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Report for Ofcom

MCT review 2015–2018: Mobile network cost modelling

Proposals for model

4 June 2014

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Contents

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1 Introduction

Ofcom has commissioned Analysys Mason Limited (Analysys Mason) to provide support in relation to the cost modelling of mobile networks used to inform the price regulation of wholesale mobile call termination (MCT), as defined in Market 7 in the European Commission's (EC) Recommendation on relevant markets – 2007/879/EC. Ofcom's existing cost model (the '2011 MCT model'), which was used in the previous review of Market 7, considered a generic operator using both 2G and 3G technology in accordance with the EC Recommendation on the *Regulatory Treatment of Fixed and Mobile Termination Rates in the EU*, released in May 2009.[1]

The 2011 MCT model calculated estimates for the costs of wholesale mobile voice termination according to both:

- the LRIC+ method, which had been used in previous iterations of Ofcom's model
- the LRIC[2] method, which was adopted for the first time in the 2011 MCT model.

As part of the preparation for the next charge control period (starting in 2015), Analysys Mason and Ofcom are updating the 2011 MCT model to reflect recent developments in the mobile market. This report presents the changes made to the 2011 MCT model for wholesale mobile voice termination in the UK for Ofcom's May 2014 consultation. It specifies the upgrades to the 2011 MCT model which have led to an updated MCT model (the '2014 MCT model'). The scope of Analysys Mason's work is limited to the Network and Cost modules; Ofcom is leading the update of the remaining modules.

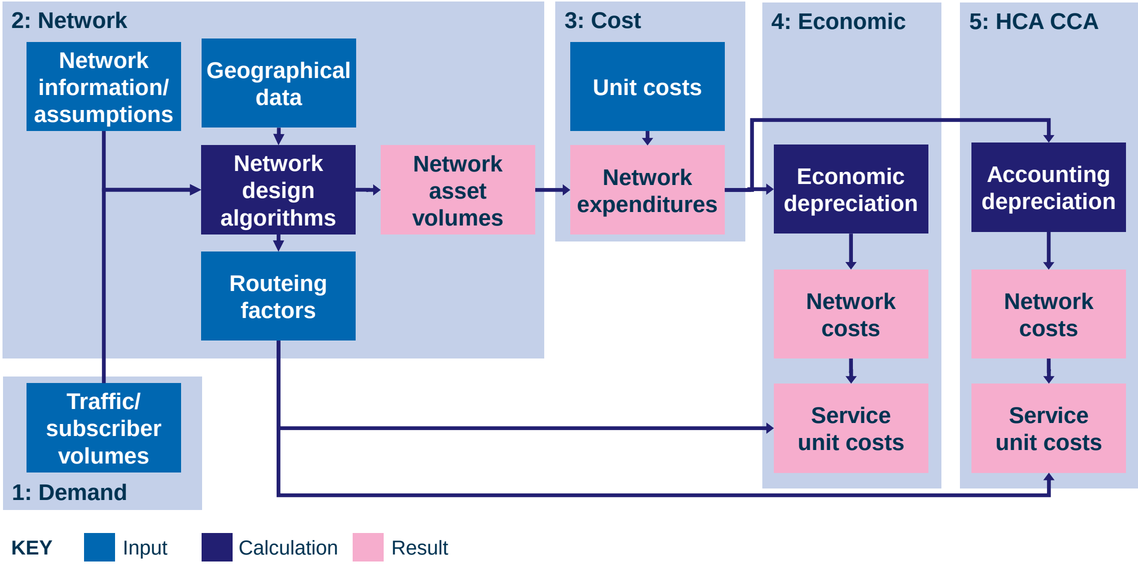
Where inputs of the Network/Cost modules have been determined by Ofcom, we cite the relevant annex of Ofcom's consultation document for reference.

The 2014 MCT model will be used to inform Ofcom's proposals in relation to setting a charge control in the relevant markets as part of its *MCT Review 2015–2018*. This report describes each change in turn and specifies the location of the calculations, the major inputs and the operator data that has influenced our proposed revisions to the 2011 MCT model. Figure 1.1 illustrates the modular form of Ofcom's 2014 MCT model.

1 See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:124:0067:0074:EN:PDF

2 For the avoidance of doubt, where we refer to "LRIC" in this report, we mean the "pure LRIC" methodology.

Figure 1.1: Modular form of Ofcom's 2014 MCT model [Source: Analysys Mason, 2014]



There is also a central Scenario Control module allowing the 2014 MCT model to be re-calculated according to parameters in a selected scenario.

Structure of this document

The remainder of this document is laid out as follows:

- Section 2 describes revisions made to the Network module for 2G/3G modelling
- Section 3 describes revisions made to the Network module for 4G modelling
- Section 4 describes revisions made to the Cost module.

The report includes a number of annexes containing supplementary material:

- Annex A describes other adjustments made to the 2011 MCT model
- Annex B presents a confidential overview of the s135 responses
- Annex C summarises the feedback received in the workshops held by Ofcom in October 2013 and January 2014 regarding the MCT model and how this feedback has been addressed in the 2014 MCT model
- Annex E spells out acronyms used in this document.

The scissor symbol and square brackets '[✂]' have been used where confidential information has been redacted from the published report.

2 Revisions to the Network module for 2G/3G modelling

This section describes the revisions made to the 2G/3G network design. In particular:

- Section 2.1 states the changes made to the HSPA network
- Section 2.2 states the changes made to the high-speed backhaul assets
- Section 2.3 states the changes made to the transmission *to* the core network
- Section 2.4 states the changes made to the transmission *within* the core network
- Section 2.5 states the changes made to other network design inputs
- Section 2.6 summarises the revisions to the spectrum holdings used for the 2G/3G networks
- Section 2.7 describes the implementation of cell breathing
- Section 0 describes why we have chosen not to model femtocells.

Each subsection gives a description of the changes as well as the conclusions drawn from operator data that influenced them.

An illustration of the 2G/3G network design is provided in Annex D.

2.1 HSPA network

To accommodate improvements in HSPA technology since the development of the 2011 MCT model, we have increased the number of modelled HSPA speeds from four to seven in the 2014 MCT model. This has enabled the inclusion of three extra speed options: 21Mbit/s, 42Mbit/s and 84Mbit/s. The first two have been chosen as speeds known to be currently deployed by all four operators in the UK, with the third being the most likely subsequent upgrade.

Adding these additional speeds has required an update to the 'data downlift factors', which are used in the model to capture the relative efficiency of carrying data traffic on different speed radio technologies compared to 3G voice. These factors are defined on the *Parameters* worksheet of the Scenario Control module. For example, in the 2011 MCT model, we used a data downlift factor of six for 14.4Mbit/s HSDPA (i.e. data traffic is carried using this upgrade with efficiency six times greater than that of R99 voice). In the 2014 MCT model, we have three higher speeds for which new data downlift factors are required. Operator data suggested a logarithmic relationship between speed and efficiency. We therefore derived a logarithmic curve from the original three speeds and used this to extrapolate the downlift factors for the three new speeds, as shown below in Figure 2.1.

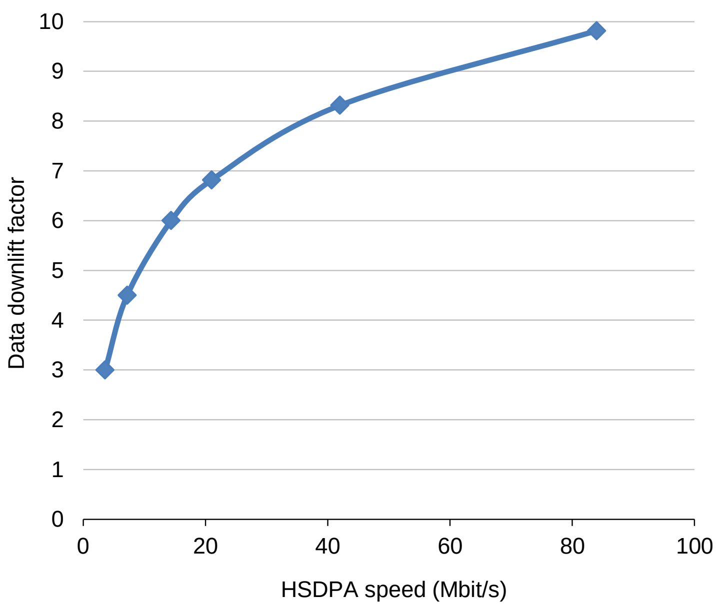
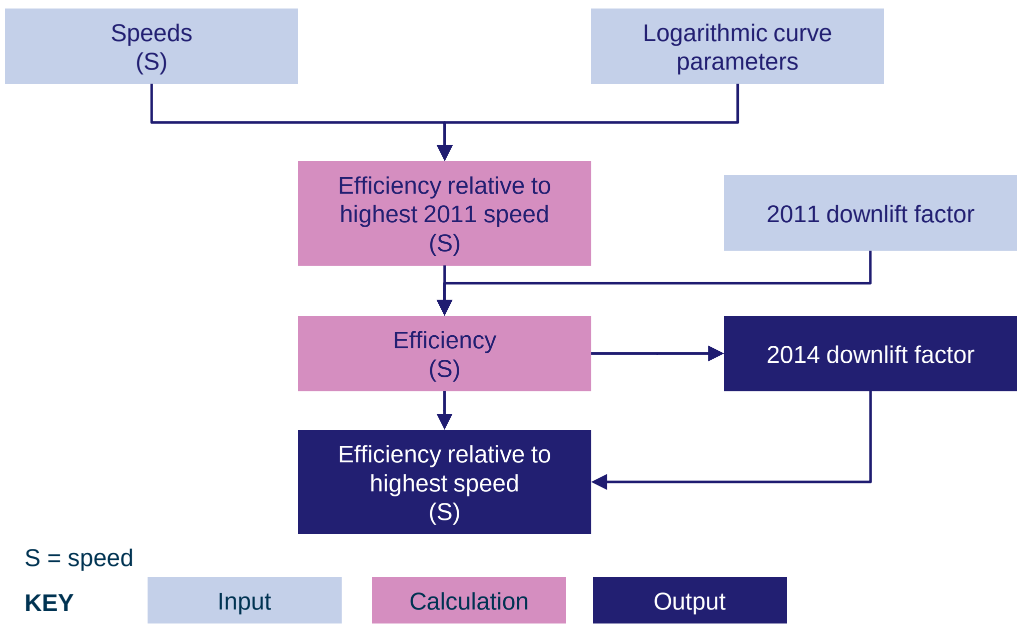


