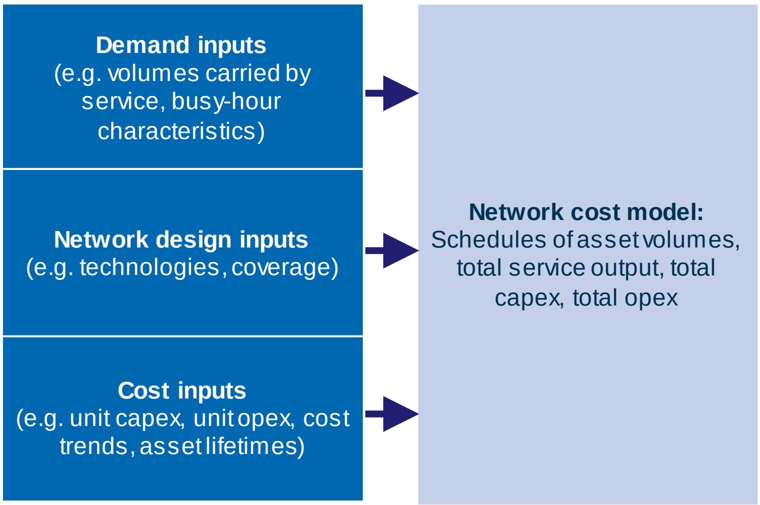
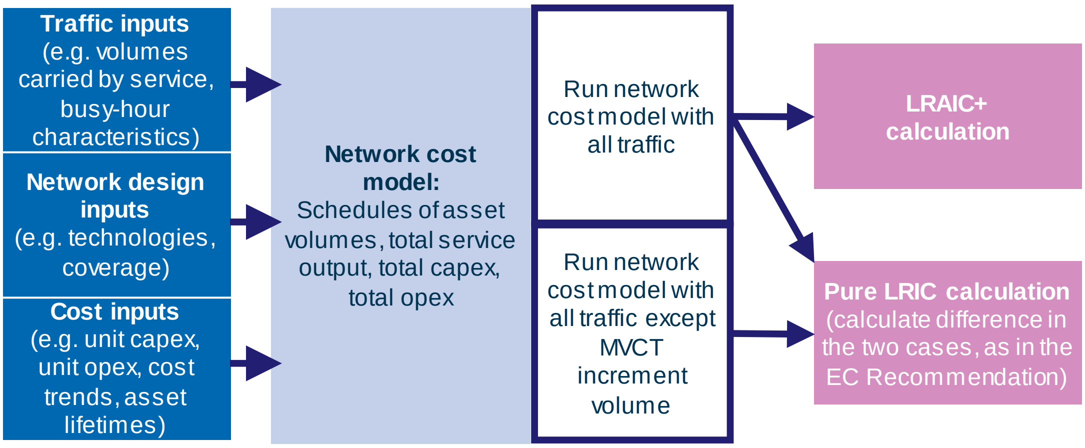


Figure 2.1: Overview of the proposed new MTR model [Source: Analysys Mason, 2018]

The proposed new MTR model then calculates long-run incremental costs for mobile network operations in Ireland. These service costs are derived using both long-run average incremental cost (LRAIC) and pure long-run incremental cost (pure LRIC) principles. The latter is in accordance with the EC Recommendation, as referenced in Section 1. This requires the LRIC model to be run twice, under different situations, as shown in Figure 2.2.

Figure 2.2: Costing approaches within the new LRIC model [Source: Analysys Mason, 2018]



A variety of network configurations can be defined, by choosing appropriate input parameters in the proposed new MTR model. This model has been set up to calculate costs for a generic efficient Irish operator, but it is also possible to adjust inputs on market share, spectrum and coverage, to reflect different configurations, such as those similar to the actual MSPs.

For a configuration defined by a given set of inputs, the proposed new MTR model derives the assets in a forward-looking manner and then determines the costs of these assets over a specified timeframe (up to 50 years).

These costs are then recovered by the services assumed to be conveyed over this network during its lifetime using an economic depreciation calculation. Capital costs are determined using a weighted average cost of capital (WACC), determined by ComReg in a separate workstream. No remaining terminal value is applied within the proposed new MTR model at the end of the cost recovery period.

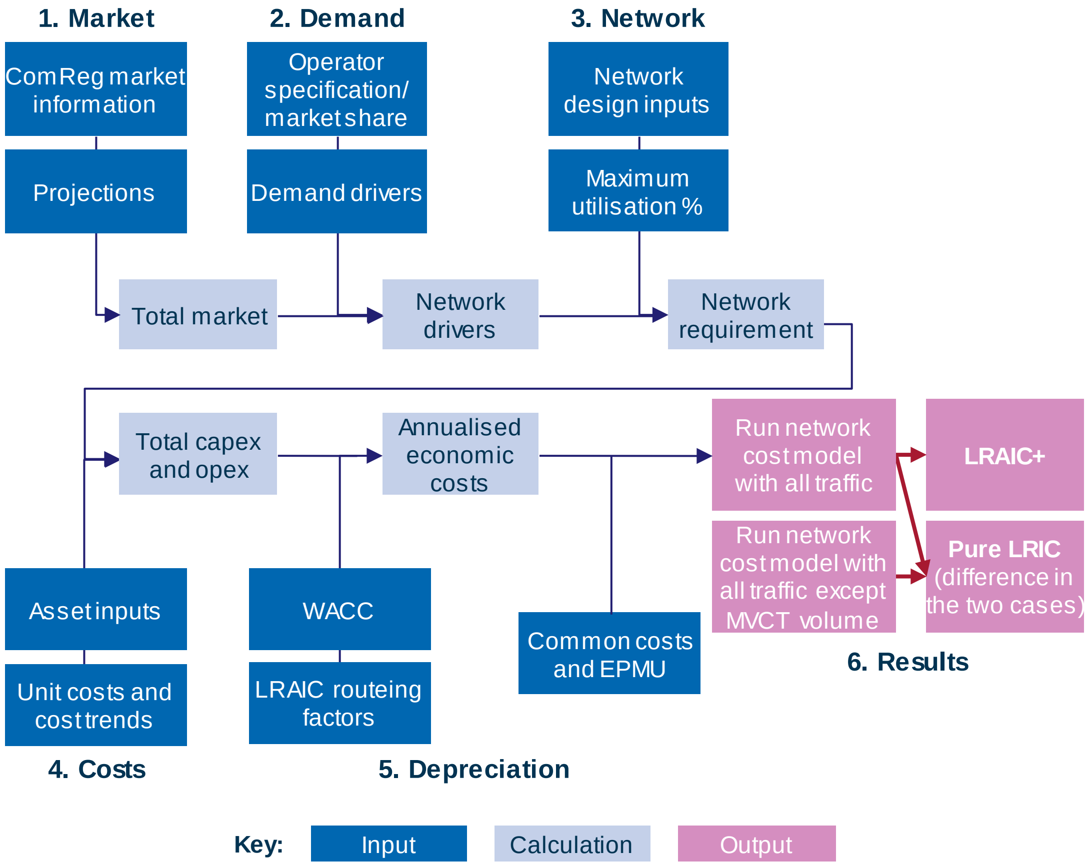
The proposed new MTR model applies the modified scorched-node principle. This allows some top-down validation of the bottom-up asset calculation. Based on operator information, we have:

- compared the modelled number of radio sites with the actual number (by geotype)
- used typical average numbers of switch locations to identify a reasonably efficient, typical network structure for a modern national MSP.

In addition, the overall expenditures in the proposed new MTR model have been checked in aggregate against the total top-down expenditure information submitted to us by the MSPs.

The overall flow of the proposed new MTR model is shown in Figure 2.3 below.

Figure 2.3: Overview of the proposed new MTR model calculation flow [Source: Analysys Mason, 2018]



The proposed new MTR model uses ComReg market information (from 2003 onwards) as inputs, and projects these market parameters over time to produce a long-term forecast of traffic and subscribers. Demand and network inputs are defined, as either universal standard parameters or for specific operator definitions (e.g. generic 'average' operator, hypothetical operator with an assumed market share, and representative templates for actual MSPs). Maximum utilisation factors are applied to various network element capacities to reflect realistic and design loading.

The network requirement is combined with cost inputs which determine the level of capital and operating expenditures (capex and opex) required for the network, including the ongoing replacement of assets. The proposed new MTR model depreciates the expenditures over time, using an economic depreciation algorithm which considers network output (based on long-run average routeing factors), price trends, and a discount rate to reflect the return on capital employed (i.e. the time-discounting of cost recovery relative to expenditure outflow).

Finally, the proposed new MTR model produces two sets of outputs:

- the costs of MVCT according to a LRAIC(+) methodology
- a pure LRIC of MVCT which is derived by running the proposed new MTR model twice (once with, and once without, wholesale MVCT traffic).

In Annex B of this specification document we detail the source of various inputs as follows:

- [1] Analysys Mason estimate
- [2] Analysys Mason estimate informed by operator *input* information or data
- [3] Analysys Mason estimate informed by operator *output* information or data (e.g. scorched-node reference to total amounts of operator equipment, or reconciliation reference to total amounts of opex)
- [4] Irish market average based on operator data (rounded or standardised where appropriate)
- [5] Standard technical parameter
- [6] Previous MTR model.

2.3 Basic operation

The proposed new MTR model is presented in a single Excel workbook, which can be stored in a local directory and opened as a single file. In the public version, there are no external links to other workbooks. The proposed new MTR model should be compatible with all versions of Microsoft Excel (from 2000 onwards). The proposed new MTR model must be run in slightly different ways, depending on which of the three main outputs the user requires. These three outputs are:

- the LRAIC+ for the modelled network, including all cost mark-ups
- the pure LRIC of MVCT for the modelled network
- the LRAIC+ of the modelled network in the case where it is not carrying MVCT traffic, including all cost mark-ups.

The first two outputs can be calculated at the same time for a modelled network by clicking on the button labelled ‘Run Pure LRIC’ on the *Control* worksheet. This activates a simple macro which runs the proposed new MTR model twice (with and without termination), and pastes the necessary quantities onto the *PureLRIC* worksheet. An output cell at the top of the *Control* worksheet indicates when the pure LRIC calculation was last executed. In addition to calculating the pure LRIC of a network, after the macro has finished the proposed new MTR model is set up to calculate the LRAIC+ of the network end-to-end.

To calculate just the LRAIC+ for a modelled network, the ‘Pure LRIC calculation’ input needs to be set to ‘LRAIC’ on the *Control* worksheet, before pressing the **F9** (recalculate) key. For some versions of Excel a full recalculation (**Control+Alt+F9**) may be required. The proposed new MTR model has run and calculated when ‘calculate’ is no longer displayed in the Excel status bar. The proposed new MTR model may take a few seconds to fully calculate, particularly if run on an older computer.

The pure LRIC calculation requires the modelling of a network that does not carry terminated traffic. The pure LRIC is calculated using a macro. Therefore, to inspect this modelling state explicitly, set the ‘Pure LRIC calculation’ input to ‘PureLRIC’ on the *Control* worksheet and press **F9**/**Control+Alt+F9**.

3 MTR modelling principles

As part of a separate workstream, Analysys Mason has developed a report that considers the overarching principles and methodologies for ComReg to apply in its future decision instruments and when developing pricing models for wholesale voice call termination services (for both the fixed and mobile markets).[3] The considerations in that report ('the principles report') are:

- the price control employed, including the costing increment
- the modelling structure to be used for costing purposes
- aspects of the costing approach
- the degree of consistency in the approach taken for FVCT/MVCT.

The report makes several principled recommendations to ComReg, some of which are directly relevant to the development of the proposed new MTR model and are summarised in Figure 3.1 below.

Figure 3.1: Recommendations from the principles report [Source: Analysys Mason, 2018]

Aspect	Recommendation
Price control	• The method of calculating costs of termination should be pure LRIC
Model structure	• Bottom-up models of the appropriate networks should be developed for costing purposes, capable of costing each year in the period 2017–2022 in nominal currency
Costing approach	• A generic hypothetical existing operator should be modelled • Economic depreciation should be the starting point. However, an alternative method can be used for one or more asset types, provided it can be properly justified as being a good approximation to the economic cost recovery over the lifetime of these assets • The modelled operators should be assumed to have reasonably productively efficient scale during the next regulatory period, assumed to be the average scale of the actual number of large network operators having near-100% national population coverage in Ireland • A contestable market and therefore immediate scale should be assumed • Reasonable demand forecasts should be developed across all modelled services, balancing economies of scope and scale with the efficient utilisation levels of each technology generation • The modelled termination services should assume an efficient number of points of interconnect and layers of interconnection • Modern technologies for the future regulatory period should be considered
Degree of consistency in approaches for FVCT and MCVT	• The models should recognise the effects of dynamic efficiency through the assumed technologies and assumed migration between them • A single, internally consistent forecast of the voice market in Ireland should be developed • The models should also calculate the common costs which are not recovered if a pure LRIC approach is applied to voice termination

3 See our report for ComReg, *Pricing principles and methodologies for future regulation of wholesale voice call termination services*.

The following subsections set out the modelling principles that we adopted when constructing the new MTR model for ComReg. We have classified the conceptual issues to be considered in terms of four dimensions: operator, technology, services and implementation, as shown in Figure 3.2 below.

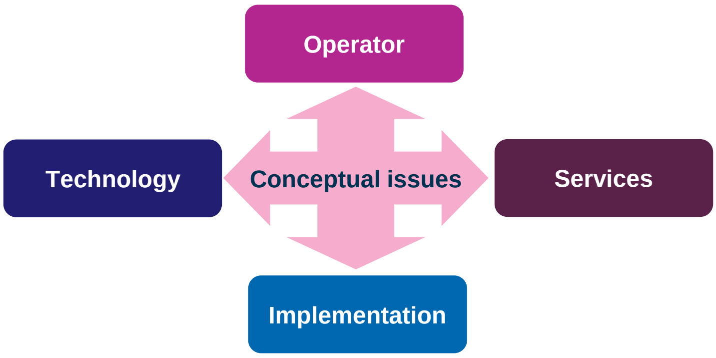


Figure 3.2: Framework for classifying conceptual issues [Source: Analysys Mason, 2018]

We consider each dimension in turn in Sections 3.1–3.4 below.

3.1 Operator

The following operator-related concepts are considered in this section.

Figure 3.3: Decisions on the operator-related conceptual issues [Source: Analysys Mason, 2018]

Section	Conceptual issue	Conclusion for ComReg's proposed new MTR model
3.1.1	Type of operator	Develop a model of a generic hypothetical existing efficient operator
3.1.2	Network footprint and roll-out	Assume 2G/3G coverage roll-out consistent with the previous MTR model Assume 4G coverage reaches 2G coverage levels in long term
3.1.3	Scale	Assume 33.3% market share for the modelled operator in all years (given there are three network operators at present). This includes service provider and MVNO volumes in the market, so that full-scale operations can be modelled

3.1.1 Type of operator

The principles report is clear that a generic hypothetical existing efficient operator should be modelled, rather than actual operators.

3.1.2 Network footprint and roll-out

All mobile networks in Ireland currently provide significant coverage using their 2G/3G networks, as required by their licences. These actual levels of coverage should be reflected in the proposed new MTR model, as they were in the previous MTR model.

The previous MTR model expressed coverage in terms of geographic area, whilst the proposed new MTR model expresses coverage in terms of population. On this basis, we have assumed input levels of 2G and 3G 2100MHz population coverage that lead to similar levels of area coverage for those technologies as found in the previous MTR model. The input population coverage (and corresponding area coverage) for the proposed new MTR model are summarised below in Figure 3.4 and compared to those found in the previous MTR model.

Figure 3.4: Input coverage of the country (unless otherwise stated) by technology in the previous and proposed new MTR models [Source: Analysys Mason, 2018]

Technology	Population coverage (new MTR model)	Resulting area coverage (new MTR model)	Area coverage (previous MTR model)
2G (from 2003)	98.7%	84.7%	84.7%
3G (2100MHz, up to 2012)	84.3%	35.5%	35.5%
3G (900MHz, by 2019, in the two rural geotypes only)	92.6% (of Rural 1 / Rural 2)	77.3%	62.8%
4G (by 2019)	98.7%	84.7%	Not applicable

We would note that these input coverage assumptions do not include the implicit coverage from capacity deployments (in particular, the 3G 900MHz coverage values excludes coverage arising from capacity-driven NodeBs deployed in urban/suburban geotypes).

We assume that both 3G and 4G deployments reach the same level of coverage as the modelled 2G network in the long term.

The cell radii for our modelled 3G and 4G coverage deployments have been calibrated to ensure that the 2016 base-station counts of the generic operator are in the range of the asset counts of actual operators, as derived using ComReg's licence data. This calibration has been undertaken on a geotype-by-geotype basis. We have not undertaken this calibration using the actual 2G base-station deployments since they comprise both coverage and capacity base stations.

The proposed new MTR model also uses a set of multipliers that we apply to estimate radii for different spectrum bands, consistent with what we have used in cost models in other jurisdictions. These are shown in Figure 3.5.

Figure 3.5: Multipliers to convert cell radii across spectrum bands [Source: Analysys Mason, 2018]

Band	800MHz	900MHz	1800MHz	2100MHz
Multiplier	1.7	1.5	1.1	1.0

3.1.3 Market share and scale

Section 5.3 of the principles report concludes that the hypothetical efficient operator used to calculate costs should be modelled:

- at a productively efficient scale over the period 2017–2022, assumed to be 33.3% of all Irish mobile subscribers and mobile traffic (i.e. including demand from service providers and MVNOs on all three networks)[4]
- assuming a contestable market, i.e. that hypothetical firms can immediately join the market and compete to supply all of the existing players' demand, meaning that the modelled operator should be assumed to achieve immediate scale
- such that its future scale is driven by reasonable demand forecasts for all the services assumed to be carried by that network (from both the retail and wholesale subscriber bases). These forecasts should allow reasonable economies of scope and scale to be captured, whilst also assuming a reasonably efficient utilisation of the network technologies over their lifetimes.

Separate market-share inputs for subscribers, voice and data can be specified on the *Control* worksheet of the proposed new MTR model.

3.2 Technology

The following technology-related concepts are considered in this section:

Figure 3.6: Decisions on the technology-related conceptual issues [Source: Analysys Mason, 2018]

Section	Conceptual issue	Conclusion for ComReg's proposed new MTR model
3.2.1	Radio network	Deploy 2G using 900MHz and 1800MHz bands, and deploy 3G as a 2100MHz overlay, with 900MHz rural coverage from 2013. Deploy 4G from 2013 onwards. Consider S-RAN based on cost trend and opex adjustments
3.2.2	Spectrum allocations	Model an operator with spectrum in the 800MHz, 900MHz, 1800MHz and 2100MHz bands
3.2.3	Spectrum payments	Reflect average payments specified in the 2012 auction documentation and the 2100MHz spectrum licences
3.2.4	Mobile switching network	Deploy MSS+MGW layered equipment. Deploy an enhanced packet core (EPC) overlay for 4G
3.2.5	Mobile transmission network	Model a national leased dark-fibre network and self-provided transmission equipment (mainly microwave-based)
3.2.6	Network nodes	Apply the modified scorched-node principle

3.2.1 Radio network

In this section we consider 2G/3G deployments, 4G deployments, voice-over-LTE, voice-over-WiFi and S-RAN in turn.

[4] The proposed new MTR model assumes a market share of 25% prior to 2014, reflecting that at that time there were four such operators (prior to the merger of O2 and Three).

2G/3G deployments

There are three generations of radio technology standards that could be used, either in isolation or in combination. These are GSM (2G), UMTS (3G) and LTE (4G).

The previous MTR model explicitly considered both 2G and 3G technologies while 4G was only considered to the extent that it was assumed that an element of future data demand would be carried on 4G. Both 2G and 3G technologies are still proven, available and being used by all operators in Ireland. In particular, 3G is now also being used to offer extensive mobile broadband services.

It appears that 2G technology will retain a significant role in the provision of MVCT in Ireland in near to medium term (i.e. certainly into the future regulatory pricing period), with 3G also playing a large role in carrying MVCT. We thus believe it is still appropriate to include both technologies in the proposed new MTR model as an efficient mechanism for delivering mobile services and MVCT over the coming years.

We therefore assume that both technologies are deployed in a similar manner as in the previous MTR model; that is, 2G and 3G are both deployed from 2003 onwards. 2G is deployed using 900MHz and 1800MHz spectrum from launch, whilst 3G is deployed using 2100MHz from launch and then supplemented with 900MHz coverage in rural areas from 2013 onwards. Given the increase in 3G data traffic in recent years, the 3G network design is parameterised on the basis that the network is planned to be congested with data traffic. Specifically, rather than assuming that the modelled 3G mobile networks are voice-centric, we assume that they are more data-centric (but still supply voice services).

We have also implemented a cell-breathing calculation in the proposed new MTR model. Cell breathing takes places in a 3G network when traffic loads increase and the subsequent rise in the signal-to-noise ratio acts to reduce the range of the cell. This reduction in range is usually anticipated to be limited by the uplink communication. We assume the coverage cell radii inputs to the proposed new MTR model to be applicable for an uplink load of up to 50% on the cells in the 3G network.

In the absence of MVCT, it can be argued that the 3G cell radii can be assumed to be slightly larger, on the basis that the 3G network can be expected to carry a consistently smaller network loading over the whole of its lifetime. We estimate the multiplier to the radius based on the percentage of total 3G loading that is MVCT. This is done using a polynomial approximation that we have used in cost models in other countries, such as Denmark. Therefore, when MVCT is included, this multiplier is 1, and when MVCT is excluded this multiplier is greater than 1. Thus, some NodeBs are included in the avoided cost base and therefore the pure LRIC.

The calculation of this multiplier can be found on the *InNwDes* worksheet of the proposed new MTR model.

4G deployments

In the previous MTR model it was concluded that although 4G mobile technologies such as LTE could be deployed in the long term, 4G was expected to be largely focused on delivering higher-rate mobile data services. Given the large capacities available in a modern network using 900MHz, 1800MHz and 2100MHz frequencies, it is unlikely that a 4G overlay would be used to deliver large volumes of wholesale mobile voice termination in the short to medium term.