Figure 2.1: Illustration of data downlift factors [Source: Analysys Mason, 2014]

Figure 2.2 illustrates the calculation of the relative efficiencies of the new HSPA speeds and the new data downlift factors.

Figure 2.2: Illustration of the data downlift calculation for HSPA [Source: Analysys Mason, 2014]



Each HSPA upgrade is deployed according to two inputs: a year when deployment starts and a number of years to complete deployment. The assumptions used for each upgrade in the 2014 MCT model are summarised in Figure 2.3 below.

Figure 2.3: Deployment assumptions by HSPA upgrade [Source: Analysys Mason, 2014]

HSPA upgrade	First year of deployment	Years to complete	Explanation
3.6Mbit/s	2006/07	2	Retained from 2011 MCT model
7.2Mbit/s	2007/08	2	Retained from 2011 MCT model
14.4Mbit/s	2009/10	3	Retained from 2011 MCT model
21Mbit/s	–	–	Not used; instead, 42Mbit/s upgrades are first deployed when 14.4Mbit/s deployment is complete
42Mbit/s	2012/13	3	s135 responses indicate that 42Mbit/s deployments are advanced by 2013/14, as explained in Annex B.1
84Mbit/s	–	–	s135 responses do not indicate use of this upgrade, as explained in Annex B.1

2.2 High-speed backhaul

In the 2011 MCT model, sites could be served by two last-mile access (LMA) backhaul options:

- Self-provided microwave links that have a speed of 2Mbit/s, 4Mbit/s, 8Mbit/s, 16Mbit/s or 32Mbit/s; such microwave links are assumed to require on average 1.3 hops, and each hop requires a 'base unit'[3] (assumed to comprise the equipment at both ends of the link); or
- Ethernet, assumed to be a single high-speed backhaul product of undefined speed.

We have included additional options for high-speed backhaul. Their exact definition has been determined based on operator data, as described in Annex B.2 of this report.

In the 2014 MCT model, we have added six high-speed options to the backhaul design. Three of these options are leased Ethernet; these become available in a specified year (currently 2009/2010) within the model and replace the Ethernet option present in the 2011 MCT model. The other three options are for Ethernet-based microwave links; these become available in the same specified year within the model and work in addition to the microwave links present in the 2011 MCT model. We propose that:

- the speeds at which these links should operate are 100Mbit/s, 300Mbit/s and 500Mbit/s,[4] parameterised as 50, 150 and 250 2Mbit/s-equivalent circuits in the model respectively
- the proportion of sites which will use leased Ethernet links as a means of high-speed backhaul (as opposed to owned microwave) is 33% in all years, derived as an average value from the data submitted by the operators in response to the s135 information requests

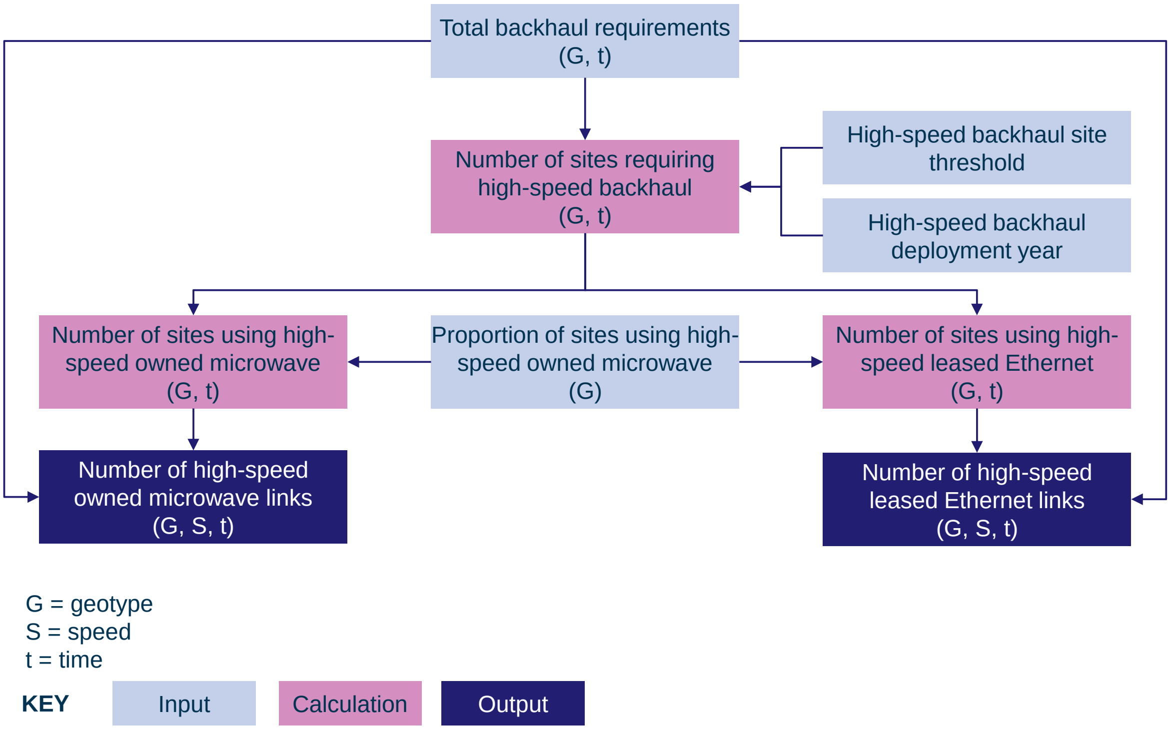
3 The cost of this base unit is also assumed to include the cost of a 2Mbit/s link, which is why the 2Mbit/s link asset has a cost of zero.

4 The 500Mbit/s option is not currently required to serve the traffic volumes in the 2014 MCT model, but it is included in the event that a more aggressive traffic scenario is tested, leading to these links being required in the longer term.

- the values used for the associated opex and capex are derived using operator data where this has been provided; otherwise, the values have been extrapolated from the current (lower-speed) values assuming a logarithmic relationship.[5]

Figure 2.4 illustrates how the high-speed backhaul options are calculated in the Network module. The new inputs can be found on the *Params - other* worksheet and the new calculations are located on the *Nw-other* worksheet.

Figure 2.4: Illustration of the high-speed backhaul calculation [Source: Analysys Mason, 2014]



2.3 Transmission to the core network

In the 2G/3G network in the 2011 MCT model, the LMA links to the base stations were assumed to terminate at BSC/RNC locations, some of which were remote from the main switching buildings in the core network.

In the 2014 MCT model, we now include 4G network functionality, as described in Section 3 of this report. 4G networks do not have an equivalent of BSCs and RNCs. In the absence of this layer, we instead assume that a proportion of LMA links to 4G radio sites terminate at a transmission hub site that is not within the core network. These links then require additional transmission to reach the core network. These high-speed 'hub-to-core' links are assumed to have

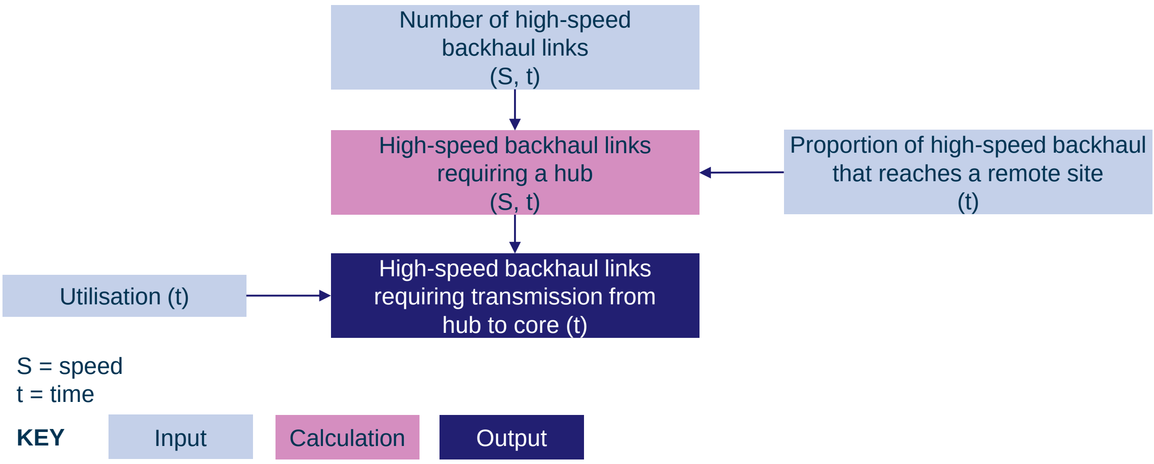
5 This logarithmic relationship is derived using the 2011 MCT model data points to calibrate a trend line that allows costs for the faster speeds to be extrapolated.

a capacity of 1,000Mbit/s (based on operator responses to the s135 dated 14 February 2014), this is parameterised as 500 2Mbit/s-equivalent circuits in the model.

To calculate the number of these hub-to-core links that are required, a fixed proportion of high-speed backhaul links are assumed to terminate at remote sites. The volume of traffic terminating at these remote sites is then calculated and the required number of hub-to-core links is then derived.

The inputs for this new functionality are specified on the *Params - other* worksheet of the Network module. The calculations occur on the *Nw-other* worksheet in the Network module and are set out in Figure 2.5.

Figure 2.5: Illustration of the calculation for transmission to the core network [Source: Analysys Mason, 2014]



2.4 2G/3G core network

We have retained the MSC–S/MGW architecture used in the 2011 MCT model for the 2G/3G core network. As described in Section 3.3, a 4G core network has been included as an overlay. We have also retained the GGSN and SGSN asset calculations. The assumed asset capacities have been modified by Ofcom as part of the calibration exercise.

For the transmission within the core network, the 2011 MCT model dimensioned 2Mbit/s circuits. For the purposes of the 2014 MCT model, we have designed a hypothetical backbone. In the following subsection we describe how we first define the core network locations and then the links between them. We also describe how traffic is migrated from the legacy core transmission network onto this new core transmission network.

2.4.1 Definition of core node locations

The 2011 MCT model indicated that up to 30 core node locations would be present in the UK, as specified by the ‘Maximum number of switch sites’ input on the *Params – other* worksheet in the Network module. We consider these locations in more detail in the 2014 MCT model.

Information was gathered from the four largest mobile operators regarding the 'Maximum number of switch sites' in the s135 notice dated 8 November 2013. Based on the evidence received, we have revised this value to be 16. Following further inspection of their actual core network deployments, we have concluded that a reasonable deployment of these nodes would be to have three core nodes in the Greater London area, one in Wales, one in Scotland, one in Northern Ireland and the remainder in England. Thirteen hypothetical locations (not in London) were then chosen based on city population, while also ensuring that Wales, Scotland and Northern Ireland each had at least one location. Three locations for London were chosen based on those parts of the London and Greater London area with the largest population (Slough, Croydon and the East London postcode area). Figure 2.6 provides a list of the core node locations and their co-ordinates (the locations are from our own geographical datasets, rather than from operator data).

Location	Latitude	Longitude
Belfast	54.597	–5.930
Bristol	51.468	–2.536
Cambridge	52.205	0.122
Carlisle	54.893	–2.933
Croydon	51.376	–0.098
Exeter	50.718	–3.534
Glasgow	55.862	–4.266
Hull	53.746	–0.337
Leicester	52.632	–1.131
Liverpool	53.421	–2.967
London East	51.577	0.014
Newcastle	54.978	–1.618
Slough	51.511	–0.595
Southampton	50.918	–1.357
Swansea	51.627	–3.952
Wolverhampton	52.592	–2.142

Figure 2.6: List of backbone locations and their co-ordinates [Source: Analysys Mason, 2014]

2.4.2 Definition of transmission links

We have plotted a set of point-to-point links between the nodes to create resilient rings. Figure 2.7 below shows the core node locations and our assumed links. This backbone comprises 19 links with a total point-to-point length of 2,413km.

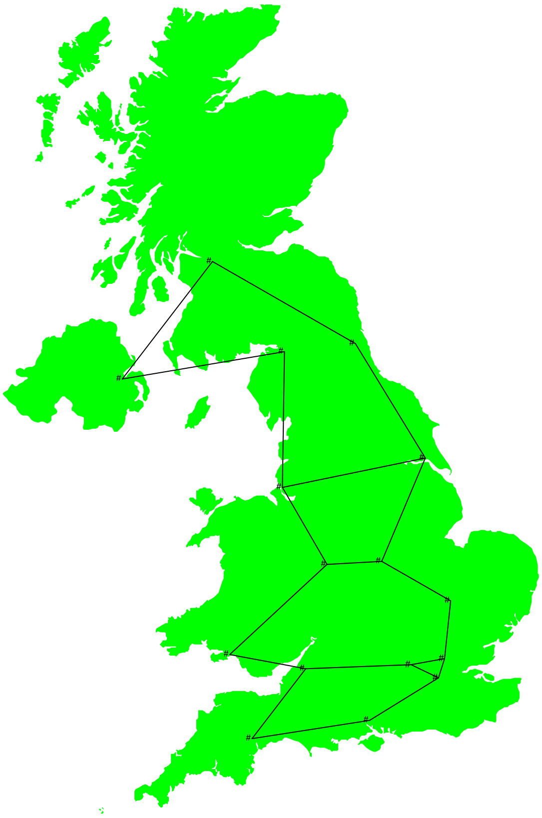


Figure 2.7: Core node transmission links [Source: Analysys Mason, 2014]

2.4.3 Definition of network migration

The transmission network is assumed to begin carrying traffic in a specified year (2011/2012 in the 2014 MCT model), with all traffic migrated onto it over a specified number of years (zero years as defined in the 2014 MCT model). The legacy backbone network is then shut down. This short period of overlap is consistent with what is seen in other regulators' mobile cost models (e.g. Norway).

All inputs in relation to this new transmission network can be found on the *Params - other* worksheet of the Network module.

2.5 Other network design inputs

The radio blocking probability is an input in the 2G/3G radio network design related to the dimensioning for voice traffic. A blocking probability of x% assumes that a traffic channel will only be unavailable for x% of attempted calls. Several operators indicated that they now assume a radio blocking probability of around 1% in both the 2G and 3G networks, rather than the value of 2% that has historically been considered. We have therefore converted both of these inputs (on the *Params - 2G* / *Params - 3G* worksheets) to be a time series of values. They take the value 2% before 2010/2011 (as in the 2011 MCT model) and the value of 1% from 2010/2011.

Following analysis of the evidence provided by operators in response to the s135 requests, we are proposing to revise a number of other 2G and 3G network design inputs. A summary of these changes can be found in Figure 2.8 below. These were based on taking rounded averages of operator data, where there were at least two submissions. Certain values, highlighted below with an asterisk, were set at values chosen by Ofcom in order to achieve closer calibration of the 2014 MCT model to operator asset counts.

Some of the values in the 2011 MCT model were based on estimates or assumptions (e.g. the proportion of BSC–SGSN traffic which traverses the core network). The 2013/2014 modelling has allowed for some of these inputs to be refined based on responses to the s135 requests.