However, there are economies of scale and scope associated with deploying a 4G overlay with the 2G/3G networks, due to asset sharing. For example, 4G base stations can be co-located at existing radio network sites and can also share the use of the transmission networks. Based on our experience in other jurisdictions, the inclusion of 4G technologies in a mobile cost model has some impact on the pure LRIC of wholesale MVCT and a larger impact on the LRAIC+ of wholesale MVCT. 4G is also a proven technology in Ireland, having been deployed since 2013. In our view, therefore, 4G technology should be captured in the proposed new MTR model to understand its impact on the costs of MVCT (as a minimum from increased economies of scope). We assume that 4G technology will use the 800MHz and 1800MHz spectrum made available in the 2012 auction, with 3.6GHz spectrum being made available from 2018 onwards.

Point 12 of the 2009 EC Recommendation states that "the bottom-up model for mobile networks should be based on a combination of 2G and 3G employed in the network".[5] This reflects the technologies that were available at that time. The Recommendation went on to state that "the cost model should be based on the efficient technological choices available in the time frame considered by the proposed new MTR model, to the extent that they can be identified." When this was published in 2009, the efficient technology choice was 2G/3G, as 4G could not yet be identified. Today, however, 4G is an identifiable efficient technology choice, and so in our view it is justifiable to consider it in the modelling and in the timeframe considered.

VoLTE

We also believe that it is necessary to include the functionality of a VoLTE platform (as the next generation of mobile telephony), in order to understand the cost impact on wholesale MVCT within the forthcoming regulatory period. This will allow ComReg to assess the impact of considering VoLTE as a means of delivering wholesale MVCT in the future, as the technology emerges. Unlike other aspects of mobile networks, in our experience a VoLTE platform is a relatively simple set of assets to model, comprising a collection of centralised call-server electronics and software. We have therefore included a reference design that can be refined in the future, should Irish-specific data become available.

By default, the proposed new MTR model assumes that the VoLTE platform is not deployed, meaning that all forecast voice is carried using 2G and 3G networks. We believe this is currently

5 European Commission C(2009) 3359 final COMMISSION RECOMMENDATION of 7.5.2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU; see http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:124:0067:0074:EN:PDF.

reasonable, given the lack of Irish operator VoLTE deployments as of 2017 and therefore the lack of certainty in terms of modelling the costs of such a platform in the Irish context. Our reference design for VoLTE can be activated in future, once greater certainty arises.

VoWiFi

In February 2017, eir launched a voice-over-WiFi (VoWiFi) service in Ireland.[6] This method of calling allows voice call legs to be made over WiFi networks, in which case they do not need to be carried over mobile radio networks (and therefore only use the mobile core network assets).

In principle, a proportion of mobile-originated voice could be carried as VoWiFi in the proposed new MTR model, with these services having routeing factors that only use the core network assets. The extent to which VoWiFi may be used in the future is uncertain as it is dependent on WiFi network coverage and quality in Ireland, which is largely out of the control of the Irish MSPs.

We have implemented VoWifi network services in the new proposed MTR model, with an assumed proportion of 2G, 3G or 4G voice is carried over VoWiFi. However, there is no evidence at this point in time that VoWiFi traffic will form a material proportion of total mobile voice traffic in the long-run. We therefore have set our VoWiFi forecast to be zero in all years for the purposes of the proposed new MTR model.

S-RAN

The previous MTR model assumed that 2G BTS and 3G NodeBs would remain as separate pieces of equipment in the long term. In recent years, however, vendors have designed base stations that provide 2G and/or 3G and/or 4G functionality. This is referred to as single-RAN (S-RAN) equipment. Responses received from operators in response to the 13D information request indicate S-RAN is being used in Ireland.

If S-RAN were to be considered in the proposed new MTR model, this new technology would result in fewer base-station units (i.e. one per site). This would lead to lower operating costs per site (e.g. through more efficient power use), but there would be a significant capex outlay for new base-station units (which have a higher unit cost than any one of three radio technologies standalone, due to their greater functionality). Two options for modelling the impact of S-RAN would be:

- To dimension new ‘combined base station’ assets and sub-components, which are deployed as replacements for existing base stations over a defined period, or
- To adjust the unit cost levels of the standalone units and model a wide-scale replacement of these units to trigger appropriate levels of capex.

We considered that the first option would involve considerable effort to parameterise and then calculate the number of S-RAN assets deployed. This is because it would require a significant

[6] See https://www.eir.ie/WiFiCall/

number of network design inputs as well as matching cost inputs. We have therefore chosen to implement the second option in the proposed new MTR model, to enable S-RAN deployment to be considered through modification of the modern equivalent asset (MEA) unit costs.

For each standalone radio asset, we include a S-RAN-equivalent in the asset list (prefixed "S-RAN:") which is assumed to be activated in a given year (with the existing standalone assets deactivated in the same year). These assets are assumed to have an associated unit capex and unit opex that are a proportion of the standalone assets, using the same cost trends as the standalone assets.[7]

S-RAN is assumed to be activated in the proposed new MTR model from 2014 onwards.

3.2.2 Spectrum allocations

The spectrum holdings of the three current mobile network operators in Ireland are shown in Figure 3.7. We have assumed that the generic operator has one-third of the available spectrum within each band from 2013 onwards, rounded to the nearest block size of 5MHz.

Figure 3.7: Spectrum holdings by operator and band, in MHz [Source: ComReg website,[8] 2018]

Operator	800MHz	900MHz	1800MHz	2100MHz	3.6GHz
Three	2×10	2×5 + 2×10	2×20 + 2×15	2×30	*100*
Vodafone	2×10	2×10	2×25	2×15	*85/105*
Meteor	2×10	2×10	2×15	2×15	*80/85*
Total	**2×30**	**2×35**	**2×75**	**2×60**	*265/290*
Generic operator	*2×10*	*2×10*	*2×25*	*2×20*	*2×45*

Prior to 2013, the spectrum holdings are consistent with the spectrum holdings from the previous MTR model. Specifically, this corresponds to 2×7.2MHz of 900MHz spectrum, 2×14.4MHz of 1800MHz spectrum and 2×15MHz of 2100MHz spectrum.

Each band can be assumed to be used for either capacity or coverage for one of the three radio technologies. Our choices for the generic operator are summarised in Figure 3.7 below.

Figure 3.8: Assumed use of spectrum holdings by band [Source: Analysys Mason, 2018]

Network layer	800MHz	900MHz	1800MHz	2100MHz
2G coverage		All years all geotypes		
2G capacity			All years all geotypes	

[7] We assume the costs of S-RAN asset opex is 70% of its standalone asset equivalent (i.e. 30% less, based on information contained in http://www.analysysmason.com/About-Us/News/Newsletter/Single-RAN-LTE-overlay-Oct2013-RDTW0/). We assume the same multiplier applied to S-RAN asset capex.

[8] Extracted from https://www.comreg.ie/industry/radio-spectrum/licensing/search-licence-type/mobile-licences/.

Network layer	800MHz	900MHz	1800MHz	2100MHz
3G coverage		From 2013 in the two rural geotypes		Default band for 3G coverage
3G capacity				All years
4G coverage	All years in both rural geotypes		From 2014 in the three non-rural geotypes	
4G capacity	From 2015 in the three non-rural geotypes		From 2015 in all geotypes	

The proposed new MTR model includes a cross-check on the *InByOp* worksheet to ensure that all spectrum holdings are allocated to one of these six uses.

We currently assume 3.6GHz spectrum is allocated to the generic operator for use from 2018 onwards. Our assumptions are based on the outcome of the auction.[9]

3.2.3 Spectrum payments

We have used the following sources for the spectrum payments:

- the 2100MHz spectrum licences, as published on the "Mobile licences" page of ComReg's website[10]
- ComReg's information notice, document 12/123, published following the auction of 800MHz, 900MHz and 1800MHz spectrum in 2012[11]
- Ofcom's analysis of the Irish 2012 spectrum auction[12]
- ComReg's publications on the 3.6GHz auction.[13]

We consider these in turn below.

Fees for 2100MHz spectrum

For the 2100MHz band, we consider the access fees and annual fees separately, having extracted the time series of access fee payments from the licences for each operator. From these values, we derive an average access fee per paired MHz over time. We also use the regular annual fees indicated by the licences to calculate an average annual fee per paired MHz over time. These fees are then added together, converted to real-terms 2017 EUR (the base currency of the proposed new MTR model) and applied to the modelled generic operator's allocation of paired 2100MHz spectrum. These costs are included directly in the proposed new MTR model as opex.

9 See https://www.comreg.ie/media/dlm_uploads/2017/06/ComReg-1746.pdf

10 See https://www.comreg.ie/industry/radio-spectrum/licensing/search-licence-type/mobile-licences/.

11 See https://www.comreg.ie/?dlm_download=information-notice-results-of-the-multi-band-spectrum-auction.

12 See https://www.ofcom.org.uk/__data/assets/pdf_file/0032/78629/annex_8.pdf.

13 See https://www.comreg.ie/industry/radio-spectrum/spectrum-awards/3-6ghz-spectrum-award/.

Fees for spectrum auctioned in 2012

The outcome of the 2012 auction was to specify final upfront fees and spectrum usage fees. We treat these as capex and opex respectively.

For ***spectrum usage fees*** prior to 2013, we use the values implied by the previous MTR model.

For spectrum usage fees from 2013 onwards, we use the values per paired MHz implied by band on p.10 of ComReg information notice, document 12/123, as these are applied to all operators and so could be assumed to be equally applicable to the generic operator. Since it is indicated that these fees are adjusted by inflation each year, we convert them to real-terms 2017 EUR and assume no real-terms change thereafter.

For the ***final upfront fees***, which vary by operator, we use the reserve spectrum fees for the 2013–2015 and 2015–2030 licences by band (page 10 of ComReg information notice, document 12/123) as a starting point for deriving upfront fees applicable to the generic operator.

We also use the relative spectrum values per MHz derived from the absolute values calculated by Ofcom in Table A8.7.3 of their report for their final statement on annual licence fees for the UK published in September 2015. These relativities are shown below in Figure 3.9.

Figure 3.9: Spectrum valuation multipliers relative to the 1800MHz band [Source: Ofcom, 2015]

Band	800MHz	900MHz	1800MHz
Multiplier	58.9/23.1=2.55	35.6/23.1=1.54	1.00

We also apply a global multiplier of 578,154 so that the total fees implied for all spectrum sold in the auction corresponds to what was actually paid by all operators in the auction (EUR481.7 million in 2012 EUR, as stated in page 5 of ComReg information notice, document 12/123). This is illustrated in Figure 3.10 below.

Figure 3.10: Illustration of spectrum fee calculation [Source: Analysys Mason, 2018]

Band	Spectrum allocated (MHz)	Duration	Reserve price per paired MHz (EURm)	Fee per paired MHz (EUR)	Estimated price paid (EURm)
800MHz	2×30	2013–2015	0.510	2.55×578,154	44.2
900MHz	2×30	2013–2015	0.510	1.54×578,154	26.7
1800MHz	2×45	2013–2015	0.255	1.00×578,154	26.0
800MHz	2×30	2015–2030	1.652	2.55×578,154×(1.652/0.510)	143.3
900MHz	2×35	2015–2030	1.652	1.54×578,154×(1.652/0.510)	101.0
1800MHz	2×75	2015–2030	0.826	1.00×578,154×(0.826/0.255)	140.5
Total					**481.7**

These fees per MHz are then applied to the spectrum holdings of the generic operator. We assume that the fees for a 2013–2015 licence were incurred in 2012 and those for the 2015–2030 licence in

2015. We also assume that the 2015 upfront fee is paid again (i.e. no change in real terms) in 2030, as our modelling assumption for future spectrum fees.

Other fees

The assumed capex for 3.6GHz spectrum is set to the population-weighted average capex paid per MHz by the three MNOs. The assumed opex is based on the population-weighted average spectrum usage fee paid by the three MNOs.

Regarding other spectrum bands being awarded in the future (700MHz, 1.4GHz, 2.3GHz etc.), we understand there are no plans set out for the award structure and timing, meaning that any assumption on spectrum payments (and allocations) would be entirely speculative.

We do not believe it is appropriate to include these other three bands at this time. In particular, the proposed new MTR model makes a trade-off of deploying fewer sites with more spectrum, which is a trade-off that needs to be reflected through the assumed accompanying spectrum payments.

3.2.4 Mobile switching network

A single-technology radio network would employ either legacy (single-generation) switches or a next-generation switching structure. The switching network for a combined 2G+3G radio network could either be:

- two separate 2G and 3G structures with separated transmission, each containing one or more interlinked MSCs, GSNs and points of interconnect
- one upgraded legacy structure with a combined transmission network, containing one or more interlinked MSCs, GSNs and points of interconnect that are both 2G- and 3G-compatible
- a combined 2G+3G switching structure with a next-generation IP transmission network, linking pairs of media gateways (MGWs) with one or more MSSs, data routers and points of interconnect, separated into circuit- and packet-switched layers.

The 2009 EC Recommendation suggests that the switching network layer “could be assumed to be NGN-based”. Mobile switching networks have been evolving for many years now, and an operator entering the market today would certainly deploy the latest technology; even existing operators have upgraded their networks. Consequently, the mobile switching network(s) that must be modelled is closely related to the timeframe of the hypothetical existing operator (which upgrades legacy MSC switches in conjunction with 3G deployment and then again for 4G deployment).

To capture the upgrades necessary for 4G network deployment, we have assumed the use of an industry-standard enhanced packet core (EPC) architecture. The main components of an EPC architecture are deployed as an overlay, and comprise:

- serving gateway (SGW) – routes data between the end-user device and external networks
- mobility management entity (MME) – main node for signalling control (for mobility/security).

We have included these assets in the proposed new MTR model.

The introduction of VoLTE requires the deployment of an IP multimedia subsystem (IMS) in the core network. The main component in an IMS core is the call server (CS), which contains several voice service functions. Session border controllers (SBCs) and telephony application servers (TASs) must also be deployed to manage voice services (in particular, the TAS manages call forwarding, waiting and transferring). The VoLTE platform must also communicate with the 4G data platform (via the MME/SGW), and so upgrades are required to certain existing network elements such as the MSS.

A VoLTE platform shares many of the components of a VoIP platform in a fixed network. Therefore, in principle, the assumed costs of the VoLTE platform in the proposed new MTR model could be calibrated using inputs related to VoIP platforms captured in any cost modelling used by ComReg for the pricing of FVCT.

3.2.5 Mobile transmission network

Connectivity between mobile network nodes falls into a number of types:

- base-station last-mile access (LMA) to a hub
- hub to BSC or RNC (if applicable)
- BSC or RNC to main switching sites (containing MSC or MGW) if not co-sited
- between main switching sites (between MSC or MGW).

Typical solutions for providing transmission include:

- leased lines (E1, STM1 and higher, 100Mbit/s and higher)
- self-provided microwave links (2-4-8-16-32, STM1 microwave links, Ethernet microwave)
- leased fibre network (leased/dark fibre with either STM or Gbit fibre modems).

The choice of mobile network transmission varies among the actual mobile operators and can change over time. An operator today would most likely adopt a scalable and futureproof Ethernet-based transmission network (though the exact purchase of the transmission of this network may depend on the prevailing preferences of the operator).

We believe it is reasonable to model a modern mobile network transmission architecture. This implies a national fibre network for collecting and carrying traffic back to the main switching sites (assumed to be located at several geographically separate locations in Dublin) and carrying traffic between these sites. 2G equipment that was available in 2003 would typically have relied on STM1 interfaces, and the layered core network switches (MSS–MGW) would typically be based on Gbit/s IP interfaces. The choice between leasing managed STM/Gbit services and self-supply of transmission equipment is likely to vary depending on the strategic decisions and partnerships of each mobile operator; however, we have modelled leased dark fibre with self-supplied transmission equipment.

We recognise that real operators use different mixes of leased-line and microwave backhaul. Based on operator data, we have chosen to apply predominantly microwave links (on the basis that this is an efficient approach for backhaul transmission, particularly in rural areas), with a smaller proportion of leased lines (in Dublin and smaller cities). The use of self-provided microwave backhaul links should provide a reasonably efficient upgrade path for HSPA and 4G sites, as microwave capacity upgrade costs are relatively small once the primary link is established. We have also modelled the options for faster Ethernet-based microwave, which will have the necessary capacity for the 4G radio network.

3.2.6 Network nodes

Mobile networks can be considered as a series of nodes (with different functions) and links between them. When developing a deployment algorithm for these nodes, it is necessary to consider whether the algorithm accurately reflects the actual number of nodes deployed. Allowing the proposed new MTR model to deviate from the operators' actual number of nodes may be justified in the situation where the operators' network is not viewed as efficient or modern in design.

Specification of the degree of network efficiency is an important costing issue. When modelling an efficient network using a bottom-up approach, several options are available:

Actual network — This approach implements the exact deployment of the real operator without any adjustment to the number, location or performance of network nodes.

Scorched-node approach — This approach assumes that the historical locations of the actual network node buildings are fixed, and that the operator can choose the best technology to configure the network at and between these nodes to meet the optimised demand of an efficient operator. For example, this could mean replacing legacy equipment with best-in-service equipment.

The scorched-node approach, therefore, determines the efficient cost of a network that provides the same services as the incumbent network, taking as given the current location and function of the incumbent's nodes.

Modified scorched-node approach — The scorched-node principle can be reasonably modified in order to replicate a more efficient network topology than that currently in place. Consequently, this approach takes the existing topology and eliminates inefficiencies. In particular, it can mean:

- simplifying the switching hierarchy (e.g. reducing the number of switching nodes, or replacing a number of small switches with a larger modern switch)
- changing the functionality of a node (e.g. reducing a small exchange to the equivalent of a remote multiplexer, upgrading a picocell base station

location to be for a macrocell base station instead[14], or removing remote BSCs at hub sites and using BSCs co-located with MSCs).

Scorched-earth approach

The scorched-earth approach determines the efficient cost of a network that provides the same services as actual networks, without placing any constraints on its configuration, such as the location of the network nodes. This approach models what an entrant would build if no network existed, based on a known location of customers and forecasts of demand for services.

This approach gives the lowest estimate of cost, because it removes all inefficiencies due to the historical development of the network, and assumes that the network can be redesigned perfectly to meet current criteria.

The previous MTR model adopted a modified scorched-node approach to the modelling of mobile networks and we have chosen to retain this approach in the proposed new MTR model. The modified scorched-node approach dimensions a hypothetical network that is comparable to actual operator node counts, whilst ensuring that the network design is modern and reasonably efficient, reflecting for example the modern approach to deploying equipment functionality at different nodes in the network. This calibration to actual node counts has been achieved using ComReg's mobile site database, as described in Section 3.1.2 and illustrated in Annex C.

3.3 Services

The following service-related concepts are considered in this section.

Figure 3.11: Decisions on the service-related conceptual issues [Source: Analysys Mason, 2018]

Section	Conceptual issue	Conclusion for ComReg's proposed new MTR model
3.3.1	Service set	Provide all the commonly available Irish mobile services (both voice and non-voice)
3.3.2	Traffic volumes	Apply a market-average profile to the modelled 1/N operator
3.3.3	Points of interconnect	Mobile interconnection will be modelled at two points
3.3.4	Wholesale or retail costs	Only wholesale network costs will be included in the proposed new MTR model

3.3.1 Service set

Economies of scope and scale, arising from the provision of both voice and data services across a single infrastructure, will reduce the unit cost for voice and data services. This is particularly true for networks built on modern architectures, where voice and data services can be delivered via a single platform.

[14] A macrocell is a standard radio network base station, whereas a picocell is a smaller base station that is deployed, for example, to provide extra capacity to a traffic hotspot.

As a result, a full list of services must be included in the proposed new MTR model, as a proportion of network costs will need to be allocated to these services. This also implies that both end-user and wholesale voice services need to be modelled, so that the voice platform is correctly dimensioned and costs are fully recovered from the applicable traffic volumes.

Some of the non-voice services are proven services (particularly services like SMS on mobile networks). However, other non-voice services, such as 4G mobile broadband, can give rise to forecast uncertainty when included in the regulated prices for voice. It is necessary to understand the implications for voice costs of the forecast made for such uncertain non-voice services – and as a result, the proposed new MTR model is capable of considering a range of forecast scenarios to maximise understanding in such areas. The services that we consider are as follows.

Figure 3.12: Mobile network traffic services [Source: Analysys Mason, 2018]

Service	Service explanation
On-net mobile calls	Voice calls between two subscribers (retail, MVNO or inbound roamer) of the modelled operator
Outgoing calls to other mobile operators	Voice calls from a subscriber (retail, MVNO or inbound roamer) of the modelled operator to another domestic mobile operator
Outgoing mobile calls to fixed	Voice calls from a subscriber (retail or MVNO or inbound roamer) of the modelled mobile operator to a fixed destination (including non-geographic numbers, etc.)
Outgoing calls to international	Voice calls from a subscriber (retail, MVNO or inbound roamer) of the modelled mobile operator to an international destination
Domestic incoming	Voice calls received from another mobile or fixed operator and terminated to a subscriber (retail, MVNO or inbound roamer) of the modelled operator
International roaming (inbound) to mobile	Voice calls received from an international operator and terminated to a subscriber (retail, MVNO or inbound roamer) of the modelled operator
Voice-over-WiFi	Voice calls carried over a public WiFi network rather than the mobile radio network of the modelled operator
On-net SMS	SMS between two subscribers (retail, MVNO or inbound roamer) of the modelled operator
Outgoing SMS	SMS from a subscriber (retail, MVNO or inbound roamer) of the modelled operator to another network operator
Incoming SMS	SMS received from another operator and terminated to a subscriber (retail, MVNO or inbound roamer) of the modelled operator
On-net MMS	MMS between two subscribers (retail, MVNO or inbound roamer) of the modelled operator
Outgoing MMS	MMS from a subscriber (retail, MVNO or inbound roamer) of the modelled operator to another operator
Incoming MMS	MMS received from another operator and terminated to a subscriber (retail, MVNO or inbound roamer) of the modelled operator
2G packet data	Megabytes of packet data (excluding IP overheads) transferred to and from a subscriber (retail, MVNO or inbound roamer) using the 2G data network
Release-99 (low-speed) packet data	Megabytes of packet data (excluding IP overheads) transferred to and from a subscriber (retail, MVNO or inbound roamer) using the 3G low-speed data network (Release-99 bearers)

Service	Service explanation
HSDPA packet data	Megabytes of packet data (excluding IP overheads) transferred to a subscriber (retail, MVNO or inbound roamer) using the HSPA network
HSUPA packet data	Megabytes of packet data (excluding IP overheads) transferred from a subscriber (retail, MVNO or inbound roamer) using the HSPA network
4G packet data	Megabytes of packet data (excluding IP overheads) transferred from a subscriber (retail, MVNO or inbound roamer) using the 4G network

The voice and SMS services set out above are also modelled separately for each radio technology on which they are carried (i.e. 2G, 3G and 4G), in order to capture the different levels of resources consumed by a unit of traffic on each radio technology.

3.3.2 Traffic volumes

A holistic approach to forecasting traffic evolution is required, for consistency in the forecasting of voice between the fixed and mobile networks in Ireland. Consequently, the voice forecasts used in the cost models developed for costing FVCT and MVCT will need to be aligned (for example the fixed-to-mobile voice in the two models should be aligned, after adjusting for market share if required).

The volume of traffic associated with the subscribers of the modelled hypothetical existing operator is the main driver of costs in the network, and the measure by which economies of scale and scope can be exploited.

Given our decision to adopt an operator with a market-average scale in Section 3.1, this scale is applied to the total volumes applicable to the market with one exception. In the previous MTR model, actual data volumes included in the model for the period 2007–2013 were reduced by 33%. For continuity purposes, we have applied a 33% reduction to actual data volumes for the period 2007–2013, but for 2014 onwards in the new model we apply the full market data volumes (i.e. no reduction).

3.3.3 Points of interconnect

Interconnection to mobile networks is typically offered at a national level, because the interconnecting operator typically does not know where the mobile subscriber is, so it is sometimes necessary to route a call across the mobile network when the handset is in another region of the country.

Based on data received following the 13D information request, on average operators have points of interconnect at two distinct locations. Therefore, we believe that interconnection to other networks can be carried out efficiently at two points (which allows for redundancy in the event of equipment failure).

3.3.4 Wholesale or retail costs

The costs of a business's retail activities can be assumed to be either separated or integrated within the business, as illustrated in Figure 3.13 below.

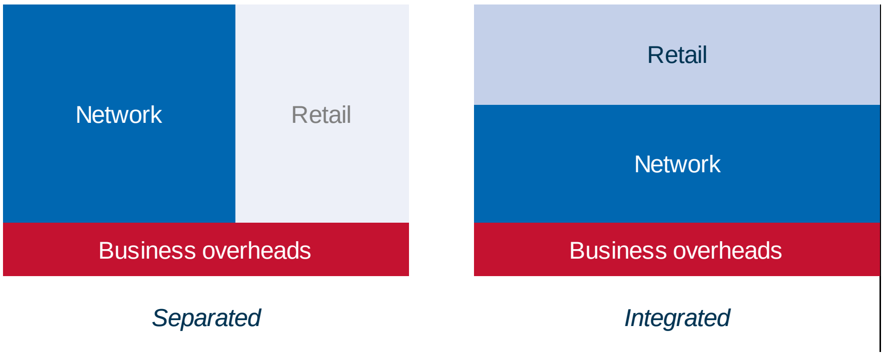


Figure 3.13: Options for consideration of retail costs [Source: Analysys Mason, 2018]

In the *separated* case, network services (such as traffic) are costed separately from retail activities (such as handset subsidy or brand marketing). Business overheads are then marked up between network and retail activities, and the wholesale cost of supplying mobile termination is only concerned with the costs of the network plus a share of business overheads attributable to the network.

In the *integrated* case, retail costs are considered integral to network services and included in service costs through a mark-up, along with business overheads. Consequently, there is no concept of 'wholesale' access to mobile termination in the integrated case, as all retail costs are included in the service costing.

To date, ComReg has identified its market analysis as that relating to the wholesale MVCT market. As such, we have considered only those costs that are relevant to the provision of the wholesale network termination service in a vertically separated business. However, costs that are common to network and retail activities *may* be recovered from both wholesale network services and retail services. This are treated as a mark-up to the network incremental costs (though they are excluded from the pure LRIC by definition).

A vertically separated approach results in many non-network costs being excluded from the cost of MVCT. However, it brings with it the need to consider the proportion of business overheads to be defined as the share attributable to network services as opposed to retail operations. (in the LRAIC+ calculation).

3.4 Implementation

The following implementation-related concepts are considered in this section.

Figure 3.14: Decisions on the implementation-related conceptual issues [Source: Analysys Mason, 2018]

Section	Conceptual issue	Conclusion for ComReg's proposed new MTR model
3.4.1	Increment approaches	Calculate pure LRIC and LRAIC+

3.4.2	Depreciation method	Use economic depreciation, starting from 2003
3.4.3	Modelling timeframe	Employ a 50-year modelling timeframe
3.4.4	WACC	Use value derived by ComReg
3.4.5	Mark-up mechanism	Use EPMU for LRAIC+. No mark-up is required in the pure LRIC case. Calculate unrecovered costs from using pure LRIC

3.4.1 Increment approaches

Sections 3.2 and 3.3 of the Analysys Mason report entitled "Pricing principles and methodologies for future regulation of wholesale voice call termination services" state that the capability to calculate a pure LRIC increment is required and will be included in the proposed new MTR model.

We have also implemented a LRAIC+ model, as this allows a comparison with the total costs of the network, rather than just the avoidable costs. The proposed new MTR model also allows the calculation of costs that are notionally "unrecovered" from terminated voice if pure LRIC is used rather than LRAIC+.

3.4.2 Depreciation method

Section 5.2 of the principles report describes the depreciation methods available in more detail.

Recital 18 of the 2009 EC Recommendation does state a preference for economic depreciation and therefore we have implemented a multi-year calculation capable of calculating economic depreciation. This can reflect the dynamically efficient build-up of assets over successive technology generations (2G, 3G and 4G). Our depreciation calculation is described in more detail in Section 8.

This method requires a start date for the dynamically efficient hypothetical existing operator to be defined. Consistent with the previous MTR model, we assume a start date of 2003 for the calculation. The modelling timeframe, in terms of the years that can be calculated, is considered further in Section 3.4.3 below.

3.4.3 Modelling timeframe

The time series, namely the period of years across which demand and asset volumes are calculated in the proposed new MTR model, is an important input. A long time-series:

- allows the consideration of all costs over time, providing the greatest clarity within the proposed new MTR model as to the implications of adopting economic depreciation
- provides greater clarity on the recovery of all costs incurred from services
- provides a wide range of information with which to understand how the costs of the modelled operator vary over time and in response to changes in demand or network evolution.

The time series itself should be equal to the lifetime of the operator, allowing full cost recovery over the entire lifetime of the business. However, it is impractical to identify the lifetime of an operator.

Hence, we have assumed that the time series should be at least as long as the longest asset lifetime used in the proposed new MTR model.

The previous MTR model had a modelling timeframe of 2003–2033. We believe it is reasonable to continue using 2003 as the assumed first year of the modelled operator. However, since the proposed new MTR model must also consider 4G deployments (which we assume are deployed from 2013 onwards), we are of the view that the option to model costs over a longer timeframe is beneficial, since 20 years after 2013 may be insufficient for considering the long-run costs of the 4G network (particularly if additional sites are required).

For a cost model of mobile networks, the longest-lived assets (such as owned sites) are normally of the order of 25 years, and a longer modelling time series of 50 years is often used. The discounting of costs in years beyond this period would be such that any terminal value would be minimal. Therefore, we have chosen a modelling timeframe of 2003–2053 for the proposed new MTR model.

3.4.4 WACC

ComReg has a value of 8.63% for the nominal pre-tax weighted average cost of capital (WACC), as published in ComReg Document 14/136 and D15/14.[15] This value is used in the proposed new MTR model (and was also applied in the previous MTR model). Since the proposed new MTR model works in real 2017 EUR, the 8.63% figure for WACC is first transformed into a real-terms WACC over time by removing inflation (in the same way as in the previous MTR model), which we base on the consumer price index (CPI). Historical values for the CPI are sourced from the Central Statistics Office (CSO), while forecast values are taken from the Bank of Ireland.[16]

3.4.5 Mark-up mechanism

Non-incremental costs may be included in the final cost result of mobile termination, according to the different increment definitions discussed in Section 3.4.1. These can include:

- Traffic common costs – parts of the deployed traffic-driven network that are common to all network services (e.g. the mobile licence fee)
- Non-network common costs, or ‘business overheads’, common to network and retail services – cost components that are common to all functions of the business (e.g. the CEO’s salary).

The 2009 EC Recommendation specifically excludes the recovery of common costs from voice termination. However, (part of) the common costs have usually been included in the cost boundary in the past (i.e. as within the LRAIC+ approach). The proposed new MTR model therefore includes the option to recover common costs from the voice termination service when using the LRAIC+ approach. Where common costs are not directly allocable, an alternative allocation mechanism is

15 See https://www.comreg.ie/media/dlm_uploads/2015/12/ComReg14136.pdf, Table 1.

16 For historic information, see http://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/Define.asp?maintable=CPA01&PLanguage=0. For the forecast information, see the outlook reports published on https://corporate-economy.bankofireland.com,

required if the common costs are to be included in the final cost results from the proposed new MTR model. Two methods are commonly discussed:

Equi-proportionate mark-up (EPMU)	In this method, the incremental cost of all increments is increased by the same percentage. The percentage is calculated as the ratio of total common costs to total incremental costs. Applying an EPMU is straightforward, and results in a uniform treatment of all the service costs in the business, as well as not requiring any supporting information.
Ramsey pricing, and its variants	In Ramsey pricing, the common costs are marked up using a calculation that relies upon the elasticities of the various services consumed. By marking up common costs in proportion to inverse elasticities, the common costs are loaded onto inelastic services, leaving more sensitive services to bear a lower burden of common costs. Ramsey pricing can also be defined to consider cross-elasticities and externality benefits. Economically, this approach can therefore aim to maximise service consumption. The application of Ramsey pricing requires additional aspects of the calculation to be specified: the precise method for calculating the mark-up and relevant price elasticities, and possibly also welfare externality parameters.

In ComReg's recent consultation on the pricing of services for Markets 3a and 3b, other options are set out for allocation of shared costs. In particular, ComReg proposed to allocate traffic costs on the fixed core network using revenue per user[17].

We note the ERG's view that Ramsey pricing is practically infeasible due to the complex and dynamic information requirements regarding demand elasticities.[18] In their fixed core modelling, ComReg have taken the view that allocation by revenue per user is an approximation of Ramsey pricing. We note that this approach is feasible in this case, as most revenue can be attributed to the different traffic types (e.g. leased line revenue is separable from broadband revenue).

However, we do not believe this to be the case in mobile networks, where a high proportion of revenue arises from subscription payments rather than traffic usage. Therefore, attributing all revenue to different traffic types would require an allocation mechanism to be agreed upon.

Therefore, we do not believe that ComReg's preferred approach in the fixed network modelling can be replicated in the mobile network modelling.

Moreover, the use of an EPMU for the mark-up of common costs in the modelling of mobile networks is supported by regulators and practitioners because it is fair, objective and easy to implement. It is also consistent with regulatory practice used predominantly in the EU.

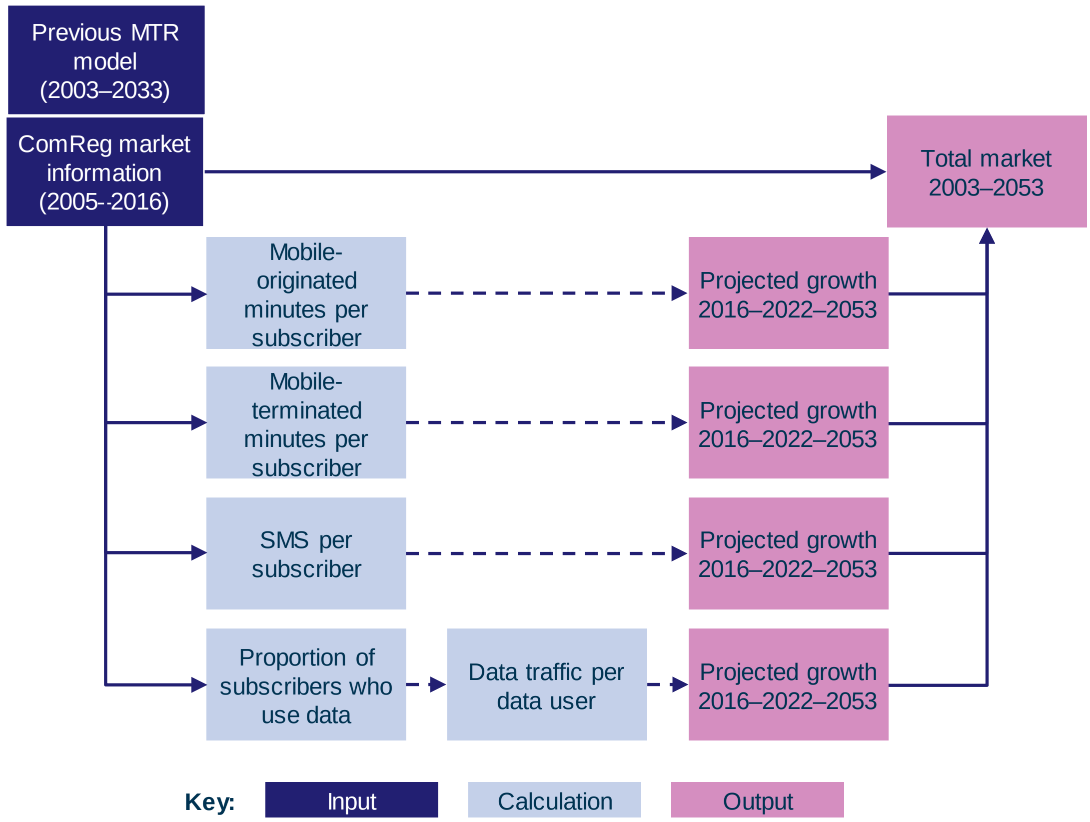
17 ComReg document 17/26, Section 8.5.8. See https://www.comreg.ie/publication-download/pricing-wholesale-services-wholesale-local-access-wla-market-wholesale-central-access-markets.

18 ERG COMMON POSITION: Guidelines for implementing the Commission Recommendation C (2005) 3480 on Accounting Separation & Cost Accounting Systems under the regulatory framework for electronic communications, p.23.

4 Market calculations

The proposed new MTR model uses ComReg statistics on the total market in Ireland, supplemented by information provided by Irish mobile network operators and the previous MTR model, to drive the forecasts for both mobile market subscribers and traffic. This market information is then rearranged to suit the categories used in the proposed new MTR model itself. Voice, SMS and data traffic are treated separately.[19] Voice and SMS are split into sub-categories: *incoming*, *outgoing* and *on-net* traffic. All three are also split into the different radio technologies used. An outline of the market calculation is shown in Figure 4.1.

Figure 4.1: Market calculation framework [Source: Analysys Mason, 2018]



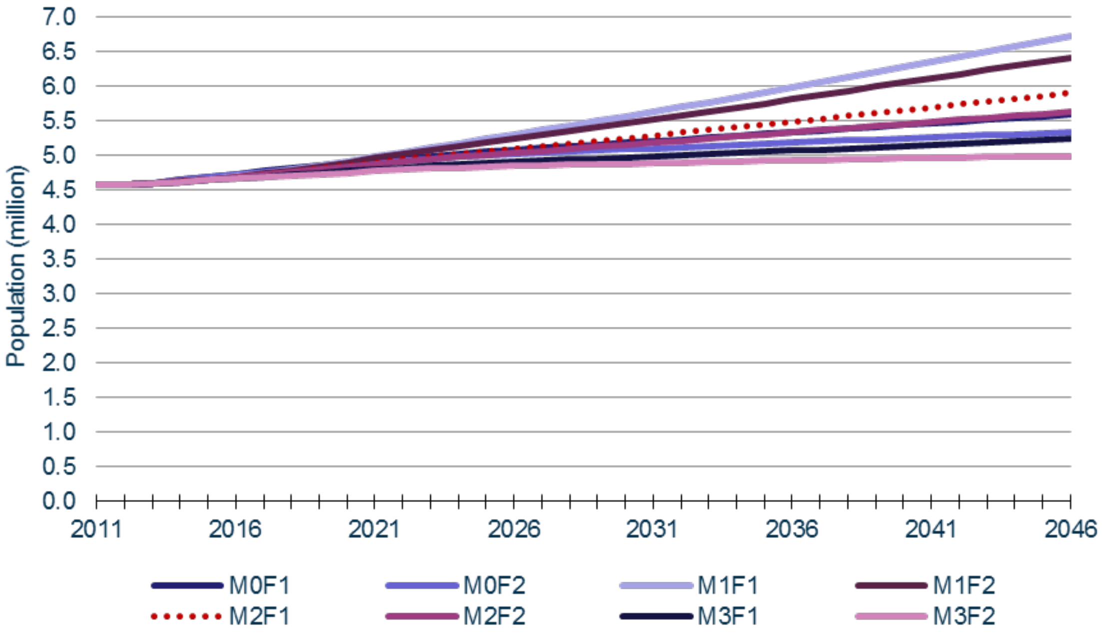
The rest of this section describes the voice traffic (Section 4.2) and data traffic (Section 4.3) captured in the proposed new MTR model, and concludes with a summary of the structure of the *InMkt* worksheet (Section 4.4).

19 SMS has very little impact on the mobile network deployment.

4.1 Population and penetration

Our population time series is taken from sources published by the CSO. Our forecast is based on the "M2F1" scenario published by the CSO in 2016 for the period 2011-2046.[20] The CSO has published eight forecasts, as shown in Figure 4.2 below.[21] We have chosen the M2F1 scenario (the red dotted line below) as the forecast that is closest to the midpoint of the eight forecasts. This is consistent with the choice made for the previous MTR model.

Figure 4.2: Comparison of CSO forecasts [Source: CSO, 2016]



Our historical time series for 2003–2016 is taken from a separate publication by the CSO.[22] Historical values for 2011–2016 are also provided by the CSO with its forecasts, but there is a small discrepancy (less than 0.5% in percentage terms) between the two sources. We have therefore applied the year-on-year percentage growth indicated by the CSO forecast to the historical time series for 2003-2016 from 2016 onwards. Our population forecast is shown in Figure 4.3 below, which reaches 5.62 million people by 2046. We will revisit these forecasts when finalising the proposed new MTR model should CSO issue updated versions.

20 See http://www.cso.ie/en/statistics/population/populationandlabourforceprojections2016-2046/.

21 These eight options reflect different combinations of assumptions regarding migration ('M') and population fertility ('F'). The M0 case assumes zero migration, M3 assumes a negative net migration in all years, whilst M1/M2 assume a positive net migration from 2016/2018 onwards respectively. The F1 case assumes a constant fertility rate from 2010 onwards, whilst the F2 case assumes a decrease in the fertility rate until 2026.

22 See http://www.cso.ie/en/releasesandpublications/er/pme/populationandmigrationestimatesapril2016/.

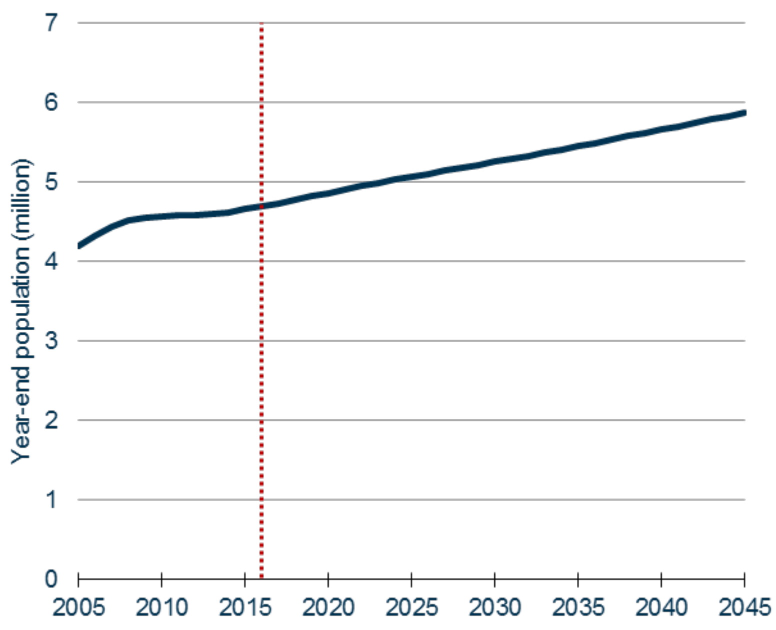


Figure 4.3: Population forecast for Ireland [Source: CSO, 2018]

4.2 Voice traffic

Historical total voice traffic and subscribers from 2005 to 2016 are used to derive a forecast for the duration of the proposed new MTR model. Usage per subscriber is then assumed to have reached a steady state, remaining constant from 2021 onwards. This evolution is shown in Figure 4.4.