Figure 2.8: Summary table of network design inputs revised using responses from the s135 notices (values highlighted with an asterisk were set at different values in order to achieve closer calibration of the 2014 MCT model to operator top-down asset counts) [Source: Analysys Mason, 2014]

Name	Worksheet	Value in the 2011 MCT model	Value in the 2014 MCT model
Average call duration (2G incoming) (minutes)	*Params - 2G*	1.7	1.8
Average call duration (2G outgoing and on-net) (minutes)	*Params - 2G*	1.65	2
2G call attempts per successful call	*Params - 2G*	1.5	1.6
GPRS data rate (kbit/s)	*Params – 2G*	9.05	20*
Proportion of GPRS data in the downlink	*Params - 2G*	75%	77%
Proportion of BSC–MSC traffic which traverses the core network	*Params - 2G*	50%	60%
Proportion of BSC–SGSN traffic which traverses the core network	*Params - 2G*	50%	100%
Proportion of SGSN–GGSN traffic which traverses the core network	*Params - 2G*	50%	100%
Proportion of MSC–MSC traffic which traverses the core network	*Params - 2G*	50%	100%
Average call duration (3G incoming) (minutes)	*Params - 3G*	1.7	1.8
Average call duration (3G outgoing) (minutes)	*Params - 3G*	1.7	1.8
Average call duration (3G on-net) (minutes)	*Params - 3G*	1.65	2
3G call attempts per successful call	*Params - 3G*	1.5	1.3
Proportion of data traffic in the downlink	*Params - 3G*	75%	88%
Proportion of RNC–MGW traffic which traverses the core network	*Params - 3G*	50%	75%
Proportion of RNC–SGSN traffic which traverses the core network	*Params - 3G*	50%	100%
Proportion of SGSN–GGSN traffic which traverses the core network	*Params - 3G*	50%	100%
Traffic overhead RNC–SGSN	*Params - 3G*	20%	3%
Traffic overhead SGSN–GGSN	*Params - 3G*	20%	3%
Minimum number of switch sites	*Params - other*	3	11
Maximum number of switch sites	*Params - other*	30	16
Capacity of a VMS (subscribers)	*Params - other*	4,000,000	22,000,000
Capacity of an SMSC (message/s)	*Params - other*	500	5,800
Capacity of HLR (subscribers)	*Params - other*	2,000,000	4,000,000

2.6 Spectrum allocations and valuations

The 2011 MCT model assumed that 2×30MHz of 1800MHz spectrum was available for the 2G network. This assumption has been updated in the 2014 MCT model so that 2×10MHz of this spectrum is refarmed for 4G purposes in 2012/2013. Therefore, the ongoing fees associated with that spectrum are removed from the costs of the GSM licence fee asset and included in the 4G licence fee asset.

The 2011 MCT model further assumed that the 3G network had access to 2×10MHz of 2100MHz spectrum. Since that model was finalised, all four UK operators have now been found to be using at least three carriers in their 3G network (though not necessarily all in the 2100MHz band). Therefore, we reflect this in the 2014 MCT model by assuming the modelled operator gains access to a third 2×5MHz 2100MHz carrier in 2012/2013.

Spectrum allocations and valuation is discussed further in Annex 15 of Ofcom's consultation document.

2.7 Implementation of cell breathing

The rationale for a cell-breathing adjustment to the 3G cell radius is to capture the traffic dependency of the cell radius in 3G networks.[6] This effect is compounded by the fact that the voice capacity of a 3G coverage network is very high, meaning that a modelled coverage network in general is often sufficient to carry the modelled traffic (and therefore no base stations are avoided with the removal of MCT). If cells 'breathe', then coverage can become patchy in the long term as traffic levels increase and the cell coverage shrinks. When choosing the number (and location) of its coverage sites, an operator would therefore look forward and assume a certain level of long-term loading so as to avoid excessive cell breathing. The result of this set of assumptions is that some NodeBs are in fact avoidable with termination, on the basis that they were deployed taking the existence of that traffic into account (and a different number would have been deployed were that traffic not expected).

In order to take the cell-breathing effect into account within the 2014 MCT model, we have implemented a calculation which allows an adjustment factor to be placed on cell radii when termination is switched off. This calculation involves three steps:

1. Calculate the maximum utilisation of 3G carriers in the 2014 MCT model, both including and excluding voice termination.
2. Use these two utilisations as estimates for the long-term cell loading in the network design.
3. Derive a corresponding change in 3G cell radii using these two estimates of cell loading and the cell-breathing curve in Figure 2.9.

[6] This is a technical issue relating to 3G networks only; it does not affect 2G or 4G networks.

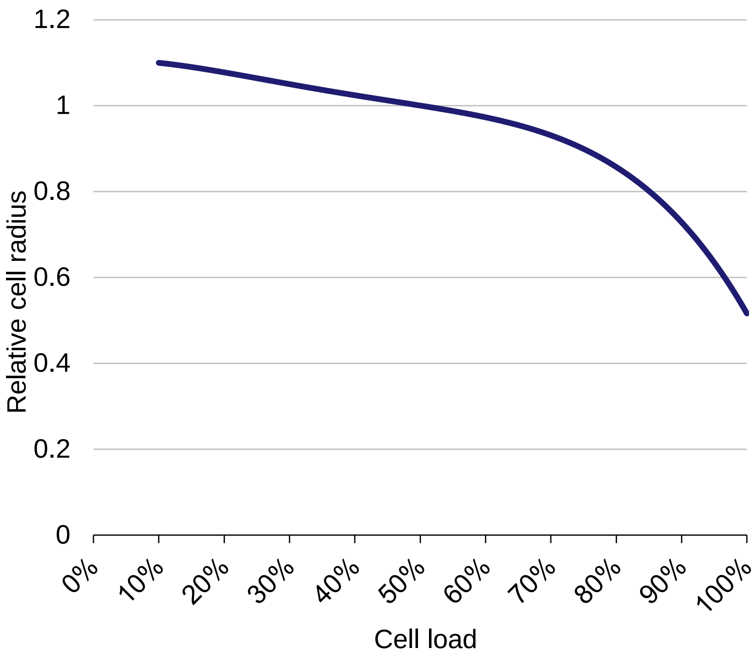


Figure 2.9: Estimated cell-breathing effect, relative to the cell radius assumed at 50% cell loading [Source: Analysys Mason, 2013]

Within the 2014 MCT model the cell-breathing curve shown in Figure 2.9 takes the form:[7]

$$y = -2.4629x^4 + 3.5425x^3 - 1.7633x^2 + 0.0951x + 1.1044$$

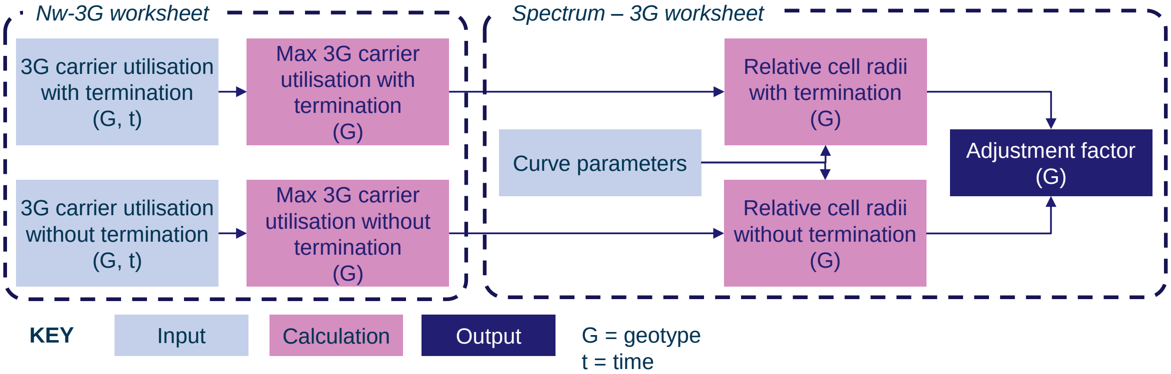
The first step is to calculate the maximum utilisation of 3G carriers, with and without termination. This calculation sits on the *Nw-3G* worksheet of the Network module. The assumption is that the maximum utilisation by geotype represents the long-term cell loading for the 3G network in that geotype. Relative cell radii are then calculated based on these cell-loading values from the curve shown in Figure 2.9. The final adjustment factor to the 3G cell radius in each geotype is then taken as the ratio of the relative loading values with and without termination.

The inputs can be found on the *Spectrum - 3G* worksheet of the Network module, and the cell-breathing ratios can be updated using a macro, which can be run from a button on that worksheet.

The 2014 MCT model also includes a switch in the Scenario Control module that enables this adjustment to be turned on or off. This calculation, and the worksheet location of its steps, is shown in the flowchart in Figure 2.10 below.

[7] This equation was derived as a polynomial trendline for the curve shown in Figure 2.9. The same equation was used in our work for the Danish Business Authority.

Figure 2.10: Flowchart illustrating the cell-breathing adjustment calculation [Source: Analysys Mason, 2014]



Having tested the sensitivity of the 2014 MCT model results to this adjustment we found that the traffic-driven nature of the 2014 MCT model means that the impact of the cell-breathing does not have a material impact, and consequently is not included in the model base case.

2.8 Treatment of femtocells

The 2011 MCT model did not include femtocells explicitly. Although femtocells have become more widespread in the UK since the 2011 MCT model was finalised, all operator data we received indicated that less than 1% of voice/data traffic is currently carried by femtocells. Modelling them explicitly would therefore lead to less than a 1% decrease in the traffic carried by the macrocell layer, which would have a negligible impact on the macrocell deployments. Therefore, on the basis of materiality, we do not propose to model these assets explicitly in the 2014 MCT model.