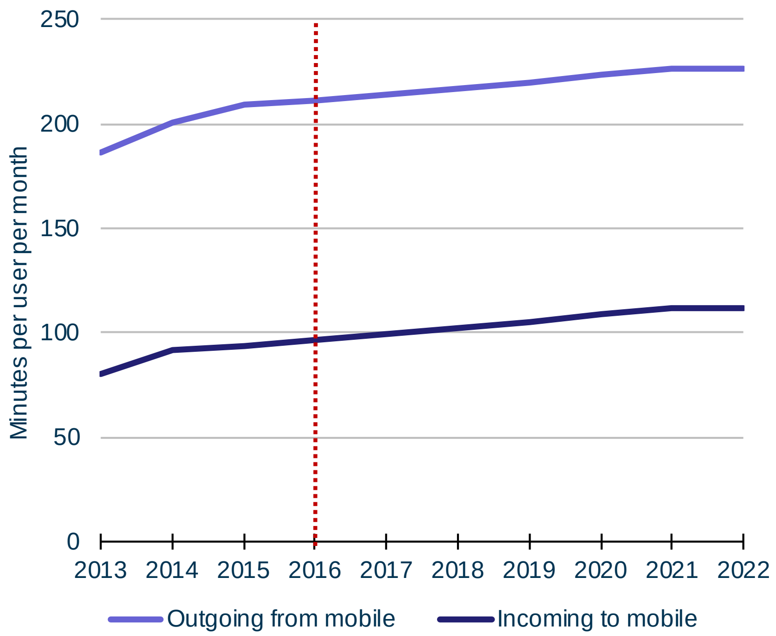


Figure 4.4: Evolution of voice usage in Ireland [Source: ComReg and Analysys Mason, 2018]

From this voice traffic by user, and assuming the number of voice users remains constant from 2021 onwards, total voice traffic is calculated for on-net, outgoing off-net and incoming off-net voice. These three categories are added up in Figure 4.5, showing that total voice traffic is forecast to rise only in line with population growth from 2021 onwards.

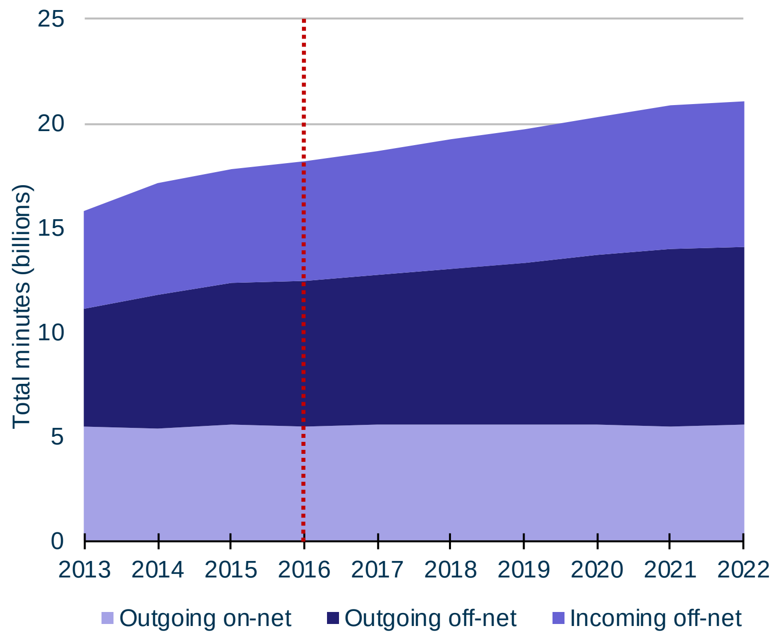


Figure 4.5: Evolution of total voice usage in Ireland [Source: ComReg and Analysys Mason, 2018]

In the previous MTR model, the share of voice traffic carried by the 2G network fell to 20% in the long run. We have retained this for the proposed new MTR model, as shown in Figure 4.6 below.

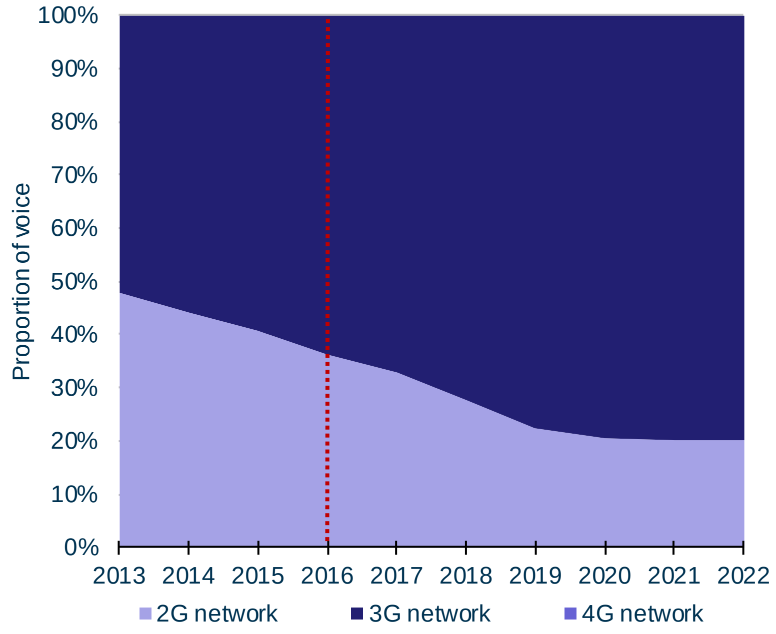


Figure 4.6: Evolution of the split of voice traffic by technology, when assuming no VoLTE is deployed [Source: ComReg and Analysys Mason, 2018]

The proposed new MTR model also includes the functionality to migrate voice traffic to a VoLTE platform. We have included a conservative forecast of VoLTE traffic, in case ComReg decides to explore this option once plans for VoLTE technology in Ireland crystallise. The split of the remaining voice between the 2G and 3G networks is then assumed to occur in the same relative proportions as assumed in 2G/3G-only case shown in Figure 4.6 above. This is illustrated in Figure 4.7 below.

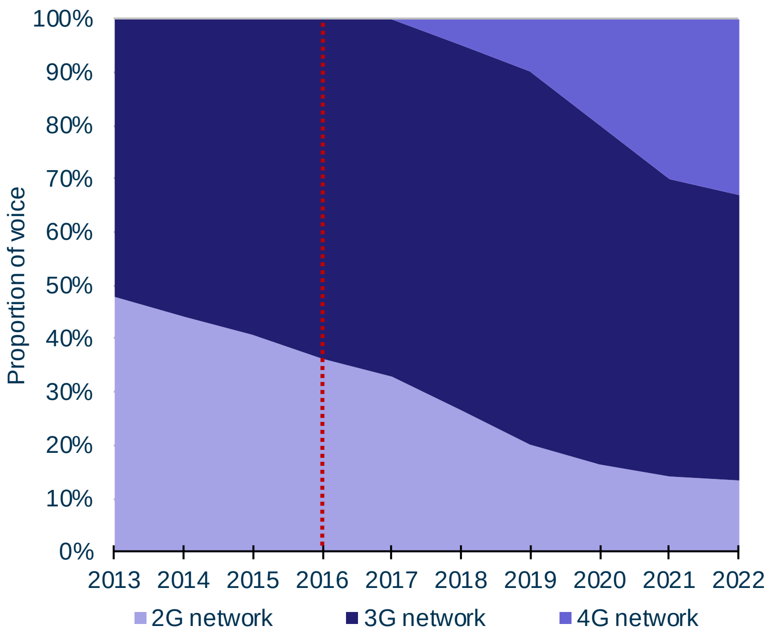


Figure 4.7: Evolution of the share of voice traffic by technology, when including the VoLTE forecast [Source: ComReg and Analysys Mason, 2018]

4.3 Data traffic

Our starting point for the data forecasts has been those published by ComReg in 2015, underlying its cost–benefit analysis of a change in use of the 700MHz band.[23] These three cases, referred to as Low, Medium and High scenarios, are illustrated in Figure 4.8 below.

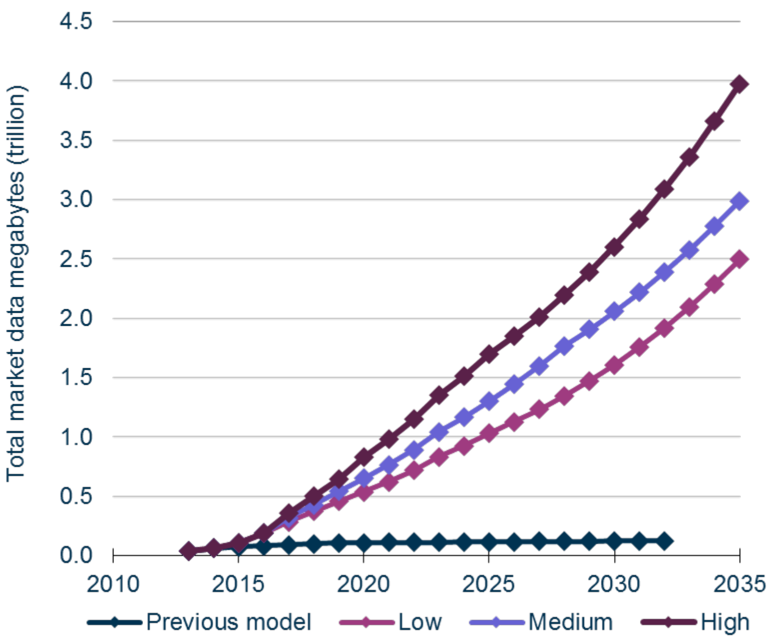


Figure 4.8: Data forecasts (total megabytes) published by ComReg in 2015 [Source: ComReg, 2018]

These forecasts were developed taking into account increased mobile penetration and usage per device, population growth, WiFi offload and declining use of legacy technology handsets. In

23 ComReg Information Notice 15/62. In particular, see https://www.comreg.ie/csv/downloads/ComReg1562a.pdf, Figure 4.

addition, it does not assume the use of future mobile technologies, so it is assumed to be carried by the technologies we have included explicitly in the proposed new MTR model.

In relation to the data forecast, there are several key choices that have to be made on the *Control* worksheet in the proposed new MTR model. These are:

- The starting point forecast – we have chosen the Low forecast, as this corresponds most closely to the actual market volumes in the period 2014–2016
- Whether to apply a 33% reduction to the historical data volumes, as per the previous MTR model – we do currently apply this reduction.
- The first year in which flat usage per subscriber is assumed –we have assumed 2035 (the final year of the data forecast provided by ComReg).

The proposed new MTR model then calculates its own data forecast using these inputs, by calculating the megabytes of usage per data subscriber per month until the first year of flat usage (2036), and then applying this usage per subscriber to the forecast subscriber base in future years. Our resulting forecast usage per data subscriber is illustrated in Figure 4.9 below.

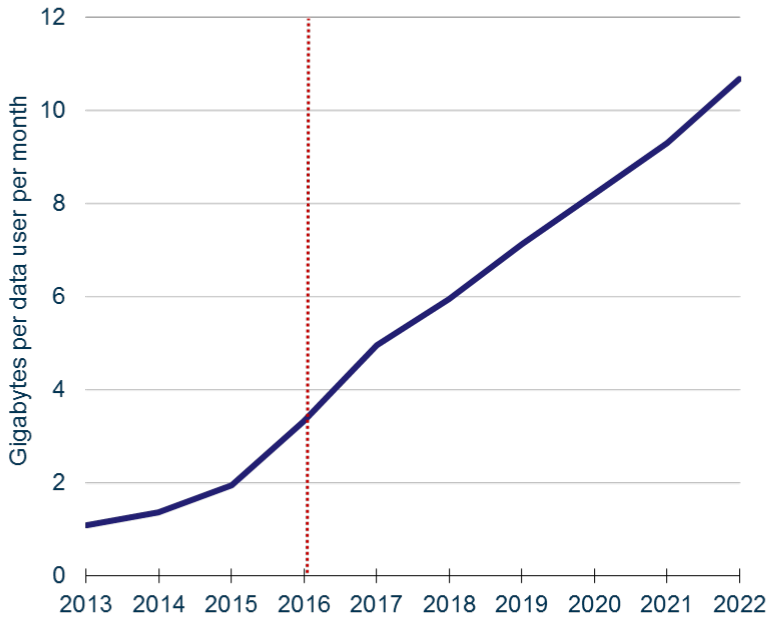


Figure 4.9: Forecast of data consumption per subscriber [Source: ComReg and Analysys Mason, 2018]

This significant increase in volume on a year-to-year basis leads to a corresponding increase in the number of sites and base stations, as no new spectrum is made available in the proposed new MTR model. This is a standard approach in regulatory costing so as not to preclude these future market developments. The resulting forecast of total megabytes is shown in Figure 4.10 below.[24]

24 We note that the report indicates that this data forecast is for 3G and 4G technologies only.

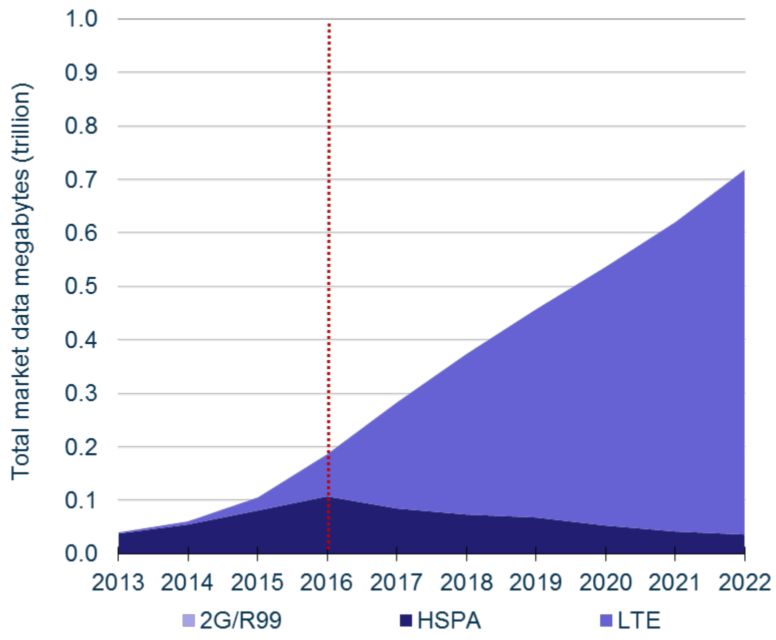


Figure 4.10: Forecast of total megabytes modelled in the Irish market [Source: ComReg and Analysys Mason, 2018]

In the early years of the proposed new MTR model (prior to 2013), the High-Speed Packet Access (HSPA) radio network upgrades area assumed to carry almost all of the 3G data traffic (HSDPA for the downlink traffic and HSUPA for the uplink traffic). 2G and 3G Release-99 (R99) volumes rapidly become a negligible proportion of data traffic. Since 2013, 4G has rapidly grown to account for almost 40% of the total data traffic by 2016, and is forecast to reach 90% by 2022. Meanwhile, HSPA is projected to decline to 10% of data traffic, as shown in Figure 4.11 below.

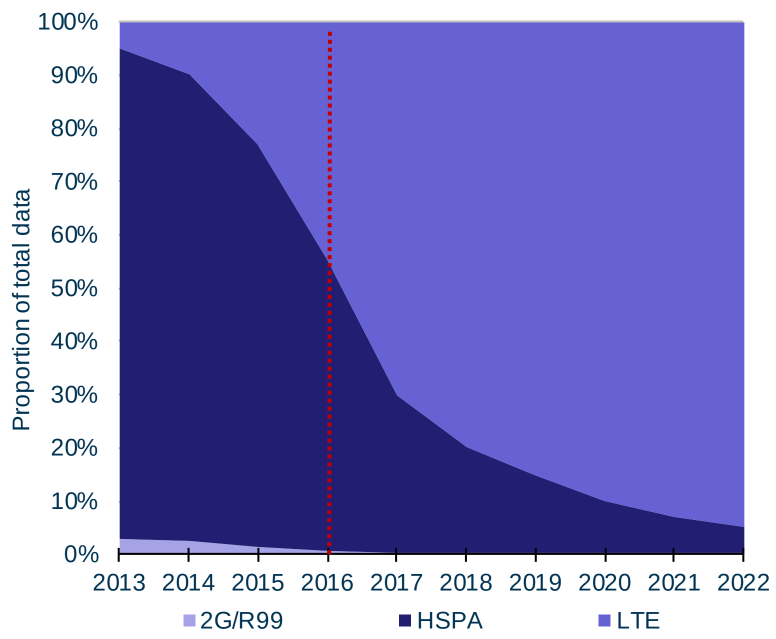


Figure 4.11: Evolution of the share of data traffic by technology [Source: ComReg and Analysys Mason, 2018]

4.4 *InMkt* worksheet

1. Quarterly market data	• Collates data from the quarterly ComReg market statistics from 2005 to Q3 2017
2. Historical market information	• Reorders the data into the categories used in the proposed new MTR model and only keeps end-of-year values • Stores statistics from the previous MTR model • Stores population information from the CSO
3. Forecast market information	• Derives forecasts for the whole duration of the proposed new MTR model (until 2053), starting from the existing market information • Splits the traffic by technology (2G/3G/4G for voice traffic and SMS, 2G/R99/HSDPA/HSUPA/4G for data traffic) • Links in the chosen data forecast from ComReg forecasts and applies an adjustment where required in order to account for those years where the megabytes reported by operators in the 13D information request are greater than those in ComReg market data (currently, an uplift is required in 2016 only, of 7%)
4. Total market volumes	• Contains distributions for the split of traffic by technology and service for the whole duration of the proposed new MTR model • Calculates the total volume of traffic by technology and service
5. Data for charts	• Contains data calculated for charts

5 Demand calculations

The demand calculations are used to determine the traffic measures that dimension the network of the modelled operator. They determine, from the whole market and the market share of the modelled operator, what is the peak traffic load that the network needs to be able to handle. This is calculated based on the share of traffic in the busy hour, the average duration of voice calls, and the proportion of data traffic in the busiest data path (uplink or downlink).

The remainder of this section is structured as follows:

- the calculation of network loading on the *NwLoad* worksheet (Section 5.1)
- the spreading of this load across the modelled geotypes (Section 5.2).

5.1 *NwLoad* worksheet

This worksheet calculates the loading at the various levels of the network based on the traffic throughput.

1. Market share	• Links in the modelled operator's market share by service.
2. Total volumes for the network	• Multiplies the total market by the operator's market share to obtain the total volume of traffic carried by the selected operator.
3. Load calculations	• Specifies inputs for — busy days in a year for voice (250) and SMS/data (365) — proportion of total traffic that occurs in the busy-days for voice (79%) and SMS/data (100% by definition) — proportion of busy-day traffic that occurs in the voice busy-hour for voice (8.0%), SMS (5.8%) and data (6.2%) — proportion of busy-day traffic that occurs in the data busy-hour for voice (5.3%), SMS (6.6%) and data (6.8%) • Calculates busy-hour Erlangs (BHE) for each 2G and 3G voice service in both the voice busy hour and the data busy hour, starting from the annual traffic volumes[25]. This is further uplifted by 10% to allow for fluctuations in busy-hour loading, as was assumed in the previous MTR model. • A proportion of 2G voice can also be assumed to be carried as half-rate voice in the radio layer, thereby reducing the calculated 2G radio BHE (the proposed new MTR model assumes this proportion is zero in all years)

[25] For busy-hour voice in the data busy-hour, this uses the formula *(annual voice traffic/voice busy days)* × *proportion of annual voice in the voice busy days* × *proportion of busy-day voice traffic in the data busy-hour*, Other variations are calculated analogously, including the busy-hour SMS, MMS and data volumes.

- Calculates busy-hour Mbit/s for each 4G voice service for both the voice busy hour and the data busy hour, assuming the AMR-WB codec standard channel rate of 12.65kbit/s
- Specifies inputs for:
  - call attempts per successful call (1.30, from the previous MTR model)
  - additional ringing time per call of 7 seconds
  - radio loading factors (with on-net traffic multiplied by two since both legs are carried by the radio network)
  - average call duration of two minutes[26]
- Calculate an additional ringing time per minute of 4.55 seconds
- Calculates total radio busy-hour loading for each voice service by uplifting by 4.55% and multiplying by the radio loading factors
- Calculates busy-hour SMS for both the voice busy hour and the data busy hour, starting from the annual volumes
- Calculates busy-hour MMS for both the voice busy hour and the data busy hour, starting from the annual volumes
- Specifies inputs for the proportion of data service traffic in the uplink versus the downlink for the five modelled data types
  - 73% of **2G megabytes** occurring in the downlink direction
  - 65% of **3G R99 megabytes** occurring in the uplink direction
  - 100% of **HSDPA megabytes** occurring in the downlink direction
  - 100% of **HSUPA megabytes** occurring in the uplink direction
  - 90% of **LTE megabytes** occurring in the downlink direction
- Calculates busy-hour data Mbit/s for both the voice busy hour and the data busy hour, starting from the annual volumes.

4. Network load for voice

- Calculates total 2G and 3G BHE in the radio network voice busy hour.

5. Network load for 2G data

- Calculates downlink busy-hour Mbit/s for 2G data traffic in the data busy-hour.

6. Network load for 3G voice and R99 data

- Calculates BHE for voice and data traffic in their respective busy hours, converting R99 UMTS data into voice-equivalent channels using a conversion factor based on an assumed rate per channel element (CE) of 32kbit/s downlink for R99 data
- Calculates the peak BHE, by taking the maximum of the voice busy hour and the data busy hour

[26] We assume a mobile-originated call duration of 2 minutes, which is consistent with https://www.comreg.ie/media/dlm_uploads/2016/09/ComReg-1676a.pdf, Section B.1.4

- Repeats these calculations excluding MVCT, so that the proportion of total 3G BHE comprised by MVCT can be calculated over time (this is used for the pure LRIC calculation).

7. Network load for HSPA

- Links in total HSDPA and HSUPA load in the data busy hour.

8. Network load for 4G

- Links in VoLTE load in the data busy hour and downlink 4G load in the data busy hour to determine total downlink 4G load in the data busy hour.

9. Network load for backhaul

- Defines the amount of provisioned bandwidth for supporting the busy-hour data Mbit/s in the radio network for each data bearer (accounting for additional overheads and uplifts)
- Calculates the provisioned downlink data in the voice and data busy hours for data traffic
- Defines the amount of provisioned bandwidth for supporting the voice BHE in the radio network (accounting for handover and reversing out the adjustment for half-rate voice made to the 2G radio BHE)
- Calculates the provisioned upstream/downstream data Mbit/s for voice traffic in both the voice and data busy hours
- Calculates the total load in both the voice and data busy hours, and the peak load, by taking the maximum of the voice and data busy hour. This is calculated for 2G, 3G and 4G separately.

10. Network load for BSC, BSC-MSC and BSC-SGSN

- Defines the amount of provisioned bandwidth in Mbit/s for supporting BSC-core data traffic (reversing out the adjustment for half-rate voice made to the 2G radio BHE)
- Calculates the provisioned downlink data in the voice and data busy hours for data traffic
- Defines the amount of provisioned bandwidth for supporting the voice BHE in the radio network in BSCs and BSC-core links
- Calculates the provisioned duplex data in the voice and data busy hours for voice traffic
- Calculates the total BSC load in the voice and data busy hours, and the peak load, by taking the maximum of the voice and data busy hour.

11. Network load for RNC, RNC-MSC and RNC-SGSN

- Defines the amount of provisioned bandwidth for supporting the busy-hour Mbit/s in the radio network (including additional overheads). This is undertaken for each data bearer and is calculated in terms of the RNC throughput
- Calculates the provisioned downlink Mbit/s in the voice and data busy hours for data traffic through the RNC
- Defines the amount of provisioned bandwidth for supporting the voice BHE in the radio network through the RNC

- Calculates the provisioned duplex data in the voice and data busy hours for voice traffic through the RNC
- Calculates the total load in the voice and data busy hours, and the peak load, by taking the maximum of the voice and data busy hour.

12. Network load for core-core traffic

- Calculates the network BHE for voice traffic in the voice and data busy hours
- Calculates the amount of core–core busy-hour Mbit/s for voice traffic in the voice and data busy hours, by applying the proportion of voice traffic that is conveyed between core sites
- Calculates the amount of core–core busy-hour Mbit/s for data traffic in the voice and data busy hours, by applying the proportion of data traffic that is conveyed between core sites
- Calculates the peak core–core Mbit/s, by taking the maximum of the voice and data busy hour.

13. Network load for switches and servers

- Calculates the load on the data servers using the number of data subscribers and inputs for active packet data protocols (PDP) contexts and simultaneous active users (SAU)
- Calculates the number of minutes in a busy day for the wholesale billing system
- Calculates the number of 2G and 3G and 4G call attempts in the busy hour
- Calculates the number of SMS in the busy hour
- Calculates the interconnection BHR including ringing time in the voice busy hour
- For each server in the list, calculates or links in the individual load amount.

5.2 *NwShare* worksheet

This worksheet splits out network loading by geotype.

1. Traffic by geotype

- Determines input for the proportion of traffic by geotype, if full network coverage.

2. Coverage by geotype

- Links in the population coverage by technology.
- Calculates area coverage by geotype
- Calculates the proportion of population covered by each technology in each geotype
- Calculates the actual distribution of traffic within the covered areas.

3. Network 2G voice traffic by geotype	• Links in 2G voice BHE in the radio network • Calculates 2G voice BHE in the radio network by geotype.
4. Network UMTS R99 voice traffic by geotype	• Links in UMTS R99 BHE in the radio network • Calculates UMTS R99 BHE in the radio network by geotype.
5. Network HSPA traffic by geotype	• Links in HSDPA and HSUPA busy-hour Mbit/s of the radio network • Calculates HSDPA and HSUPA busy-hour Mbit/s of the radio network by geotype.
6. Network 4G traffic by geotype	• Links in downlink 4G busy-hour Mbit/s of the radio network • For each geotype, calculates the 4G busy hour Mbit/s, in the downlink, of the radio network.
7. Network traffic into backhaul	• Links in peak Mbit/s load in the busy hour passing through the backhaul network • Links in peak Mbit/s load in the voice busy hour passing through the backhaul network • Calculates peak Mbit/s load passing into the backhaul network by geotype.
8. Network traffic for RNC	• Links in peak RNC load in Mbit/s • Calculates peak RNC Mbit/s passing into the core network by geotype.

6 Network calculations

The network calculations within the proposed new MTR model take the demand drivers and other network inputs and compute the number of each network element that is needed. The structure and nature of the network design inputs is described in Section 6.1. These network design calculations cover the full range of layers in the network hierarchy, as follows:

- geotypes, network design inputs and utilisation factors (Section 6.1)
- radio network (Section 6.2)
- last-mile access (Section 6.3)
- hub to core transmission (Section 6.4)
- BSCs and RNCs (Section 6.5)
- remote BSC and remote RNC to core transmission (Section 6.6)
- core-to-core transmission (Section 6.7)
- switches and support systems (Section 6.8)

6.1 Network design inputs

Network design inputs are either operator-specific or universal. Operator-specific inputs for the selected operators are linked in from the *InByOp* worksheet. Universal network design inputs are entered on the *InNwDes* worksheet.

6.1.1 *InGeo* worksheet

The definition of geotypes is central to the modelling, as it allows the modelling of the different dynamics of network deployments in different geographies (for example, coverage-driven deployments in rural areas, versus capacity-driven deployments in urban areas).

We have defined geotypes for the proposed new MTR model based on the 2011 Census Electoral Divisions available from the CSO.[27] For each electoral division, we calculate population density (using “land area” rather than “total area”, to exclude inlets such as the Shannon Estuary, as can be seen in Figure 6.2 below) and use these values to define five geotypes. The characteristics of the geotypes, including the population density thresholds used to define them, are presented in Figure 6.1 below.

Figure 6.1: Characteristics of geotypes [Source: CSO and Analysys Mason, 2018]

Geotype	Population density	Population	Land area (km^2)	Proportion of national population	Proportion of national land area
Dense urban	>2500	1 210 282	302	26.38%	0.44%

27 2011 Census Boundaries, Electoral Divisions, published by Central Statistics Office, licensed under Creative Commons Attribution 4.0 (CC BY4.0), available at https://data.gov.ie/dataset/census-2011-boundary-files.

Geotype	Population density	Population	Land area (km²)	Proportion of national population	Proportion of national land area
Urban	500–2500	886 677	878	19.32%	1.28%
Suburban	100–500	813 354	3 921	17.73%	5.73%
Rural 1	20–100	1 339 366	34 749	29.19%	50.75%
Rural 2	<20	338 573	28 616	7.38%	41.80%

The geotype of 90 electoral divisions (out of 3409) has been manually changed to a neighbouring geotype (for example, from urban to dense urban) if they were surrounded by electoral divisions of that geotype. This was to achieve greater contiguity of the geotypes, which we illustrate below.

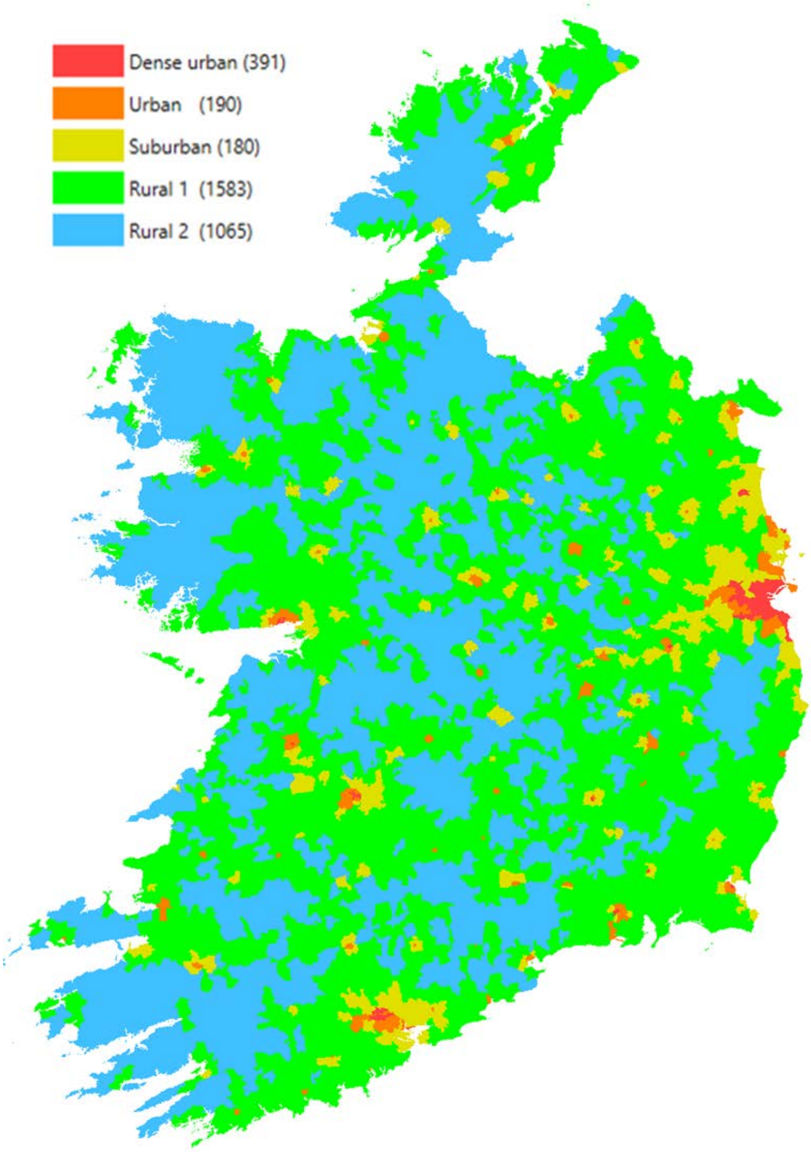


Figure 6.2: Map of geotypes [Source: Analysys Mason, 2018]

Note: the numbers in parentheses indicate the number of electoral divisions in each geotype

By ordering the 3409 electoral divisions in the country by population density, an area-population curve can be defined. This curve is used to define the area coverage for the modelled mobile networks by geotype, based on assumed total population coverage.

6.1.2 *InByOp* worksheet

0. Selected
- Contains inputs from the sections below for the selected operator (the generic operator in the published MTR model).

The following sections exist in the full version of the proposed new MTR model only.

1. Market share inputs
- Specifies market share assumptions for voice traffic, data traffic and subscribers by operator.

2. Coverage inputs
- Specifies population coverage assumptions by technology and operator.
- Specifies coverage frequency by technology, geotype and by operator.

3. Spectrum inputs
- Specifies paired MHz assumed by geotype and by operator for:
  - 2G coverage
  - 2G capacity
  - 3G coverage, specified separately by band
  - 3G capacity, specified separately by band
  - 4G coverage, specified separately by band
  - 4G capacity, specified separately by band.

4. GSM inputs
- GSM blocking probability by operator, with 2% assumed for the generic operator.

5. UMTS inputs
- UMTS blocking probability by operator, with 1% assumed for the generic operator.

6. HSPA inputs
- HSDPA deployment dates by geotype and by operator
- HSUPA deployment dates by geotype and by operator
- HSDPA carriers and HSUPA carriers by operator.

7. 4G inputs
- 4G carrier deployment dates by geotype and by operator.

8. LMA and hub to core inputs
- Proportion of links that are microwave/self-provided by operator
- Proportion of sites connected via Hub (rather than direct to core) by operator
- Radio sites per hub by operator.

9. Core sites
- Core sites by operator.

6.1.3 *InErlang* worksheet

Erlang conversion table

- For network blocking probabilities of 0.1%, 1%, 2%, 3% and 5%, this table returns the number of Erlangs for a given number of channels between 0 and 14 000. This is used to calculate, for example, sector capacity in Erlangs in GSM base-station deployments.
- A second table specifies, for the chosen GSM blocking probability and assuming 0, 1, 2, 3 or 4 channels reserved for GPRS data, this table returns the number of Erlangs for a given number of TRX per sector on average between 0 and 286.

6.1.4 *InNwDes* worksheet

1. Coverage

- Cell radius and cell area for outdoor coverage
- Cell 'pi' of 2.6 to calculate the cell area covered
- Frequency used for coverage added in each year, linked from the selected operator
- Coverage area by technology and geotype.

2. Spectrum

- Amount of paired spectrum in each coverage and capacity layer, linked from the selected operator
- Size of a radio channel, in MHz
- Calculation of the number of channels available
- Number of UMTS channels reserved for voice and low-speed R99 data (not HSPA)
- Number of channels available for traffic load.

3. GSM capacity

- Input of cell reuse factor for different values of paired MHz
- Input of the average sectorisation of GSM sites by geotype
- Input of physical TRX per sector limit, along with the calculation of the effective limit on average by geotype
- Calculation of the maximum number of TRX per sector, either by spectrum or by geotype
- Input of the GSM channels reserved for 2G packet data over time
- Input for the channels reserved for signalling
- Input of GSM channel rates (9.6kbit/s for AMR voice and 24kbit/s for 2G data)
- Linked in input of GSM blocking probability
- Calculation of Erlang capacity per site.

4. UMTS capacity

- Input of R99 channel rate for a single channel element in Mbit/s (assumed to be 0.032Mbit/s)
- Input of the average sectorisation of UMTS sites

- Input of soft- and softer-handover overheads of 20% and 10% respectively
- Input of the number of R99 signalling channels per carrier, minimum and maximum R99 carriers per carrier (pooled at the NodeB)
- Linked in input of UMTS blocking probability
- Calculation of Erlang capacity per carrier (pooled at the NodeB)
- Calculation of Erlang capacity per site
- Input of channel kit size (in channel element terms, CE)
- Inputs and calculation of cell radius adjustment for cell breathing calculation. Specifically, the proportion of 3G BHE that is MVCT in 2019 (*x*) is used to calculated a cell radius multiplier using the formula $-2.46x^4+3.54x^3-1.76x^2+0.10x+1.10$. This multiplier is applied when the proposed new MTR model is run excluding MVCT. This formula has been previously calibrated by Analysys Mason for this purpose in other cost models.

5. HSPA capacity

- Input of the cell peak to effective rate for data throughput of 40%
- Specification of the HSDPA and HSUPA rate ladder.

6. 4G capacity

- Input of the cell peak to effective rate for data throughput of 40%
- Specification of the 4G rate ladder
- Specification of the VoLTE bitrate.

7. Physical sites

- Input of percentage for sites deployed as single technology or co-located sites of 80% in urban geotypes and 70% otherwise
- Input of percentage of sites which are deployed on owned infrastructure of 20%.

8. LMA and hub to core

- Specification of the LMA and hub-core rate ladders
- Linked operator inputs for site transmission choice, hub co-location, leased LMA, and hub-core link parameters for rings or point-to-point hub-core transmission.

9. RNC and BSC

- Linked inputs for the number of BSC/RNC locations, and the proportion of load served in each geotype
- Specification of the BSC and RNC capacity ladders and capacity assumption by geotype.

10. BSC-core traffic

- Specification of the remote BSC-core rate ladder and protocols
- Input for the redundancy in BSC-core links.

11. RNC-core traffic

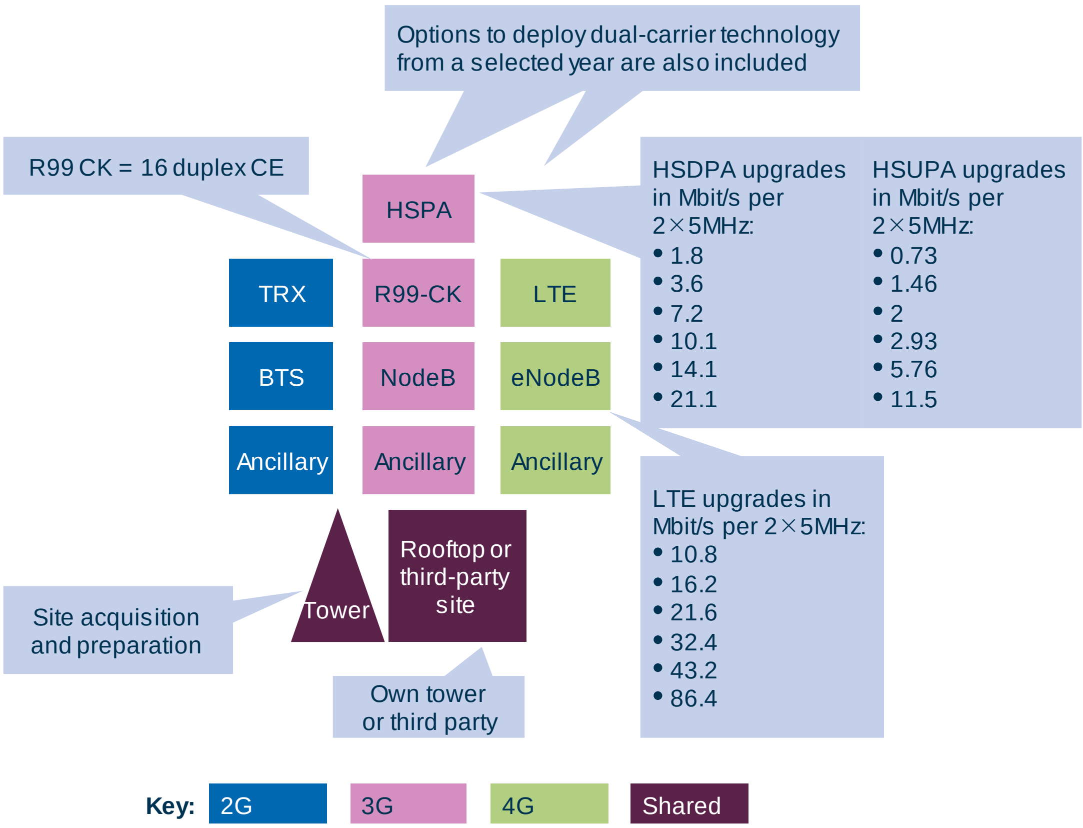
- Specification of the remote RNC-core rate ladders
- Input for the redundancy in RNC-core links
- Input for the protocol used for voice and data interfaces.

12. Core-core traffic	• Linked input for the number of core sites by geotype • Input proportions of traffic conveyed across the core • Input transmission protocols for voice and data layers • Specification of the core-core rate ladder, and number and distance of hops in the fibre core network.
13. Switches and servers	• Input of capacity for each network element in the list • Input of the minimum number and redundancy multiplier for each network element in the list.
14. Spectrum	• Input reserve prices per paired MHz (2012 EUR), converted into a capex per paired MHz (2017 EUR) • Input opex per paired MHz (2012 EUR), converted into an opex per paired MHz (2017 EUR).
15. Utilisation factors	• Maximum utilisation factors for network capacity for each set of network elements • TRX/CE utilisation factors include an adjustment from network busy hour to cell-by-cell busy hour.

6.2 Radio network

The network design for the radio layer considers the three radio technologies (2G GSM, 3G UMTS and 4G LTE) with radio capacity upgrades, as well as the physical site requirements (single technology sites, co-located sites, own tower sites and third-party installations). The network design first considers sites for coverage and then considers the radio interface traffic loading to calculate the additional assets required to carry this loading.

Figure 6.3: Overview of the modelled radio networks [Source: Analysys Mason, 2018]



6.2.1 *NwDes* worksheet

Part of this worksheet contains the radio network calculation, for each technology.

1. GSM calculations

- Links in the area to be covered
- Calculates area coverage added in each year
- Links in area per site
- Calculates the number of sites added for coverage in each year
- Calculates the total number of sites for coverage
- Calculates capacity of the coverage deployment
- Calculates sites required for voice BHE
- Calculates BHE which cannot be supported by the coverage deployment and must be supported by capacity upgrades
- Calculates the number of capacity BTS layers which must be added to coverage sites
- Calculates BHE which cannot be supported by upgraded coverage sites, and must have new sites deployed
- Calculates the number of new (capacity) sites needed to support remaining BHE
- Calculates the total number of GSM sites and BTS
- Calculates the number of TRX in the coverage layer of coverage sites

- Calculates the number of TRX in the coverage layer of capacity sites
- Calculates the number of TRX in the capacity layers
- Calculates the number of TRX in total
- Checks whether the reservation of channels for 2G data is sufficient for the average throughput required. This is linked to the *Control* worksheet.

2. UMTS calculations

- Links in the area to be covered and area per site
- Calculates area coverage added in each year
- Calculates the number of sites added for coverage in each year
- Calculates the total number of sites for coverage
- Calculates capacity of the coverage deployment
- Calculates sites required for R99 BHE
- Calculates capacity of the coverage deployment
- Calculates BHE which cannot be supported by the coverage deployment and must be supported by capacity upgrades
- Calculates the number of capacity carrier layers which must be added to coverage sites
- Calculates BHE which cannot be supported by upgraded coverage sites, and must have new sites deployed
- Calculates the number of new (capacity) sites needed to support remaining BHE
- Calculates the total number of UMTS sites
- Calculates the total number of UMTS R99 NodeBs
- Calculates the total number of R99 carriers and CK in the coverage carriers of NodeBs
- Calculates the total number of R99 carriers and CK in the additional capacity carriers of NodeBs.

3. HSDPA calculations

- Links in sites for coverage and HSDPA BH Mbit/s
- Calculates BH Mbit/s per site, capturing the peak-to-achieved factor and utilisation
- Calculates maximum capacity based on the HSDPA rate ladder and the number of carriers (spectrum) available
- Checks that there are sufficient UMTS sites deployed to support the data upgrades and deploys additional sites otherwise
- Calculates number of HSDPA carriers per site, which can include dual-carrier deployments after a chosen year (assumed to be 2012)
- Calculates the number of sites at each step of the HSDPA rate ladder.

4. HSUPA calculations

- As above except for HSUPA.

5. 4G calculations

- Links in the area to be covered
- Calculates area coverage added in each year

- Links in area per site
- Calculates the number of sites added for coverage in each year
- Calculates the total number of sites for coverage
- Calculates capacity of the coverage deployment, accounting for phased release of future evolutions
- Calculates sites required for 4G data busy-hour throughput
- Calculates 4G throughput which cannot be supported by the deployment and must be supported by additional sites
- Calculates the number of additional sites which must be added.