3 Revisions to the Network module for 4G modelling

The 2011 MCT model did not include 4G infrastructure. This section describes the revisions made to the network design to accommodate 4G infrastructure. The treatment of 4G is, at a high level, analogous to that of 2G and 3G technologies. In particular:

- Section 3.1 describes the design of the 4G radio network
- Section 3.2 describes the 4G spectrum allocations and fees
- Section 3.3 describes the design of the 4G core network
- Section 3.4 describes the design of the VoLTE network.

The costing calculations have also been updated to capture the cost of 4G voice within the blended cost of termination over time (for both the LRIC+ and LRIC calculations).

Each subsection gives a description of the proposed changes as well as the provisional findings drawn from operator data that influenced them. Where input values are stated, their derivation is given in more detail in Annex B.

An illustration of the 4G network design is provided in Annex D.

3.1 Radio network

The 4G radio network calculations are in several parts:

- radio coverage (described in Section 3.1.1)
- radio capacity and carrier overlays (Section 3.1.2)
- backhaul requirements (Section 3.1.3)
- site requirements (Section 3.1.4).

3.1.1 Coverage

The radio coverage calculations can be found on the *Nw-4G* worksheet in the Network module. They derive the number of eNodeBs (4G base stations) required in each year in order to provide coverage.[8]

The main inputs to the calculation are summarised in Figure 3.1 below. Their derivation is described in more detail in Annex B.7.

Figure 3.1: Description of major inputs used in the 4G coverage calculation [Source: Analysys Mason, 2014]

Name	Value	Description
Area per site	Varies by geotype and cell type	The area covered by different cell types in different geotypes, derived from cell radii input values
Area covered by 4G over time	Varies by geotype and cell type over time	Assumed area coverage in each year

8 Assumptions regarding the coverage of 4G are discussed further in Annex 11 of Ofcom's consultation document.

Geotype areas	Varies by geotype	Total area of the UK land mass that is allocated to each geotype (matching values in the 2011 MCT model)

Figure 3.2 below sets out the calculation for the eNodeBs required for coverage in the 2014 MCT model.

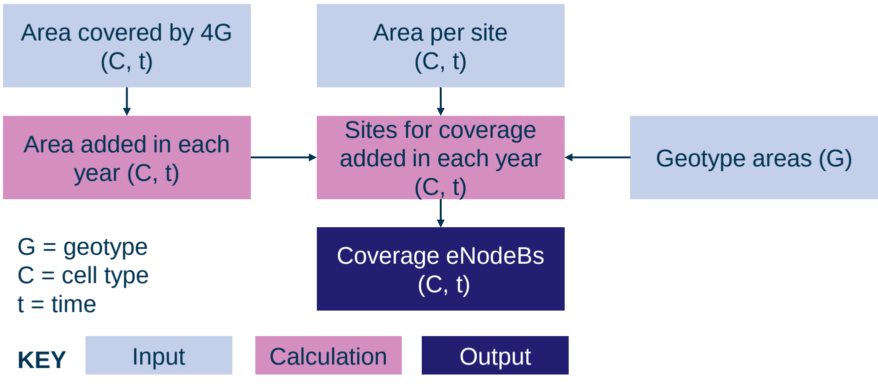


Figure 3.2: Calculation of eNodeBs for the 4G coverage requirements [Source: Analysys Mason, 2014]

For each geotype, we first calculate the incremental area that is to be covered in each year. From this, and in conjunction with the geotype areas and area per site, we calculate the incremental number of sites required in each year to provide coverage. Finally, this is aggregated to give the total number of eNodeBs required for coverage by cell type in each year.

3.1.2 Capacity overlays and carriers

These calculations can also be found on the *Nw-4G* worksheet in the Network module. This derives the number of (a) eNodeBs; and (b) carriers required in each year in order to carry the assumed volume of 4G traffic. We describe steps (a) and (b) separately below.

Most calculations are undertaken by cell type, i.e. by geotype, with the urban and suburban geotypes further split by their macrocell/microcell/picocell layers.

eNodeB requirements

The main inputs to the calculation are summarised in the following table. Their derivation is described in more detail in Annex B.7 of this report.

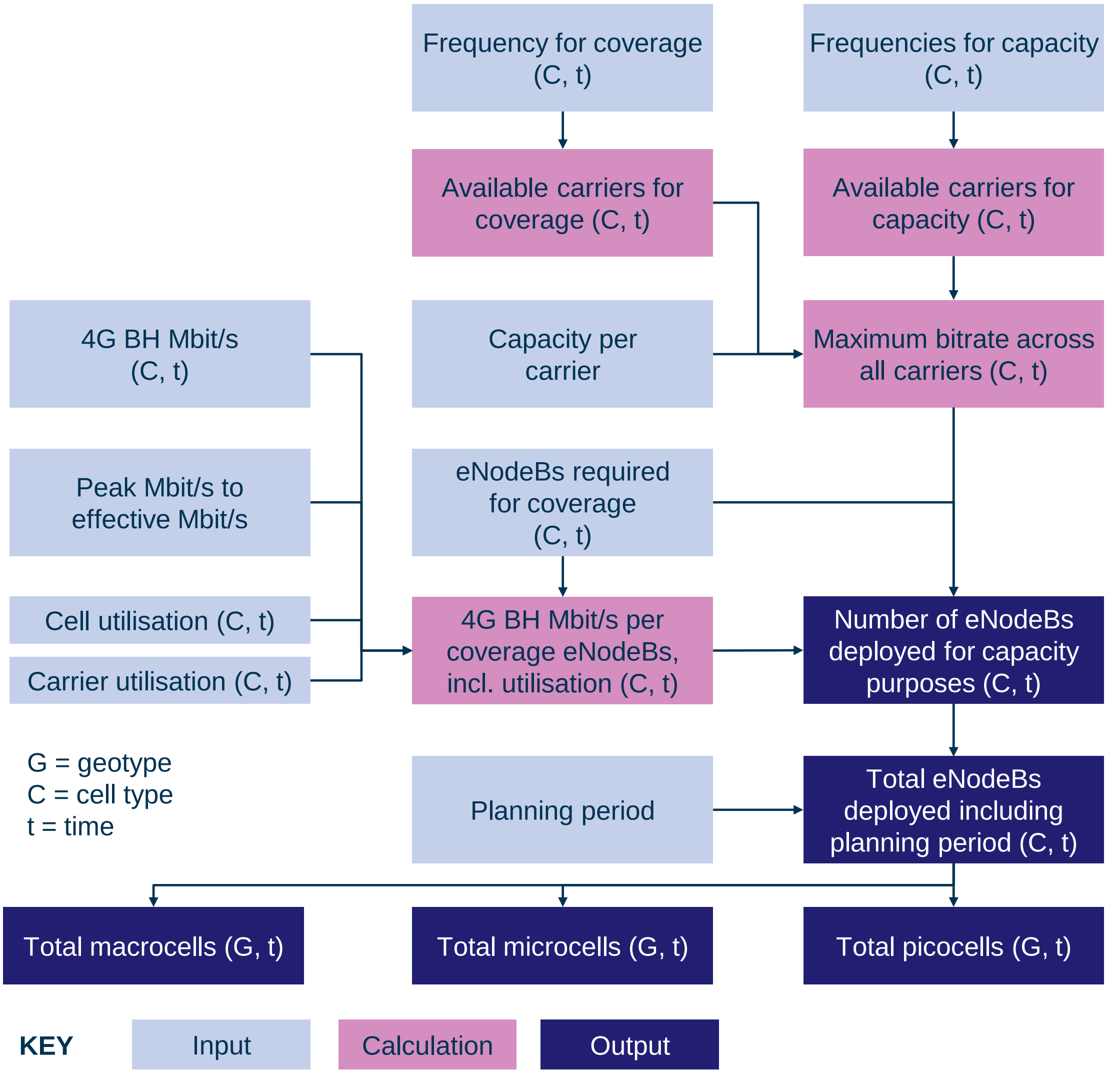
Figure 3.3: Description of major user inputs used in the eNodeB calculation [Source: Analysys Mason, 2014]

Name	Value assumed	Description
Effective Mbit/s as a proportion of peak Mbit/s	26%	For example, the peak rate might be 31Mbit/s, but the effective rate over the cell area is lower
Capacity per carrier	31Mbit/s	Peak throughput for a 2×5MHz carrier
Coverage frequency	800MHz (rural geotypes); 1800MHz (otherwise)	Frequency assumed to be used to deploy coverage eNodeBs in a geotype
Capacity frequency	1800MHz/2600MHz (rural); 800MHz/2600MHz (otherwise)	Remaining frequencies available for 4G services
Carrier size	2×5MHz	Used to derive number of carriers from

Name	Value assumed	Description
		allocated paired MHz
Planning period	12 months	Number of months elapsed between purchase and activation of an asset

Figure 3.4 below sets out the calculation for the eNodeB requirements in the 2014 MCT model.

Figure 3.4: Calculation of eNodeB requirements in the 2014 MCT model [Source: Analysys Mason, 2014]



For each cell type, we first calculate the busy-hour (BH) Mbit/s per coverage site, accounting for the utilisation factors. We also calculate the maximum bitrate across all carriers, multiplying the total number of carriers (coverage and capacity) by the capacity per carrier.

We then calculate the number of eNodeB macrocells required to carry the BH throughput using the following formula:

eNodeBs required for coverage × [(BH Mbit/s per coverage eNodeB/Maximum bitrate) – 1]

eNodeB microcells and picocells have no coverage sites, and are instead calculated using the formula:

BH Mbit/s / (Carrier utilisation × cell utilisation × peak-to-effective factor × maximum bitrate)

The planning period is then factored into the output, with the final results by cell type then aggregated into tables of macrocells/microcells/picocells by geotype over time.

Carrier requirements

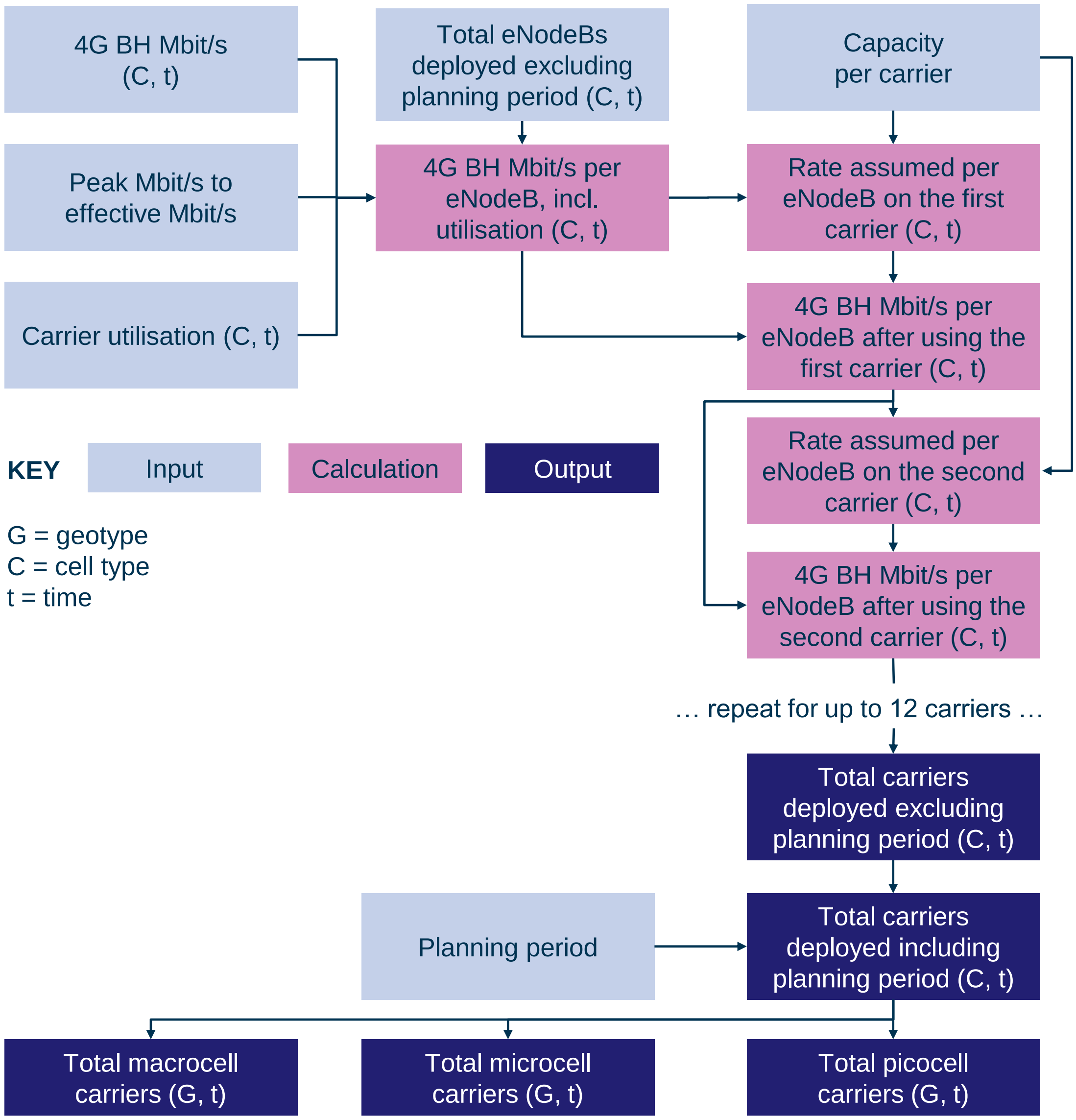
The main user inputs to the calculation are summarised in Figure 3.5 below.

Figure 3.5: Description of major user inputs used in the carrier calculation [Source: Analysys Mason, 2014]

Name	Value assumed	Description
Effective Mbit/s as a proportion of peak Mbit/s	26%	For example, the peak rate might be 31Mbit/s, but the effective rate over the cell area is lower
Capacity per carrier	31Mbit/s	Peak throughput for a 2×5MHz carrier
Planning period	12 months	Number of months elapsed between purchase and activation of an asset

Figure 3.6 below sets out the calculation for the carrier requirements in the 2014 MCT model.

Figure 3.6: Calculation of carrier requirements in the 2014 MCT model [Source: Analysys Mason, 2014]



We first calculate the BH Mbit/s per eNodeB for each cell type (including both coverage and capacity eNodeBs), again accounting for utilisation factors. For each cell type, we then determine whether deploying one carrier per eNodeB would be sufficient to carry this BH throughput (by cross-checking the BH Mbit/s per eNodeB with the maximum bitrate of a carrier). If one carrier is not sufficient, then we sequentially check whether deploying an additional carrier per eNodeB is sufficient. The functionality has been included in the 2014 MCT model to repeat this up to a maximum of twelve carriers.[9] For each given year, as soon as sufficient carriers are deployed in a cell type to carry the BH load, no further carriers are deployed.

9 This maximum of 12 carriers is assumed based on 2 operators (each with up to 6 carriers) sharing the infrastructure.

We then sum up the total number of carriers deployed across all twelve of these calculations. The planning period is then factored into the output, with the final results by cell type then aggregated into tables of macrocell/microcell/picocell carriers by geotype over time.

3.1.3 Backhaul requirements

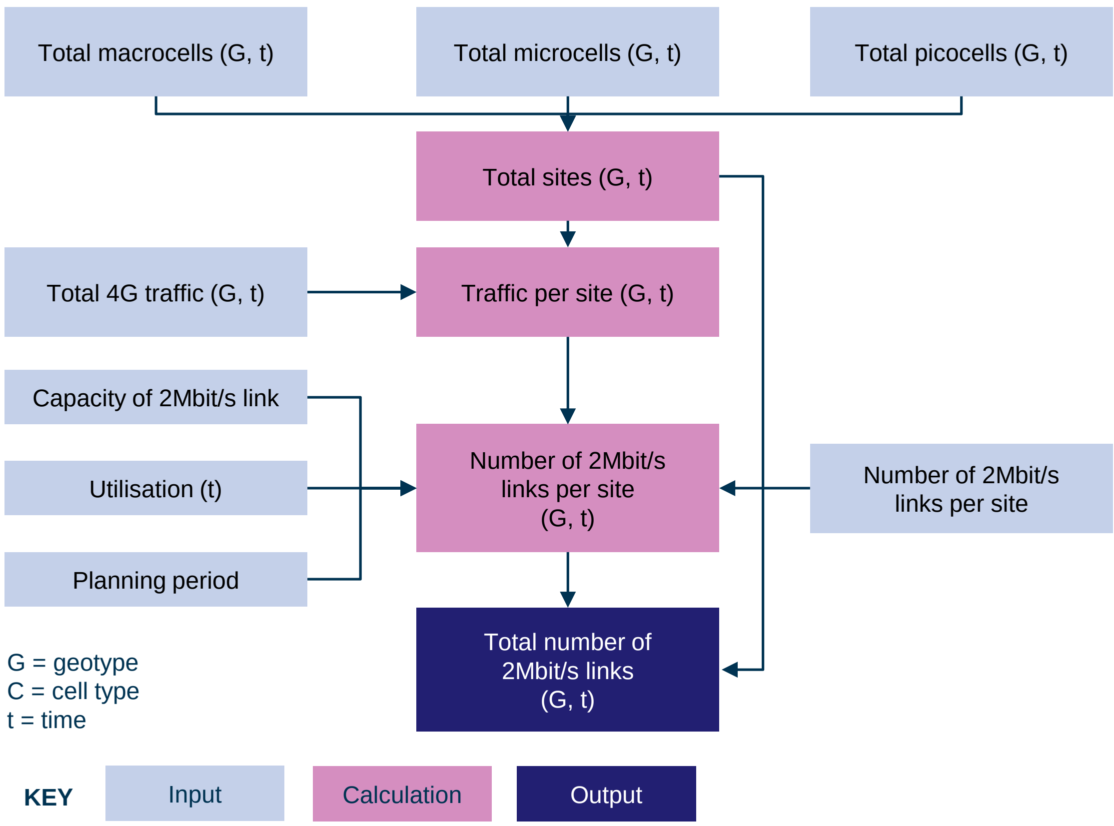
These calculations can be found on the *Nw-4G* worksheet in the Network module. They derive the transmission requirements (in 2Mbit/s-equivalent circuits) to carry the 4G traffic in the network. The calculations are undertaken separately for each geotype. The main user inputs to the calculation are described in Figure 3.7 below and are all taken from the 2G/3G network design inputs established in the 2011 MCT model.