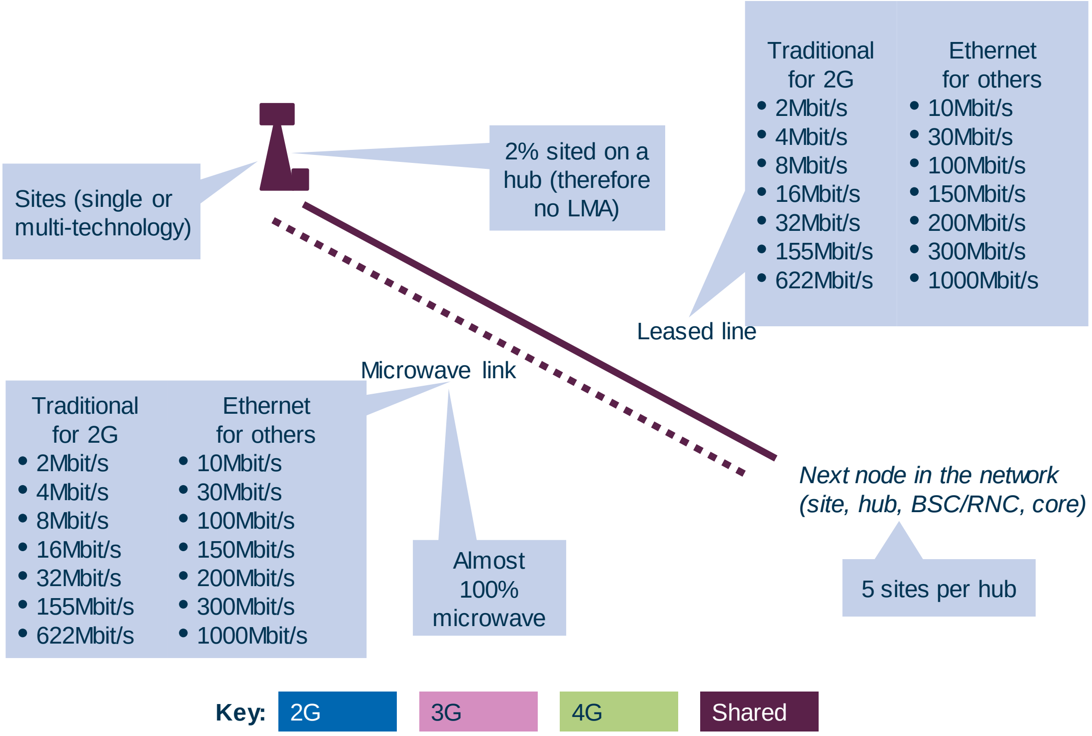
6. Physical sites

- Calculates the number of sites that are single-technology sites, split by 2G, 3G and 4G
- Calculates multi-technology sites for each possible combination
- Calculates the number of sites on own towers and on third-party sites.

6.3 Last-mile access (LMA)

The LMA network is common for all three radio network technologies. It considers two transmission protocols (ATM/SDH/PDH and Ethernet) with capacity upgrades, as well as the physical transmission infrastructure (which can be either leased lines or microwave links).

Figure 6.4: Overview of the modelled LMA networks [Source: Analysys Mason, 2018]



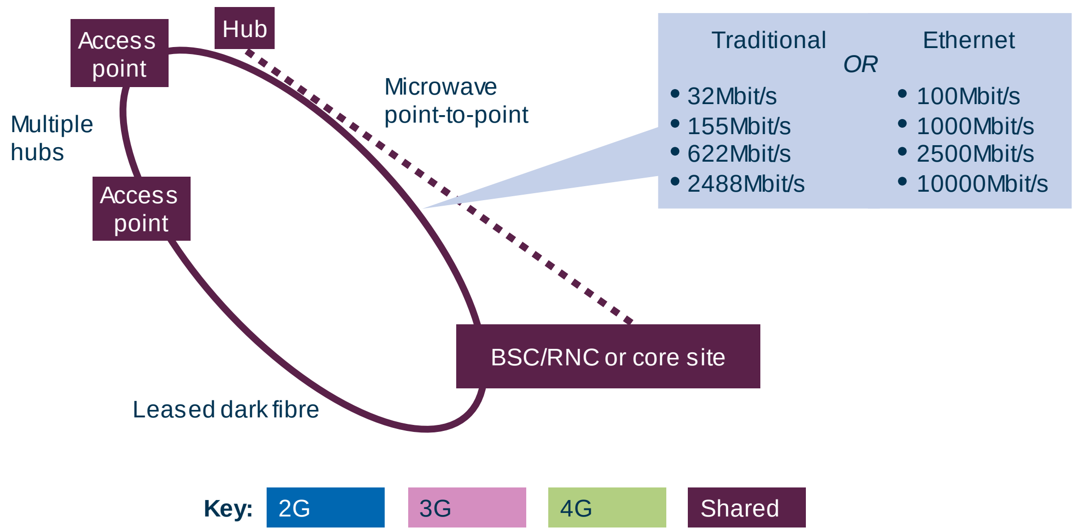
6.3.1 *NwDes* worksheet

7. LMA	• Calculates the LMA capacity requirement for single-technology sites • Calculates the LMA capacity requirement for multi-technology sites • Determines the actual capacity of LMA links by geotype according to a predefined ladder of options • Calculates the number of leased-line LMA links and self-provided/ microwave LMA links by rate according to that same rate ladder.

6.4 Hub to core transmission

The hub to core transmission network is also common for all three radio network technologies. There are again capacity upgrades, and the physical transmission infrastructure can at this level be in rings (for leased lines) or point-to-point (for microwave links).

Figure 6.5: Overview of the modelled transmission between hubs and the core network [Source: Analysys Mason, 2018]



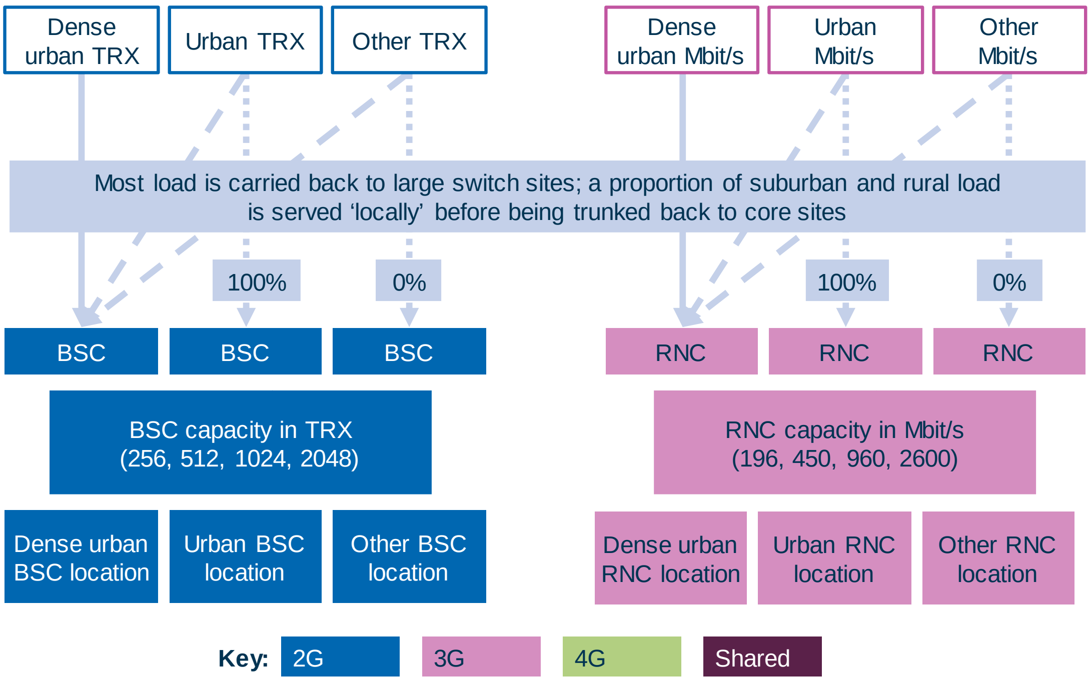
6.4.1 *NwDes* worksheet

8. Hub to core transmission	• Calculates the number of radio sites connected via a hub • Calculates the number of hubs and related point-to-point links and rings to the core network • Calculates the total network traffic at the hub layer, and split it by point-to-point link or ring • Determines the actual capacity of hub to core point-to-point links or rings by geotype according to a predefined rate ladder • Calculates the number of point-to-point links and rings by rate according to that same rate ladder • Calculates the number of hubs on rings by rate.

6.5 BSCs and RNCs

BSCs and RNCs aggregate the 2G and 3G traffic respectively. In both cases, all urban radio traffic is routed through BSCs/RNCs in its own geotype, with the remaining traffic all routed through the dense urban geotype. There are capacity upgrades implemented in the proposed new MTR model for this level as well.

Figure 6.6: Overview of the modelled BSCs and RNCs [Source: Analysys Mason, 2018]



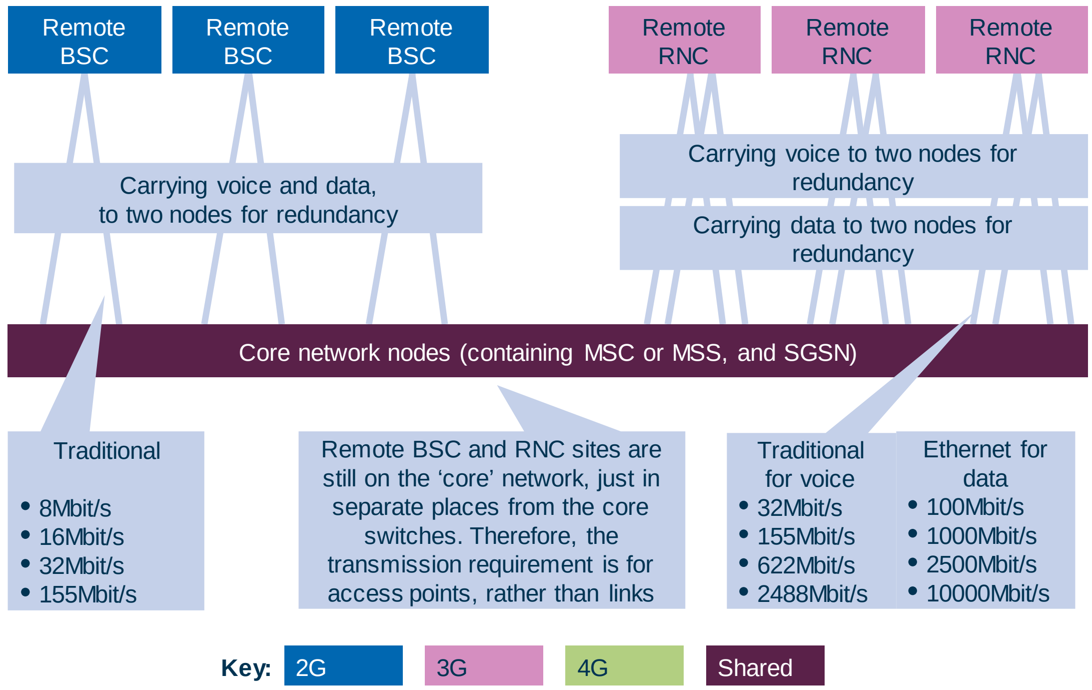
6.5.1 *NwDes* worksheet

9. BSC (to 'Total number of BSC by capacity')	• Reallocates the number of TRX needed in each geotype according to the load served 'locally' or sent to switches in the dense urban geotype • Calculates the BSCs capacity requirement per location in each geotype • Calculates the number of BSCs required in each geotype according to the capacity requirement and the unit capacity of a BSC in each geotype • Calculates the number of BSCs by capacity according to a predefined ladder.
10. RNC (to 'Total number of RNC by capacity')	• As above but for RNCs.

6.6 Remote BSC and remote RNC to core transmission

Some BSCs and RNCs are co-located with core nodes, but others are remote. BSCs to core transmission use the ATM/SDH/PDH protocol, whilst RNCs to core transmission use the ATM/SDH/PDH protocol for voice and the Ethernet protocol for data. They each follow predetermined capacity upgrades.

Figure 6.7: Overview of modelled transmission from the remote BSCs/RNCs to the core network [Source: Analysys Mason, 2018]



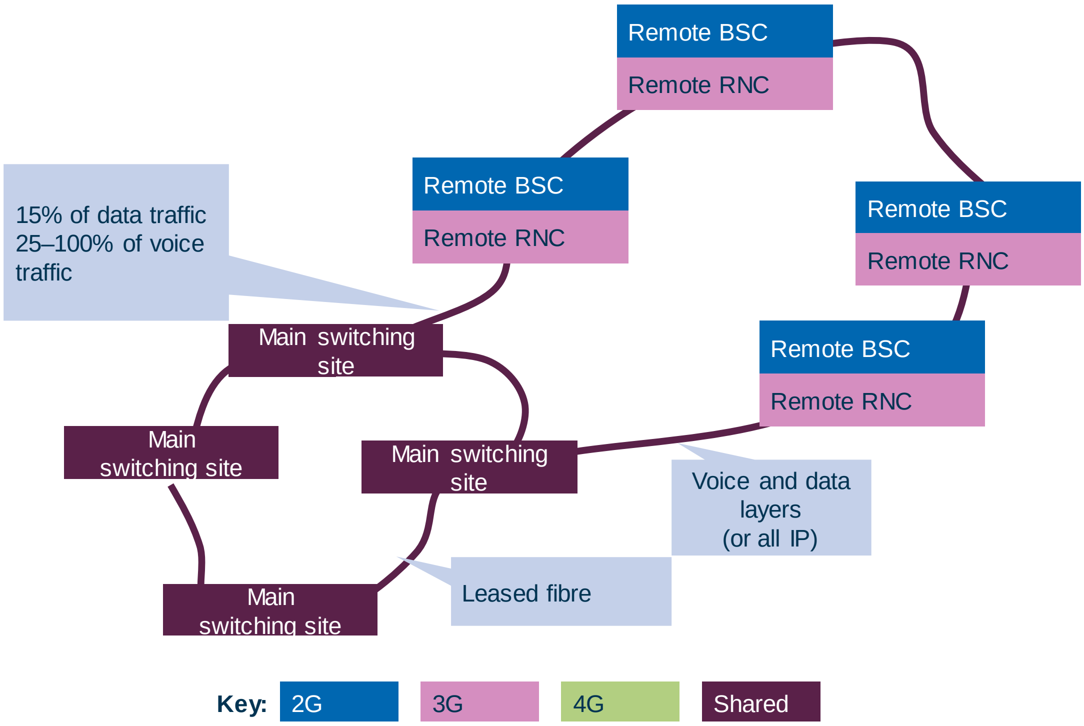
6.6.1 *NwDes* worksheet

9. BSCs (starting from 'Proportion of BSC that are remote')	• Calculates the number of remote BSCs • Calculates separately the voice and data traffic by remote BSC • Determines the actual capacity of the links to the core network by geotype according to a predefined rate ladder (separately for voice traffic to MSCs and data traffic to SGSNs) • Calculates the number of BSCs to core links by rate, separately for dense urban and other geotypes, and also for voice and data.
10. RNCs (starting from 'Proportion of RNC that are remote')	• As above but for RNCs.

6.7 Core-to-core transmission

The core network is assumed to be a ring within Dublin, with another ring to remote BSC/RNC locations. It carries a proportion of the data traffic and a proportion of the voice traffic. The ATM/SDH/PDH and Ethernet protocols can be used for voice and data layers, or all traffic carried in a converged Ethernet network. The capacity of links follows a predefined hierarchy of options.

Figure 6.8: Overview of modelled transmission within the core network [Source: Analysys Mason, 2018]



6.7.1 *NwDes* worksheet

11. Core-to-core rings	• Calculates the core-to-core traffic load (including the utilisation factor), separately for ATM/SDH/PDH and for Ethernet • Determines the actual capacity of the core-to-core links according to a predefined rate hierarchy (separately for ATM/SDH/PDH and for Ethernet) • Calculates the number of core nodes by speed.

6.8 Switches and support systems

Different types of switches are necessary to ensure the network of the operator modelled is able to function as planned to offer mobile services. Figure 6.9 presents these switches and states the minimum number required in any network. The traffic load on the network may then require larger numbers of units to be deployed. Some switches are assumed to have redundant deployments.

All switches are used by all the different radio technologies, except the MSCs used only in the 2G network and the MMEs/SGWs are used only in the 4G network.

Figure 6.9: Overview of the switch capacity assumptions [Source: Analysys Mason, 2018]

Asset	Assumed capacity driver	Minimum deployment	Asset	Assumed capacity driver	Minimum deployment
GSM MSC	BHCA	2	IN	Subscribers	1
MSS	BHCA	2	VMS	Subscribers	1
MGW	BHE	2 × 2 (for redundancy)	MMSC	Per second	1
SGSN	SAU	2	SMSC	Per second	2 × 2 (for redundancy)
GGSN	PDP	2	Billing	CDRs	1
4G MME	Gbit/s	2	PoI	BHE	2
4G SGW	Gbit/s	2	I-SBC	Mbit/s	2
HLR	Subscribers	2	Call server	BHCA	1
AUC	Subscribers	1	TAS	BHCA	1
EIR	Subscribers	1	SBC	BH voice Mbit/s	1

6.8.1 *NwDes* worksheet

12. Servers

- Calculates the number of each type of server required to handle the traffic determined in the *NwLoad* worksheet and applying to it predetermined specifications about their capacity and utilisation factor.

6.9 Switch ports

A number of port upgrades network elements are present in the proposed new MTR model, for a variety of switches. These network elements reflect the upgrade costs to connect links into switches.

6.9.1 *NwDes* worksheet

13. Switch ports

- Calculates the number of site-facing and core-facing ports for BSC and RNC switches, using E1 or 10Mbit/s port units, and for voice and data traffic heading into the core where applicable (to MGW or SGSN accordingly).

6.10 Spectrum

Spectrum fees are calculated on a year-by-year basis. Fees are calculated by band and then mapped onto 2G, 3G and 4G technology.

6.10.1 *NwDes* worksheet

14. Spectrum	• Calculates the spectrum fees incurred by band for each modelled year • Upfront fees are calculated as capex • Annual spectrum usage fees are calculated as opex • Fees are allocated to technology for each modelled year, weighted by population covered. This allows, for example, the 1800MHz fees to be split between the 2G and 4G networks.

7 Expenditure

The network design algorithms compute the assets (network elements) that are required to support a given demand in each year. A series of steps are then undertaken in order to arrive at the schedule of capex and opex over the modelling period. These steps are detailed below and summarised in the remainder of this section:

- defining the list of assets on the *InAsset* worksheet (Section 7.1)
- summarising the assets required in the network over time on the *FullNw* worksheet (Section 7.2)
- determining the assets purchased in each year on the *NwDeploy* worksheet (Section 7.3)
- calculating unit cost trends for each asset over time on the *InCostTrends* worksheet (Section 7.4)
- calculating the unit capex over time on the *UnitCapex* worksheet (Section 7.5)
- calculating the unit opex over time on the *UnitOpex* worksheet (Section 7.6)
- calculating the total capex over time on the *TotalCapex* worksheet (Section 7.7)
- calculating the total opex over time on the *TotalOpex* worksheet (Section 7.8).

7.1 *InAsset* worksheet

1. Standard cost inputs

- For a given set of cost input categories, specifies an assumed lifetime, planning period, proportion of asset replaced per annum and opex as a proportion of capex for each category.

2. Inputs by asset

- For each asset, specifies:
  - — asset name
  - — cost category
  - — cost input category (from the list in the table of standard cost inputs)
  - — flag if asset is not data-only (for use in pure LRIC cross-checks)
  - — retirement period[28]
  - — lifetime, planning period and opex as a proportion of capex based on the cost input category
  - — unit capex in real 2017 EUR
  - — unit opex in real 2017 EUR.

7.2 *FullNw* worksheet

1. Network elements by year

- Pulls together the assets required in the modelled network for each year in the modelling period.

28 By setting the value to 0, 1 or 2, the proposed new MTR model will remove the assets as traffic reduces, either in the same year, one year later, or two years later respectively. By setting the value to 100, the proposed new MTR model will retain the asset in the network until the last year of operation.

7.3 *NwDeploy* worksheet

The network design algorithms compute the network elements that are required to support a given demand in each year. In order for these elements to be operational when needed, they need to be purchased in advance, in order to allow provisioning, installation, configuration and testing before they are activated. This is modelled for each asset by inputting a planning period between 0 (no planning required) and 18 months. The number of assets purchased in each year is derived on this worksheet, accounting for:

- additional assets required to provide incremental capacity
- equipment that has reached the end of its lifetime and needs to be replaced
- advanced purchase in both cases based on the assumed planning period.

The steps taken are described below.

1. Required units in full network	• Links in the network elements, accounting for network activation from the *FullNw* worksheet.
2. Deployed assets with retirement algorithm	• Determines the maximum number of units required of each asset and the first year in which this maximum is reached.
3. Annual activation (including replacement)	• Calculates the difference between the number of units required and the number of units previously deployed that are still active (this does not remove assets before the end of their lifetime even if they are no longer required).
4. Direct equipment purchases (incl. replacement)	• Determines the equipment required across all replacement cycles, purchased prior to activation based on the planning period (fractional units of purchase are permissible on the basis that they reflect phasing of purchase over each modelled year).

7.4 *InCostTrends* worksheet

The cost of purchase for network assets varies over time. In the economic costing approach, the modern equivalent asset (MEA) provides the appropriate cost basis for purchase. Real-term unit asset cost trends are applied to 2017 unit asset costs to reflect the evolution of the modern technology unit asset costs over past and future time. The evolution of MEA unit asset costs also provides an important input into the economic depreciation calculation, as described in Section 8. Certain quantities for the economic depreciation calculation, including the capex/opex indices, are also calculated on the *InCostTrends* worksheet.

In the proposed new MTR model, we have largely applied the cost trends assumed in the previous MTR model.

These calculations are described below.

1. Equipment capex trends	• Specifies the year-on-year change in capex trends over time for a set of specified categories • Determines the year-on-year change in capex trends for each asset, based on a specified category • Calculates the cumulative year-on-year change in capex trends for each asset, indexed with the first modelled year set to be 1 • Multiplies this capex index by the network element output, which is described in Section 8.3, to give the capex cost-weighted output.
2. Equipment opex trends	• Specifies the year-on-year change in opex trends over time for a set of specified categories • Determines the year-on-year change in opex trends for each asset, based on a specified category • Calculates the cumulative year-on-year change in opex trends for each asset, indexed with the first modelled year set to be 1 • Multiplies this opex index by the network element output, which is described in Section 8.3, to give the opex cost-weighted output.