Figure 3.7: Description of major user inputs used in the backhaul calculation [Source: Analysys Mason, 2014]

Name	Value assumed	Description
Backhaul link capacity	0.8Mbit/s	An estimate as to the capacity of a single link, as used in the 2G/3G network designs of the 2011 MCT model
Planning period	0 months	Number of months elapsed between purchase and activation of an asset
Minimum E1 links per site	2	Minimum number of E1-equivalent links that are deployed per site for redundancy

Figure 3.8 sets out the calculation for the 4G backhaul requirements in the 2014 MCT model.

Figure 3.8: Calculation of backhaul requirements in the 2014 MCT model [Source: Analysys Mason, 2014]



We first calculate the 4G traffic per site based on the total number of 4G sites and the total 4G traffic that the network is carrying. From this, along with the capacity of the 2Mbit/s-equivalent backhaul links, the minimum number of 2Mbit/s-equivalent links per site, their utilisation and the planning period, we derive the number of 2Mbit/s-equivalent links required per site. The total number of 2Mbit/s-equivalent links required is then calculated, to get an equivalent measure for the backhaul requirements to serve the 4G traffic as we have for the 2G traffic and the 3G traffic.

3.1.4 Site requirements

The 2011 MCT model calculated the number of sites in the network, split by 2G-only, 3G-only and 2G/3G shared sites. In relation to sites, the key requirement for adding 4G functionality to the 2014 MCT model is to calculate the number of sites that require ancillary upgrades to house an eNodeB. Therefore, we calculate the number of sites that only house 4G technology and those that house 4G and/or 3G and/or 2G technology.

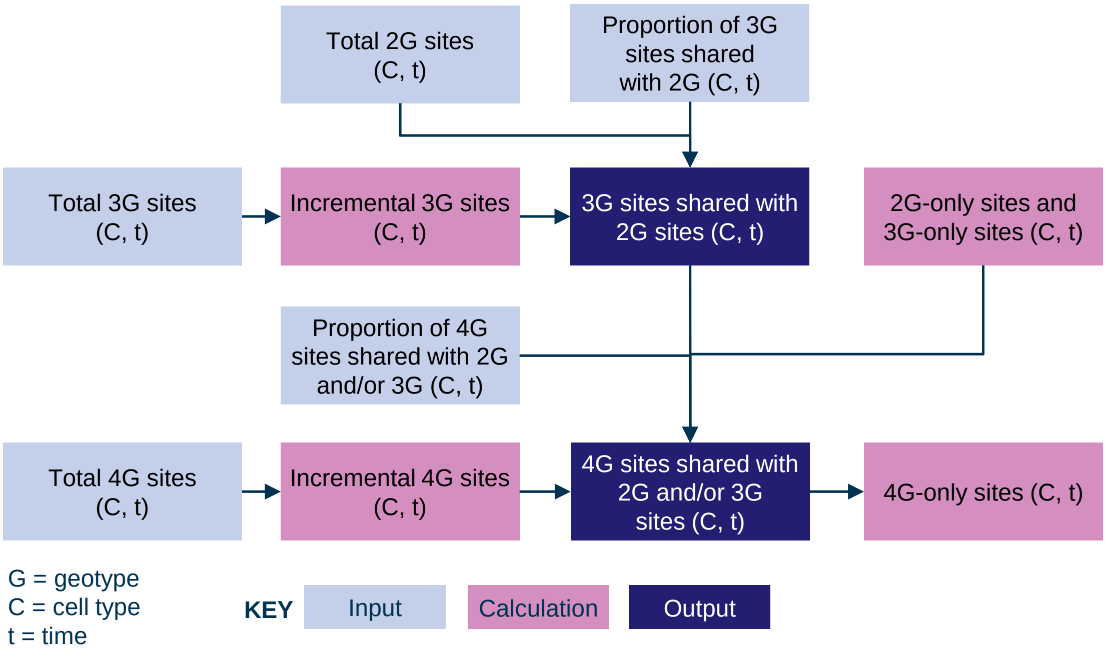
These calculations can be found on the *Nw-other* worksheet of the Network module. As in the 2011 MCT model, all calculations are undertaken by cell type, i.e. by geotype, with the urban/suburban geotypes further split by their macrocell/microcell/picocell layers. The main user inputs to the calculation are described in Figure 3.9 below.

Figure 3.9: Description of inputs used in the site requirement calculation [Source: Analysys Mason, 2014]

Name	Values assumed	Description
Proportion of 3G sites shared with 2G	Recalibrated from the 2011 MCT model	The proportion of incremental 3G sites that will be shared with 2G technology
Proportion of 4G sites shared with 2G and/or 3G	Set to be 60% from 2017/18	The proportion of incremental 4G sites that will be shared with 2G and/or 3G technologies

Figure 3.10 below illustrates the calculation of site requirements in the 2014 MCT model.

Figure 3.10: Calculation of site requirements in the 2014 MCT model [Source: Analysys Mason, 2014]



The site requirements calculation takes as its inputs the number of required sites for each technology. Then, using a set of parameters specified by cell type over time, it derives the number of sites required according to how many of these sites require a 3G site upgrade and how many require a 4G site upgrade.

3.2 Spectrum allocations and fees

Figure 3.11 summarises the inputs used for 4G spectrum allocations and fees, which can be found on the *Scenarios* worksheet of the Network module. The spectrum allocations and valuation are discussed further in Annex 15 of Ofcom's consultation document.

Figure 3.11: Summary of 4G spectrum allocation and fee inputs [Source: Analysys Mason, 2014]

Frequency	Allocation	Year available	One-off price per paired MHz in real 2012/2013 GBP	Annual price per paired MHz in real 2012/2013 GBP
800MHz	2×10MHz	2013/2014	59,800,000	–
1800MHz	2×10MHz	2012/2013	–	2,333,333
2600MHz	2×10MHz	2013/2014	10,000,000	–

3.3 4G core network

The inclusion of a 4G radio network requires the modelling of a 4G core network, which is assumed to be an Enhanced Packet Core (EPC). This is an industry-standard architecture used to carry the data traffic from 4G eNodeBs. The four main component assets of a 4G core network are:

- *serving gateway (SGW)* – this performs the signalling conversion at the IP transport level used in 4G networks
- *mobility management entity (MME)* – this provides the functional interface between fixed networks and a 4G network for packet-switched transmission, which includes the storage of information related to subscribers and their location information
- *data traffic manager (DTM)* – this comprises any other systems that handle data traffic
- *home subscriber server (HSS)* – this is the 4G equivalent of the home location register (HLR).