7.5 *UnitCapex* worksheet

1. Unit capex per network element	• Calculates the unit capex by asset in each modelled year, using the MEA capex index, scaled by the capex index value in 2017. This ensures that the unit capex is determined relative to the base year of the inputs, which is 2017.
2. Shut-down capex profile	• Determines a binary multiplier, which is zero after the network is assumed to be shut down and one otherwise.

7.6 *UnitOpex* worksheet

1. Unit opex per network element

- Calculates the unit opex by asset in each modelled year, using the MEA opex index, scaled by the opex index value in 2017. This ensures that the unit opex is determined relative to the base year of the inputs, which is 2017.

2. Shut-down opex profile

- Determines a binary multiplier, which is zero when an asset has been assumed to be completely removed due to network shutdown; otherwise, the binary multiplier is one.

7.7 *TotalCapex* worksheet

1. Total annual capex

- Multiplies the unit capex derived in the *UnitCapex* worksheet by the number of assets purchased in each year, calculated in the *NwDeploy* worksheet
- The capex is set to be zero for those assets in those year when the shut-down profile for capex from the *UnitCapex* worksheet is zero.

2. Category totals

- Aggregates the total capex by asset derived above by cost category
- Cumulates the capex by cost category over time, starting in the first year of the modelling period.

7.8 *TotalOpex* worksheet

1. Total annual opex

- Calculates the working capital allowance in each year (currently assumed to be 30/365 – i.e. one calendar month – of the weighted average cost of capital (WACC))
- Multiplies the unit opex derived in the *UnitOpex* worksheet by the number of assets active in the network in each year, calculated in the *NwDeploy* worksheet
- The opex is set to be zero for those assets in those year when the shut-down profile for opex from the *UnitOpex* worksheet is zero
- The opex is also uplifted by the working capital allowance.

2. Category totals

- Aggregates the total opex by asset derived above by cost category.

8 Depreciation

This section describes the implementation of the economic depreciation algorithm used in ComReg's proposed new MTR model. We describe this algorithm in several stages:

- Section 8.1 summarises the conceptual approach and principles of the implementation
- Section 8.2 describes the routeing factors inputs
- Section 8.3 describes the network element output calculations
- Section 8.4 describes the assumptions for the discount rates
- Section 8.5 describes the calculation steps implemented to derive economic costs.

8.1 Overview of economic depreciation

Below we describe the conceptual approach and the implementation principles of economic depreciation.

8.1.1 Conceptual approach

An economic depreciation algorithm recovers all efficiently incurred costs in an economically rational way by ensuring that the total of the (cost-oriented) revenues generated across the lifetime of the business are equal to the efficiently incurred costs, including cost of capital, in present value (PV) terms. This calculation is carried out for each individual asset class, rather than in aggregate, in order to allow the price trends and opex cost trends for each asset to be reflected.

The calculation of the cost recovered needs to reflect the time value of money. This is accounted for by the application of a discount factor on future cashflows, which is equal to the WACC of the modelled operator.

The business is assumed to be operating in perpetuity, and investment decisions are made on this basis. This means it is not necessary to recover specific investments within a particular time horizon (e.g. the lifetime of a particular asset), but rather throughout the lifetime of the business. In the economic depreciation model, this situation is approximated by explicitly modelling a period of 50 years. At the real discount rate applied (which is derived using the WACC), the PV of the cashflows in the last year of the proposed new MTR model is very small and thus any perpetuity value beyond 50 years is regarded as immaterial to the final cost result.

The constraint on cost recovery (NPV of costs = NPV of output × calculated unit costs) can be satisfied by (an infinite) number of possible cost-recovery profiles. However, it would be impractical and undesirable from a regulatory pricing perspective to choose an arbitrary or highly fluctuating recovery profile.[29] Therefore, we choose a cost-recovery profile that is in line with revenues

[29] For example, because it would be difficult to send efficient pricing signals to interconnecting operators and their consumers with an irrational (but NPV=0) recovery profile.

generated by the business. In a competitive and contestable market, the revenue that can be generated is a function of the lowest prevailing cost of supporting that unit of demand, thus the price will change in accordance with the costs of the MEA for providing the service.[30] The unit cost is therefore assumed to follow the MEA unit asset cost trend for that asset class. The cost-recovery profile for each asset class is the product of the demand supported by the asset (i.e. its economic output) and the MEA unit asset cost trend. This gives a unique solution.

The efficient expenditure of the operator comprises all the operator's efficient cash outflows over the lifetime of the business, meaning that capex and opex are not differentiated for the purposes of cost recovery. As stated previously, the proposed new MTR model considers costs incurred across the lifetime of the business to be recovered by cost-oriented revenues across the lifetime of the business. This principle implies that the treatment of capex and opex should be consistent, since they both contribute to supporting the cost-oriented revenues generated across the lifetime of the business.

8.1.2 Principles of implementation

The PV of the total expenditure is the amount which must be recovered by the revenue stream. The discounting of revenues in each future year reflects the fact that delaying cost recovery from one year to the next accumulates a further year of cost of capital employed. This leads to the fundamental equation of the economic depreciation calculation that is:

$$PV\ (expenditures) = PV\ (unit\ cost \times output)$$

The *unit cost* $\times$ *output* which the operator gains from the service in order to recover its expenditures plus the cost of capital employed is modelled as *output* $\times$ *year 1 unit cost* $\times$ *MEA price index*. This quantity is discounted because it reflects future cost recovery. (Any costs recovered in the years after a network element is purchased must be discounted by an amount equal to the WACC in order that the cost of capital employed in the network element is also returned to the operator.)

- **output** – the service volume carried by the network element
- **MEA price index** – the cumulated input price trend for the network element which proportionally determines the trend of the unit cost that recovers the expenditure (effectively, the percentage change to the cost of each unit of output over time).

This leads to the following general equations:

$$cost\ recovery\ (year\ n) = unit\ cost\ in\ year\ 1 \times output \times MEA\ price\ index$$

Using the relationship from the previous section, the above equation is equal to:

30 In a competitive and contestable market, if incumbents were to charge a price in excess of that which reflected the MEA prices for supplying the same service, then competing entry would occur and demand would migrate to the entrant which offered the cost-oriented price.

$$PV\ (expenditure) = PV\ (unit\ cost\ in\ year\ 1 \times output \times MEA\ price\ index)$$

This equation can be rearranged as follows:

$$unit\ cost\ in\ year\ 1 = PV\ (expenditure) / PV\ (output \times MEA\ price\ index)$$

Then, returning to the original equation for cost recovery in year *n*, the yearly price over time is simply calculated as:

$$\underline{yearly\ unit\ cost\ over\ time} = unit\ cost\ in\ year\ 1 \times MEA\ price\ index$$

This yearly price over time is calculated separately for the capex and opex components in one step in the proposed new MTR model.

8.2 *InRF* worksheet

Routeing factors determine the amount of each element's output required to provide each service. The routeing factors used in the proposed new MTR model are average traffic routeing factors and are converted into equivalent traffic measures using a number of derived conversion factors. All of these inputs can be found on this worksheet.

1. Source calculations

- Links in a series of standard technical parameters
- Calculates factors for conversion of the following quantities on the air interface into minute equivalents:
  - SMS, separately for GSM and UMTS
  - 2G data megabytes
  - R99 megabytes
  - HSPA megabytes
  - 4G megabytes
- Calculates factors for conversion of data traffic on transmission links.

2. Routeing factor options

- For a list of asset measure options, derives a routeing factor for that option for each of the modelled services.

3. Full routeing factor table

- For each asset and each modelled service, identifies the routeing factor from the above table based on the asset measure option for that asset.

8.3 *NwElemOut* worksheet

The quantity of network element output, by asset over time, is used as the basis on which to derive economic costs. This quantity is taken to be the annual sum of service demand produced by the asset, weighted according to the routeing factors of that asset for the modelled services. Network element output is calculated on the *NwElemOut* worksheet.

1. Service demand for the whole market	•	Links in the service volumes for the modelled network over time from the *NwLoad* worksheet.
2. Service routeing factors	•	Links in the full routeing factor table from the *InRF* worksheet.
3. Recovery profile	•	Currently set to be 0% before cost recovery is assumed to start and after cost recovery has ended, 100% otherwise.
4. Recovery profile in binary form	•	Currently set to be 1 if the corresponding entry in the recovery profile above is nonzero, and zero otherwise.
5. Network element output	•	Calculated as:

$$\textit{Service volumes} \times \textit{routeing factors} \times \textit{binary profile}$$

8.4 *InDF* worksheet

The proposed new MTR model operates in real terms and hence requires a real discount rate with which the modelled cashflows can be discounted when deriving present values. This is derived using the real cost of capital, specified on the *Control* worksheet.

1. Discount rate data

- Stores the nominal discount rate (WACC)
- Stores historic and forecast inflation
- Derives the real discount rate
- Derives the real discount rate multiplier
- Derives the real discount rate divider
- Derives the inflation multiplier from the consumer price index.

8.5 *ED* worksheet

This worksheet is where the economic costs of capex/opex are calculated over time, using the above inputs and the unit asset cost trends from the *CostTrend* worksheet, described in Section 7.4.

1. Capex per unit output

- Calculated separately for each asset across the modelling period
- Derived as the capex index over time scaled by a constant factor
- This factor is the ratio of the cumulative discounted asset capex and the cumulative discounted capex weighted output (referred to as '$\textit{PV(expenditure)} / \textit{PV(output} \times \textit{MEA price index)}$' above).

2. Opex per unit output

- Calculated separately for each asset across the modelling period
- Derived as the opex index over time scaled by a constant factor
- This factor is the ratio of the cumulative discounted asset opex and the cumulative discounted opex weighted output (referred to as '$\textit{PV(expenditures)} / \textit{PV(output} \times \textit{MEA price index)}$' above)

	• This is calculated separately to the capex per unit output since the asset unit capex trend could differ to the asset unit opex trend.
3. Total cost per unit output	• Calculates the sum of the capex per unit output and the opex per unit output, multiplied by the binary recovery profile.
4. FAC per service unit	• Calculates the multiplication of the cost per unit output matrix and the routeing factor matrix to give unit fully allocated costs (FAC) by service.
5. Total economic costs	• Calculates the total cost per unit output multiplied by the network element output • Calculates the total economic costs over time • Calculates the total discounted economic costs over time • Calculates the cumulative discounted economic costs over time • Calculates the present value of the economic costs.
6. Total costs recovered by FAC	• Multiplies the FAC per service unit by the modelled network service volumes • Calculates the total discounted FAC.

9 Results

The proposed new MTR model calculates service costs using both LRAIC and pure LRIC principles. The outputs of both these calculations can be found on the *Control* worksheet.

The remainder of this section describes these calculations:

- Section 9.1 describes how the LRAIC (and LRAIC+) are derived in the proposed new MTR model
- Section 9.2 describes how the pure LRIC is derived in the proposed new MTR model
- Section 9.3 describes the '*Control* worksheet, where the key input switches and checks for the proposed new MTR model can be identified.

9.1 Calculation of LRAIC(+)

On the *ED* worksheet, the incremental cost per unit output calculated for each asset is derived by multiplying the incremental cost per unit output by the routeing factors according to the following equation:

$$Cost(Service_k) = \sum_{assets} cost\_per\_unit\_output(asset_i) \times RouteingFactor(asset_i, service_k)$$

Business overheads are then marked up onto each incremental service cost in an equi-proportionate manner, according to the ratio of common to incremental network costs, resulting in the LRAIC+. This approach is illustrated in Figure 9.1 below.

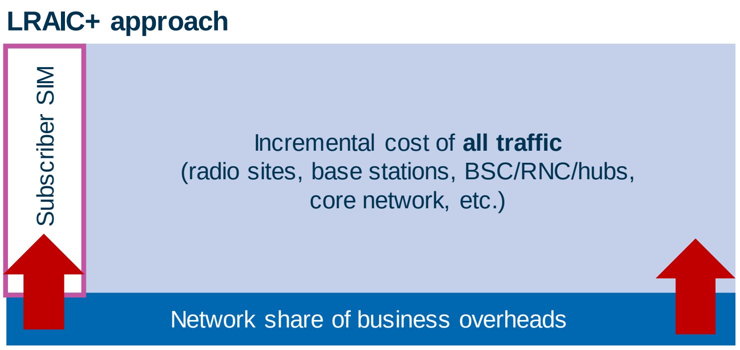


Figure 9.1: Illustration of LRAIC+ approach [Source: Analysys Mason, 2018]

Below we describe the remaining calculations required for the LRAIC (and LRAIC+) on the *LRAIC+* worksheet.

9.1.1 *LRAIC* worksheet

On this worksheet, economic costs are mapped to services and mark-ups are applied.

1. Total economic costs

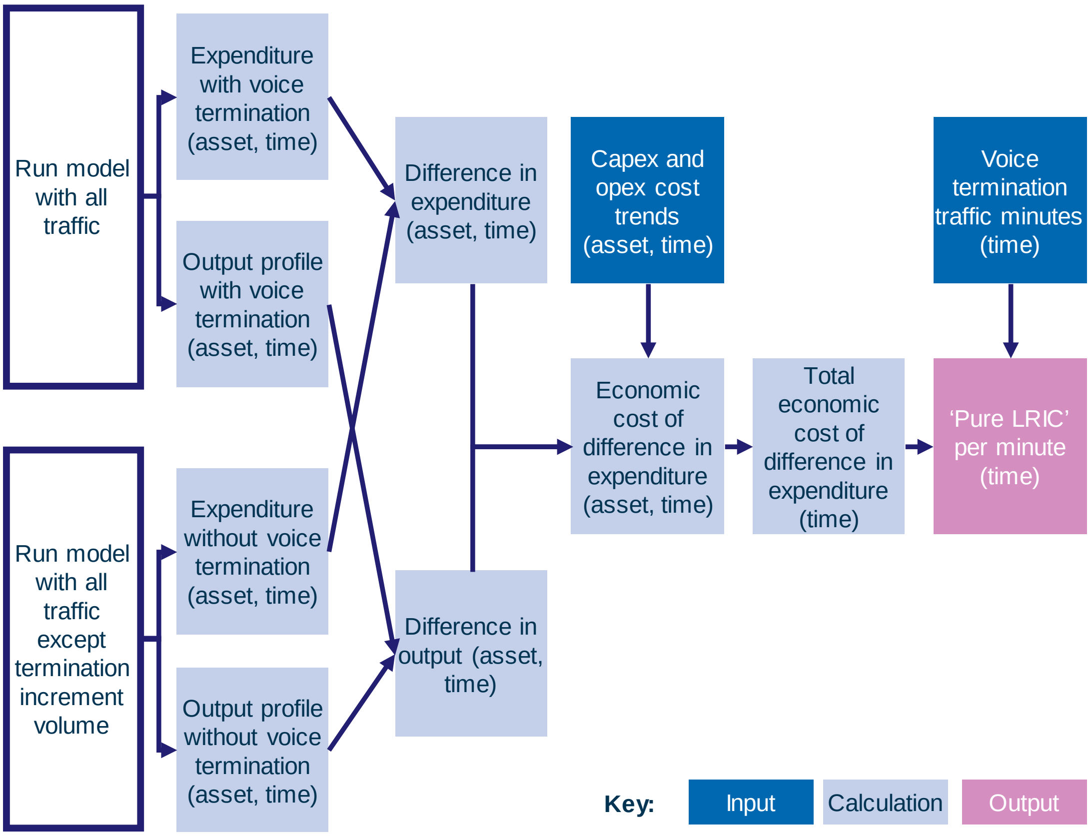
- Links in the total economic costs by asset over time from the *ED* worksheet.

2. Total overhead costs	• Identifies the business overhead costs.
3. Total incremental costs	• Derives the difference between the total economic costs and common economic costs.
4. Calculation of mark-ups	• Calculates common economic costs as a proportion of incremental economic costs in order to arrive at the EPMU.
5. Calculation of unit LRAIC	• Calculates the incremental cost per unit output by multiplying the total cost per unit output from the *ED* worksheet by the common cost proportions • Multiplies the incremental cost per unit output matrix and the routeing factor matrix to arrive at the unit LRAIC by service • Multiplies the unit LRAIC by service by the network service volumes to derive the total LRAIC by service • For a selected year, calculates the breakdown of network service unit costs by asset and service, by multiplying the incremental cost per unit output in that year by the routeing factors • Aggregates this breakdown by cost category • Calculates the total network service costs by asset and service for the selected year, and aggregates this breakdown by cost category.
6. Calculation of unit LRAIC+	• Applies the derived EPMU to the unit LRAIC by service to derive the unit LRAIC+ by service • Derives the total LRAIC+ by service • Multiplies the unit LRAIC+ by service by the network service volumes to derive the total LRAIC+ by service • Calculates the discounted LRAIC+ by service and the total present value of the LRAIC+.
7. Calculations of cost recovery	• Calculates LRAIC+ by service group • Calculates the total cumulative LRAIC+ by service group.

9.2 Calculation of pure LRIC

To calculate pure LRIC, the proposed new MTR model must be run in two different ‘states’: *with* and *without* MVCT traffic on the modelled network. Clicking on the ‘Run Pure LRIC’ macro button on the *Control* worksheet will result in the proposed new MTR model calculating twice – the total capex, total opex and assets counts over time in each case are then pasted on the *PureLRIC* worksheet. The pure LRIC of MVCT is then calculated as shown in Figure 9.2 below.

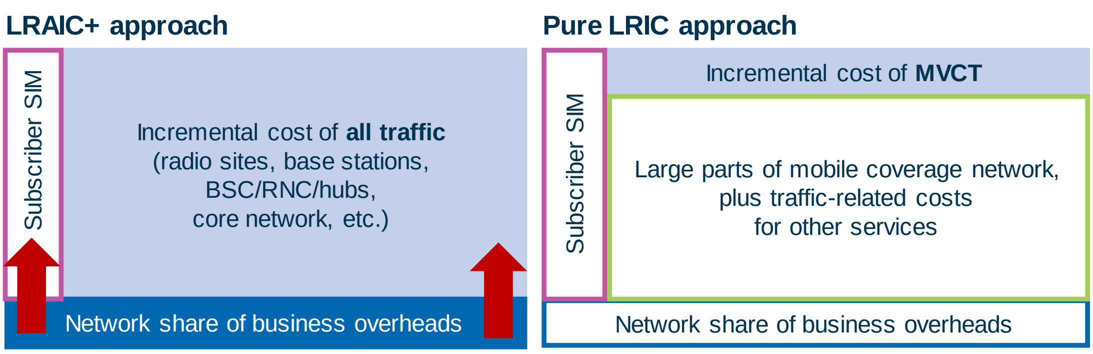
Figure 9.2: Calculation of pure LRIC [Source: Analysys Mason, 2018]



MVCT traffic is defined as both domestic incoming voice and international/roaming (inbound) voice. The difference in both capex and opex (the *avoidable* costs) between the two cases is determined from the two calculations, and economic depreciation is then applied to this difference. This is run separately for capex and opex, in order using their respective unit asset cost trends. The pure LRIC of termination in each year is then calculated as the total economic cost in that year divided by the total terminated minutes.

The avoidable cost base within the pure LRIC costing approach is compared with the average incremental cost base in Figure 9.3 below.

Figure 9.3: Comparison of LRAIC+ with the pure LRIC approach [Source: Analysys Mason, 2018]



These calculations are all undertaken on the *PureLRIC* worksheet, as described below.

9.2.1 *PureLRIC* worksheet

On this worksheet, capex and opex calculations are undertaken separately. The two sets of calculations are undertaken side-by-side, with capex on the left and opex to the far right of the worksheet.

1. Calculation of output profiles of MVCT increment	• Links in the routeing factors • Links in the network volumes (adjusting for MVCT) • Links in recovery profile and derives the binary recovery profile • Calculates the pure LRIC network element output as: $\text{Service volumes} \times \text{routeing factors} \times \text{binary profile}$ • Links in the proportion of 3G BHE excluded, and stores values pasted.
2. Expenditure and annualisation of avoidable costs	• Stores the pasted capex, opex and asset counts by asset and year for the modelled network when including MVCT • Stores the pasted capex, opex and asset counts by asset and year for the modelled network when excluding MVCT • Calculates avoided capex, avoided opex and avoided assets • Calculates the opex cost-weighted output, using the opex index and the pure LRIC network element output • Calculates the capex cost-weighted output, using the capex index and the pure LRIC network element output • Links in the capex index and opex index.
3. Economic depreciation of avoidable costs	• Calculates the total economic cost of the avoided capex and avoided opex over time • Calculates the economic cost of the avoided capex and avoided opex over time per terminated minute • Calculates the total avoided capex and avoided opex over time • Calculates the total economic costs of capex and opex over time • Calculates the PV of both the avoided expenditure and the recovered expenditure, both in total and on an asset-by-asset basis.

9.3 *Control* worksheet

The key model results are linked to the *Control* worksheet and converted back into nominal currency. At the bottom of the worksheet there are also a number of checksums calculated at key points in the proposed new MTR model calculations.

If any of these cells is non-zero, then the proposed new MTR model may not be working correctly.

The *Control* worksheet also contains several inputs and switches that the user can modify to carry out key sensitivity tests. These switches are summarised below.

Selected operators	• Allows the user to choose which operator is going to be modelled. Only operators included in the list of operators on the *InLists* worksheet can be chosen.
Deploy VoLTE	• Allows the user to choose whether to deploy VoLTE or not.
Assume cell breathing	• Allows user to select whether cell breathing is assumed in the UMTS network for the pure LRIC calculation.
Full cost recovery by year	• Determines the final year for full cost recovery for the operator modelled (corresponding to a shutdown of the modelled network). This is currently assumed to be 2045.
Spectrum renewal year	• States when the spectrum licences for the 2012 auction are assumed to be renewed.
Business overhead assumptions	• Parameterises whether a flat EPMU is assumed, or whether absolute values of annual capex and annual opex are assumed.
Site lifetime	• Allows the economic lifetime for radio sites to be specified.
Working capital allowance	• Allows the working capital allowance to be specified by the user, in terms of number of days.
Population forecast	• Allows the user to specify the population forecast to be used, from the options produced by the CSO.
2100MHz allocation	• Allows the user to specify how much paired spectrum from the 2100MHz band is allocated to the modelled operator (in multiples of 2×5MHz).
Data forecast choices	• Allows the user to specify the assumed data megabyte forecast, from a choice of three from ComReg's spectrum plan • Allows the user to mark down the historical and forecast volumes • Allows the user to specify a year after which usage per subscriber is assumed to flatten out.
Pure LRIC calculation	• Provides a drop-down list where the user can choose whether the proposed new MTR model calculates the total cost with or without termination when F9 is pressed.

Annex A Acronyms

2G	Second generation of mobile telephony
3G	Third generation of mobile telephony
4G	Fourth generation of mobile telephony
AMR-WB	Adaptive multi-rate wideband
ATM	Asynchronous transfer mode
AUC	Authentication centre
BHCA	Busy-hour (BH) call attempts
BHE	Busy-hour Erlangs
BSC	Base-station controller
BTS	Base Transceiver Station
CE	Channel element
CEO	Chief executive officer
CK	Channel kit
CPI	Consumer price index
CS	Call server
CSO	Central Statistics Office
E1	2Mbit/s unit of capacity
EC	European Commission
ED	Economic depreciation
EIR	Equipment identity register
eNodeB	Denotes the 4G equivalent of a BTS
EPC	Enhanced packet core
EPMU	Equi-proportionate mark-up
FAC	Fully-allocated cost
FTR	Fixed termination rate
FVCT	Fixed voice call termination
GGSN	Gateway GPRS serving node
GPRS	General packet radio system
GSM	Global system for mobile communications
GSN	Gateway serving node
HLR	Home location register
HSDPA	High-speed downlink packet access
HSPA	High-speed packet access
HSS	Home subscriber server
HSUPA	High speed uplink packet access
IMS	IP multimedia subsystem
IN	Intelligent network
IP	Internet Protocol
I–SBC	Interconnect session border controller
LMA	Last-mile access

LRAIC	Long-run average incremental cost
LRIC	Long-run incremental cost
LTE	Long-term evolution
MEA	Modern equivalent asset
MGW	Media gateway
MME	Mobility management entity
MMS	Multimedia message service
MMSC	MMS centre
MNO	Mobile network operator
MNP	Mobile number portability
MSC	Mobile switching centre
MSP	Mobile service provider
MSS	MSC server
MTR	Mobile termination rate
MVCT	Mobile voice call termination
MVNO	Mobile virtual network operator
NMC	Network management centre
NodeB	Denotes the UMTS equivalent of a BTS
NGN	Next-generation network
NPV	Net present value
PDH	Plesiochronous digital hierarchy
PDP	Packet data protocol
PoI	Point of interconnect
PV	Present value
R99	Release-99
RNC	Radio network controller
S–RAN	Single radio access network
SAU	Simultaneously attached users
SBC	Session border controller
SDH	Synchronous digital hierarchy
SGSN	Subscriber GPRS serving node
SGW	Serving gateway
SIM	Subscriber identity module
SMS	Short message service
SMSC	SMS centre
STM	Synchronous transport module
TAS	Telephony application server
TRX	Transceiver unit
UMTS	Universal mobile telecommunications systems
VMS	Voicemail system
VoIP	Voice over Internet Protocol
WACC	Weighted average cost of capital

Annex B Source of the inputs used in the proposed new MTR model

This annex details the source of the various inputs used in the proposed new MTR model, as set out below:

- [1] Analysys Mason estimate
- [2] Analysys Mason estimate informed by operator *input* information or data
- [3] Analysys Mason estimate informed by operator *output* information or data (e.g. scorched-node reference to total amounts of operator equipment, or reconciliation to total actual costs)
- [4] Irish market average based on operator data (rounded or standardised where appropriate)
- [5] Standard technical parameter
- [6] Previous MTR model.

Inputs to the proposed new MTR model are arranged in this annex according to the sections of the main body report.

B.1 Worksheet *InMkt*

1. Quarterly market data

Data by quarter	Sourced from ComReg's published statistics.[31]

2. Historic market information

Annual volumes from previous MTR model [6]	Sourced from the previous MTR model.
Population	Sourced from the CSO, as described in Section 4.1

3. Forecast market information

Measures in 2021 [1]	Extrapolated from actuals to 2016.
Data forecasts	Sourced from ComReg, as described in Section 4.3.
Proportions of traffic by network for 2015 and 2016 [4]	Averaged across operator data.

31 For example, see https://www.comreg.ie/industry/electronic-communications/data-portal/tabular-info/.

VoLTE migration profile [1]	Placeholder based on forecasts from other cost models.

B.2 Worksheet *NwLoad*

3. Load calculations

Busy days, busy-day traffic and busy-hour traffic [2, 4]	Averaged across operator data.
Additional uplift for fluctuations in busy-hour loading [6]	Previous MTR model.
Call attempts p, ring minutes per call and radio loading factors. [2, 4]	Call attempts and ring minutes per call based on average values of the data received from the mobile operators (answers to original Q12 of the 13D information request). Radio loading factors are standard inputs to this type of cost model.
Call attempts per successful call [6]	Previous MTR model.
Ringing time [1]	Benchmarks of other cost models.
Radio Erlangs per Erlang [5]	Standard inputs to this type of cost model.
Average call duration [1]	Consistent with values published by ComReg[32]
Proportion of data service traffic in the uplink versus the downlink. [4]	Averaged across operator data.

6. Network load for UMTS and R99 data

Conversion factor for R99 UMTS data into voice-equivalent channels based on the assumed CE rate for R99 data [5]	Conversion factor is the reciprocal of the 32kbit/s assumed for the effective UMTS channel data rate.

9. Network load for traffic from radio layer into core/ring network

Amount of provisioned bandwidth for supporting the busy-hour Mbit/s in the radio network for each data bearer [5]	Conversion factor includes soft-handover for R99 traffic as well as the mobile broadband peak to average ratio.

32 See https://www.comreg.ie/media/dlm_uploads/2016/09/ComReg-1676a.pdf, Section B.1.4.

Amount of provisioned bandwidth for supporting the voice BHE in the radio network [6]	Conversion factor includes soft-handover for voice traffic and an assumed 3G voice radio channel rate of 12.2kbit/s.

10. Network load for BSC traffic

Amount of provisioned bandwidth for supporting BSC-core data traffic [5].	Standard technical input for identifying BSC-core traffic.
Amount of provisioned bandwidth for supporting the voice BHE in the radio network in BSC-core links [6]	Conversion factor includes an assumed 9.6kbit/s 2G voice channel rate.

11. Network load for RNC traffic

Amount of provisioned bandwidth for supporting the busy-hour Mbit/s in the radio network, for each data bearer, in terms of the RNC throughput [5]	Conversion factor includes soft-handover for R99 traffic as well as the mobile broadband peak to average ratio
Amount of provisioned bandwidth for supporting the voice BHE in the radio network through the RNC. [5]	Conversion factor includes soft-handover for voice traffic and an assumed 12.2kbit/s voice radio channel rate.

13. Network load for switches and servers

Inputs for active packet data protocols (PDP) contexts [1]	Consistent with mobile LRIC models developed in other countries.
Input for simultaneous active users (SAU) [1]	Consistent with mobile LRIC models developed in other countries.

B.3 Worksheet *NwShare*

1. Traffic by geotype

Proportion of traffic by geotype, if full network coverage. [1]	Voice traffic is estimated based on the proportion of population by geotype. Data traffic is estimated based on this proportion, with additional weighting given to the dense urban/urban geotypes.

B.4 Worksheet *InGeo*

Area-population curve for Ireland, using the 3409 electoral divisions in the country, using data from various sources including the CSO	Population and area information was extracted from the geographical data files available on the Central Statistics Office (CSO) website.

B.5 Worksheet *InByOp*

We describe the assumptions in the published MTR model for the generic operator below.

1. Market share	
Market share of voice, data and subscribers [1]	Assumed to be 33.3%, as described in the Analysys Mason report entitled "Pricing principles and methodologies for future regulation of wholesale voice call termination services".
2. Coverage inputs	
2G population coverage [6]	The previous MTR model inputs are used
3G population coverage [1, 6]	The previous MTR model are used up to 2012. Additional coverage through up to 97% of population is then assumed.
4G population coverage [1, 4]	Estimated based on operator data, assumed to reach 99.96% coverage in the long term.
Frequency used to deploy coverage for each network [6]	Based on the frequency allocation of the generic operator and the previous MTR model.
Number of UMTS channels for UMTS rather than HSPA traffic [1]	Assumption for the generic operator.
3. Spectrum inputs	
Amount of paired spectrum by technology and whether this spectrum is used for coverage or capacity [1]	Based on the frequency allocation of the generic operator.
4. GSM inputs	

Number of channels reserved for 2G packet data and for signalling [1, 2]	Estimate of the technical aspects of the network. 2G data reservation cross-checked with operator data.
2G blocking probability [4]	Averaged across operator data.
5. UMTS inputs	
3G blocking probability [4]	Averaged across operator data.
6. HSPA inputs	
Deployment date of each HSDPA/HSUPA step [1]	When each HSPA carrier step can be first deployed.
7. 4G inputs	
Deployment date of each 4G step [1]	When each 4G carrier step can be first deployed.
8. LMA and hub to core inputs	
Proportion of links that are leased and the transmission protocol they use in each geotype [4]	Averaged across operator data.
Proportion of sites collocated with hubs and the transmission protocol they use in each geotype [1]	Compared to results in other cost models.
Proportion of sites connected via a hub to the core network, rather than being connected directly to the core network, the number of sites per hub, and the number of hubs per hub-core transmission link, in each geotype [1, 2]	Compared to results in other cost models and operator data.
Number of core sites [4]	Averaged across operator data.

B.6 Worksheet *InNwDes*

1. Coverage	
Cell radius for outdoor coverage [3]	Model outputs validated against actual site and base station numbers from the operators.
Radius multiplier across frequencies [1]	Consistent with that used in cost models in other jurisdictions.

Cell 'pi' which is used to calculate the cell area covered [5]	Mathematical value giving the area of a hexagon from its radius. Used in mobile LRIC models adopted in other countries.
Frequency used for coverage added in each year, linked from the selected operator [4, 6]	2G and 3G assumptions consistent with previous MTR model. 4G assumptions informed by operator data.
2. Spectrum	
Amount of paired spectrum in each coverage and capacity layer, linked from the selected operator [1]	See Section 3.2.2.
Size of a radio channel, in MHz [5]	Standard mobile network parameter.
Number of UMTS channels reserved for voice and low-speed R99 data (not HSPA) [5]	Standard mobile network parameter.
3. GSM capacity	
Cell reuse factor [5]	Standard technical parameter (estimated for each of a range of frequency allocations).
Average sectorisation of 2G sites [4]	Averaged across operator data.
Physical TRX per sector limit, along with the calculation of the effective limit on average by geotype. [1]	Estimate of BTS size.
2G voice channel rates [6]	Value of 9.6kbit/s assumed, based on AMR coding specifications.
2G data channel rates [5]	Standard technical parameter of 24kbit/s.
4. UMTS capacity	
R99 channel rate in Mbit/s [1, 5]	Standard technical parameter.
Average sectorisation of UMTS sites [4]	Averaged across operator data.
Soft- and softer-handover overheads [1, 5]	Estimate of the technical aspects of the network.
Number of R99 signalling channels per carrier, minimum and maximum R99 carriers per carrier (pooled at the NodeB) [1, 5]	Estimate of the technical aspects of the network.
Channel kit size (in CE) [5]	Standard technical parameter.

5. HSPA capacity

Cell peak to effective rate for data throughput [1]	Analysys Mason estimate of the effect of distance and other signal-to-noise factors in a HSPA deployment – only the maximum data rate is attainable close to the mast. At cell edges, a lower rate is possible. We have developed a number of technical link-budget models in other situations which suggest that the ratio of *effective data rate* to the *peak data rate* is a specific factor.
HSDPA and HSUPA rate ladder [5]	Standard technical parameter.

6. 4G capacity

Cell peak to effective rate for data throughput [1]	See above. We assume that the effects described for HSPA also apply to 4G to the same extent.
4G rate ladder [5]	Standard technical parameter.
VoLTE radio channel rate - AMR-WB codec standard (kbit/s) [5]	Standard technical parameter.

7. Physical sites

Percentage for sites available for co-location sites [1, 3]	Estimate based on operator information and consistent with other cost models.
Percentage of sites which are deployed on third-party infrastructure [4]	Estimate based on operator data.

8. LMA and hub to core

LMA and hub-core rate ladders [5]	Standard technical parameter.
Site transmission choice [1]	Standard assumption.
Proportion of sites co-located with hubs [1]	Benchmark from other models.
Proportion of LMA that is leased [4]	Averaged across operator data.
Hub-core link parameters for rings or point-to-point hub-core transmission [1]	

9. RNC and BSC

Number of locations where base station controllers (BSC) and radio network controllers (RNC) are deployed [4]	Comparable to operator data.
Share of radio traffic in the suburban or rural geotypes that is handled by a BSC or RNC in the same geotype rather than being transferred to a BSC or RNC in the urban geotype [1]	Estimated from the proportion of capacity of all BSCs/RNCs that are not in urban geotype.
Linked operator inputs for the number of BSC/RNC locations, and the proportion of load served in each geotype [6]	Input linked for the selected operator's worksheet.
BSC and RNC capacity ladders [5]	Standard technical parameter.

10. BSC-core traffic

Remote BSC-core rate ladder [5]	Standard technical parameter.
Transmission protocol used by BSC to core nodes for voice and data [2]	Informed by operator data.
Redundancy in BSC-core links [1, 5]	Estimated technical parameter

11. RNC-core traffic

Remote RNC-core rate ladders [5]	Standard technical parameter.
Transmission protocol used by RNC to core nodes for voice and data [2]	Informed by operator data.
Redundancy in RNC-core links [1, 5]	Estimated technical parameter.
Linked operator input for the protocol used for voice and data interfaces [5]	Standard technical parameter.

12. Core-core traffic

Assumed number of core sites [2]	Based on operator data.
Proportion of traffic conveyed across the core, and transmission protocol for voice and data layers [1]	Estimates taken from other cost models.
Core-core rate ladder, and number and distance of hops in the dark-fibre core network [1, 3]	Major population centres were selected to represent a core network deployment in Ireland. Distances from a city to another were measured

	using the "get directions" function of Google Maps.

13. Switches and servers

Capacity for each network element in the list [1]	Estimates taken from other cost models, and simple inputs.
Minimum number and redundancy multiplier for each network element in the list [1]	Estimated technical parameter.

14. Spectrum

Reserve prices per paired MHz	Sourced from ComReg information notice, document 12/123.
Capex per paired MHz [1]	Calibrated using actual upfront fees paid, assuming the relative prices per MHz by band calculated for the Irish auction by Ofcom.
2100MHz access fees paid	Averaged from actual licence fees in published 2100MHz licences.[33]
Recurring fees paid in other bands from 2013 onwards	Sourced from ComReg information notice, document 12/123.
Recurring fees paid in other bands prior to 2013 [6]	Previous MTR model.

15. Utilisation factors

Maximum utilisation factors for network capacity for each set of network elements [1, 3, 5, 6]	Estimated technical parameter, checking of realistic model outputs, operator estimates and information, informed by the previous MTR model as a starting point,
Uplift for cell-by-cell busy-hour adjustment [1]	Based on similar uplifts used in cost models developed in other jurisdictions.

B.7 Worksheet *InAsset*

Retirement period [1]	Estimate of delay before removal from network.
Lifetime, planning period, proportion of assets replaced per annum and opex as a proportion	Previous MTR model, estimates and assumptions, consideration of other cost models.

33 See https://www.comreg.ie/industry/radio-spectrum/licensing/search-licence-type/mobile-licences/.

of capex based on the cost input category [1, 2, 6]	
Unit capex/opex in real 2017 EUR [1, 2, 3, 6]	Estimates and assumptions, consideration of other cost models, the previous MTR model, operator information (equipment prices and total expenditures).

B.8 Worksheet *InCostTrends*

Year-on-year change in capex trends over time for a set of specified categories [6]	Starting point has been the previous MTR model.
Year-on-year change in opex trends over time for a set of specified categories [1]	Assumed to be either zero, or the same as in the previous MTR model.

B.9 Worksheet *InRFs*

Links in a series of standard technical parameters [1, 5]	Inputs needed to calculate LRAIC allocation proportions.
For each asset and each modelled service, identifies the routeing factor from the routeing factor options table based on the asset measure option for that asset [1]	Assumption for the LRAIC allocation rules.

B.10 Worksheet *InDF*

Nominal discount rate	ComReg Document 14/136 & D15/14.
Consumer price index	Historical data and forecasts sourced from the CSO[34] and Bank of Ireland[35] respectively.

B.11 Worksheet *InErlang*

Number of Erlangs for a given number of channels between 0 and 14 000, for network blocking probabilities of 0.1%, 1%, 2%, 3% and 5% [1]	Table calculated by Analysys Mason.

34 See http://www.cso.ie/px/pxeirestat/Statire/SelectVarVal/Define.asp?maintable=CPA01&PLanguage=0.

35 See https://corporate-economy.bankofireland.com/wp-content/uploads/2017/02/BOI_IRELAND_OUTLOOK_FEBRUARY_2017.pdf.

Number of Erlangs for a given number of channels and an assumed 2G blocking probability, for different numbers of GPRS channel reservations	Calculated from above table

Annex C Top-down validation of the proposed new MTR model

We have validated the asset counts and expenditures based on the top-down information provided by the MNOs in response to the 13D request. This process has included calibration of particular asset counts and reconciliation of expenditures. We describe this validation in more detail below:

- Annex C.1 illustrates our calibration of radio equipment (on a geotype-by-geotype basis) and of other assets (on a national basis)
- Annex C.2 illustrates our reconciliation of total expenditures.

When undertaking our asset calibration, we assume a market share of 40% (since Three and Vodafone both have market shares around that level, whilst Meteor is significantly lower). This is the main change we make compared to the basecase configuration of the proposed new MTR model (which assumes 33.3% market share from 2014 onwards, as described in Section 3.1.2).

C.1 Asset calibration

We received site co-ordinates by operator derived from ComReg’s licence data reporting. These were processed to estimate, by geotype, the number of base station locations by technology in each of the five geotypes defined. We assume that base station co-ordinates within 20 metres of each other are located on the same site.

In each chart, the “minimum”, “average” and “maximum” values are those calculated based on the data received from ComReg for the site locations of Meteor, Vodafone and Three (except for the first case below).

Figure C.1 illustrates our comparison of 2G base stations (900MHz and 1800MHz). ✂. As can be seen below, the modelled number of 2G base stations remains within the minimum/maximum range for each geotype.

✂

Figure C.1: Comparison of modelled 2G base stations in 2016 with Meteor, Vodafone and O2 data [Source: Analysys Mason and 13D request, 2018]

Figure C.2 illustrates our comparison of 3G 2100MHz base stations. As can be seen below, the modelled number of 3G 2100MHz base stations remains within the minimum/maximum range for each geotype.

✂

Figure C.2: Comparison of modelled 3G 2100MHz base stations in 2016 with operator data [Source: Analysys Mason and 13D request, 2018]

Figure C.3 illustrates our comparison of modelled 4G base stations. As can be seen below, the modelled number of 4G base stations remains within the minimum/maximum range for each geotype.

✂

Figure C.3: Comparison of modelled 4G base stations in 2016 with operator data [Source: Analysys Mason and 13D request, 2018]

Figure C.4 illustrates our comparison of physical sites locations. As can be seen below, the modelled number of sites remains within the minimum/maximum range for each geotype, except in Rural 2.

✂

Figure C.4: Comparison of modelled physical sites in 2016 with operator data [Source: Analysys Mason and 13D request, 2018]

Figure C.5 illustrates our comparison of 3G/4G site locations. As can be seen below, the modelled number of 3G/4G sites is close to, but not within range of the minimum and maximum for the urban, rural 1 and rural 2 geotypes.

✂

Figure C.5: Comparison of modelled 3G/4G sites in 2016 with operator data [Source: Analysys Mason and 13D request, 2018]

We have also calibrated a small number of other significant assets, as summarised in Figure C.6 below.

Figure C.6: Calibration of other key modelled assets in 2016 [Source: Analysys Mason, 2018]

Asset	Minimum	Model	Average	Maximum
TRX (thousands)	✂	13.8	✂	✂

Asset	Minimum	Model	Average	Maximum
BSC	✂	9	✂	✂
RNC	✂	8	✂	✂

C.2 Reconciliation of expenditures

We have calculated the unit costs for several assets based on bottom-up operator data, although information provided was extremely limited. Values were derived for the opex for sites and leased lines, as well as the capex for the following assets.

- 2G BTS, 3G NodeB and 4G eNodeB
- 3G and 4G carriers
- HSPA software upgrades
- Self-provided microwave, leased lines and leased fibre
- BSC and RNC units
- MSS, MGW, SGSN, HLR, MME and SGW.

Other unit capex assumptions are informed by either values from the previous MTR model or benchmarking of other published cost models. We apply the same indirect capex mark-ups as used in the previous MTR model.

Other unit opex assumptions are parameterised separately on the basis of opex as a proportion of capex for the following categories of asset:

- Base station equipment
- Other radio equipment (carriers, TRX, HSPA software upgrades etc.)
- Transmission equipment
- BSC/RNC switches
- Network switches
- Network servers
- Ports
- NMC

We have then compared modelled 2016 opex to actual opex from the operators where we received top-down data across the three cost categories of radio network, transmission and core network. We exclude overheads and spectrum fees in our categorisation (overheads in the proposed new MTR model are specified using the same mark-up as in the previous MTR model, whilst spectrum fees are modelled on a bottom-up basis).