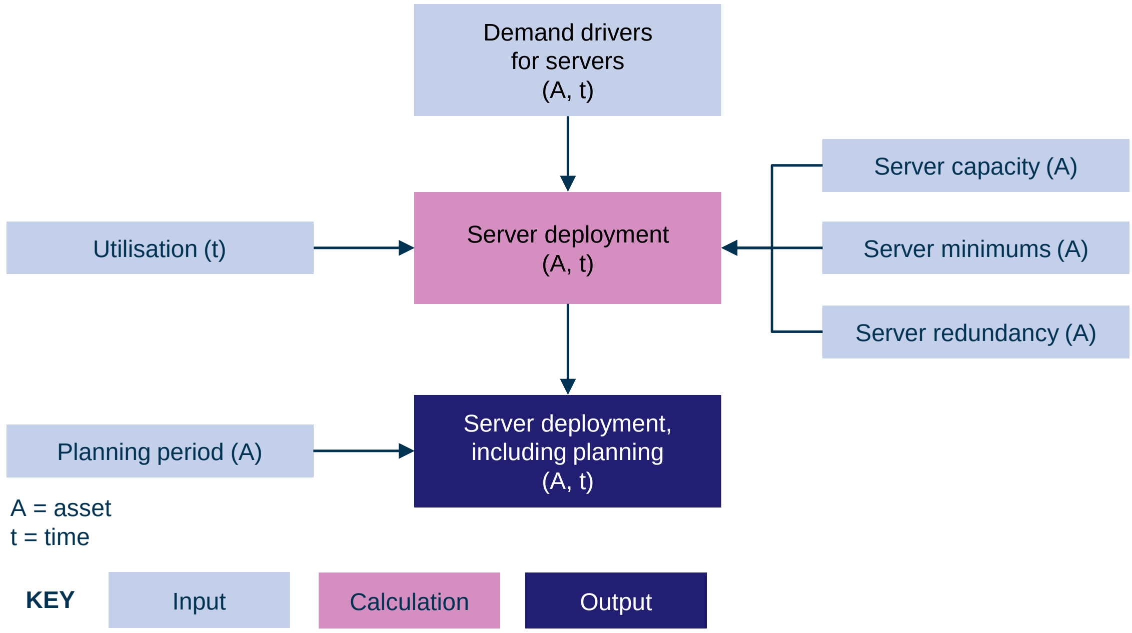
The dimensioning calculations for the 4G core network can be found on the *Nw-4G* worksheet in the Network module. These calculate the number of core network assets required to carry the 4G traffic in each year. The main user inputs to the calculation are described below.

Figure 3.12: Description of inputs used in the 4G core network calculation [Source: Analysys Mason, 2014]

Name	Description
Server capacity	The capacities of the core assets dimensioned in their respective units
Server minimums	The minimum number of servers that must be deployed
Server redundancy	A value of 2 means that each server deployed also has a spare deployed
Planning period	The number of months elapsed between purchase and activation of an asset

Figure 3.13 illustrates the calculation of 4G core network assets used in the 2014 MCT model.

Figure 3.13: Calculation of 4G core network assets in the 2014 MCT model [Source: Analysys Mason, 2014]



The servers deployed in the 4G core network are calculated according to their demand drivers, along with their assumed capacity and utilisation. The planning period is then factored into the final requirements. Figure 3.14 shows a summary of the inputs used for these assets.

Figure 3.14: Specifications of the 4G core network elements [Source: Analysys Mason, 2014]

Asset	Capacity	Minimum	Redundancy
MME	40,000Mbit/s	2	1
MME software	40,000Mbit/s	2	1
SGW	40,000Mbit/s	2	1
Data traffic manager	30,000Mbit/s	2	1
HSS	1,000,000 subscribers	1	1

The allocation of the main switching building costs between voice and data (on the *Nw-other* worksheet in the Network module) has also been updated to include the 4G core network assets.

3.4 VoLTE network

With a VoLTE platform deployed in the network, voice and data can both be provided over the 4G network under the control of the network operator.

VoLTE requires the deployment of an IP Multimedia Subsystem (IMS) in the core network. The heart of the IMS core is the call server (CS) asset, which contains the voice service functions CSCF, ENUM and DNS.[10] [11] Session border controllers (SBCs) and telephony application servers

[10] Call session control function, E.164 number mapping and domain name system, respectively.

(TASs) must also be deployed to manage voice services (with the TASs in particular managing capabilities such as call forwarding, call wait and call transfer). The IMS core assets are summarised in Figure 3.15 below.

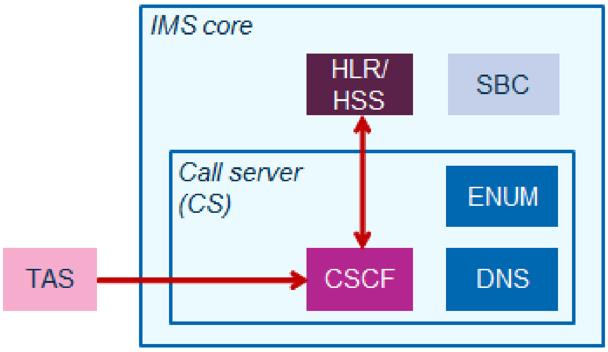


Figure 3.15: Appearance of an IMS core [Source: Analysys Mason, 2013]

The VoLTE platform must also communicate with the 4G data platform (via the MME/SGW), meaning that upgrades are required for existing assets. In particular, the MSC–S must be enhanced so that:

- calls can connect to the IMS domain via the MSC–S, to continue to provide the voice service if a 4G user is within the coverage of the 2G/3G circuit-switched networks rather than the 4G network
- calls can be handed over from the 4G network to the 2G/3G networks.

A separate converged HLR/HSS can also be deployed to manage data on the 4G subscriber base, keeping the legacy HLR unchanged. Upgrades to the network management system (NMS) may also be required.

The calculations for our VoLTE platform can be found on the *Nw-4G* worksheet in the Network module. They derive the number of assets required over time to carry the 4G voice traffic. The main user inputs to the calculation are described below.

Figure 3.16: Description of inputs used in the VoLTE network calculation [Source: Analysys Mason, 2014]

Name	Description
Capacity driver	Quantity that is used to dimension the number of assets required
Server capacity	The capacities of the assets dimensioned in their respective units
Server minimums	Minimum number of servers that must be deployed
Server redundancy	A value of 2 means that each server deployed also has a spare deployed
Planning period	Number of months elapsed between purchase and activation of an asset
4G voice call data rate	The data rate required for VoLTE calls in the radio network. Within the 2014 MCT model this takes the value of 12.65Kbit/s, taken from the specification of the Adaptive Multi-Rate Wideband (AMR-WB) standard.

11 The CSCF, ENUM and DNS are not explicitly modelled; they are contained within the CS and as such treated as a single asset.

The calculation structure for the VoLTE assets in the 2014 MCT model is the same as that for the 4G core network, as shown in Figure 3.13. The servers deployed within the VoLTE network are calculated according to their demand drivers, along with their specifications and utilisation. The planning period is then factored into the output.

Figure 3.17 summarises the inputs for the VoLTE assets modelled, namely their assumed capacities, minimum numbers and redundancies.

Figure 3.17: VoLTE asset dimensioning inputs [Source: Analysys Mason, 2014]

Asset	Capacity	Minimum	Redundancy
SBC hardware	2,000 BH voice Mbit/s	1	2
SBC software	2,000 BH voice Mbit/s	1	2
Call server hardware	2,000,000 BHCA	1	2
TAS	25,000 subscribers	1	1

The allocation of the main switching building costs between voice and data (on the *Nw-other* worksheet in the Network module) has also been updated to include the VoLTE assets, and also to allocate their costs between 4G traffic as well as 2G and 3G traffic.

4 Revisions to the Cost module

This section describes the revisions made to the Cost module for the 2014 MCT model. In particular:

- Section 4.1 describes the changes made to incorporate single-RAN (S-RAN) technologies
- Section 4.2 describes the changes made to capture the impact of infrastructure sharing
- Section 4.3 describes the revisions made to unit costs and cost trends.

Each subsection provides a description of the changes as well as the conclusions drawn from operator data that influenced them.

4.1 Incorporation of S-RAN

The 2011 MCT model assumed that 2G BTSs and 3G NodeBs remained separate pieces of equipment in the long term.

Since 2011, vendors have designed ‘combined’ base stations (i.e. units that provide 2G and/or 3G and/or 4G functionality). This is referred to as Single RAN (S-RAN) equipment.

Information received from operators in response the s135 notice dated 8 November 2013 indicates that use of S-RAN is becoming more widespread. Therefore, we consider it appropriate to consider the impact of this new technology in the 2014 MCT model. Qualitatively, having fewer base-station units can lead to lower operating costs per site (e.g. through more efficient power use). We considered two approaches to modelling the potential savings from S-RAN deployment, these were:

- defining new ‘combined base station’ assets, which are deployed as replacements for existing base stations over a defined period of time; or
- adjusting the cost trend levels to capture the new functionality within the assumed costs of the existing base-station assets.

We considered that the first option would entail a considerable exercise of parameterising and then calculating the number of S-RAN asset deployed (base stations and other sub-components) for a 2G/3G/4G network. This is because a new S-RAN design would require a significant number of new network design inputs as well as matching cost inputs.

The second option, implemented through adjusting cost trends within the Cost module) is considered to be less intricate than the first option and requires a much smaller amount of information regarding the costs of S-RAN equipment, which operators have been able to provide. On this basis, we have selected the second option (an adjustment of the cost trends).

Our proposed implementation within the Cost module means that separate 2G, 3G and 4G assets are still calculated in the Network module. However, the 2G, 3G and 4G unit capex and opex values are adjusted to reflect that each specific 2G, 3G and 4G technology comprises a proportion of the cost of the combined technology S-RAN equipment.

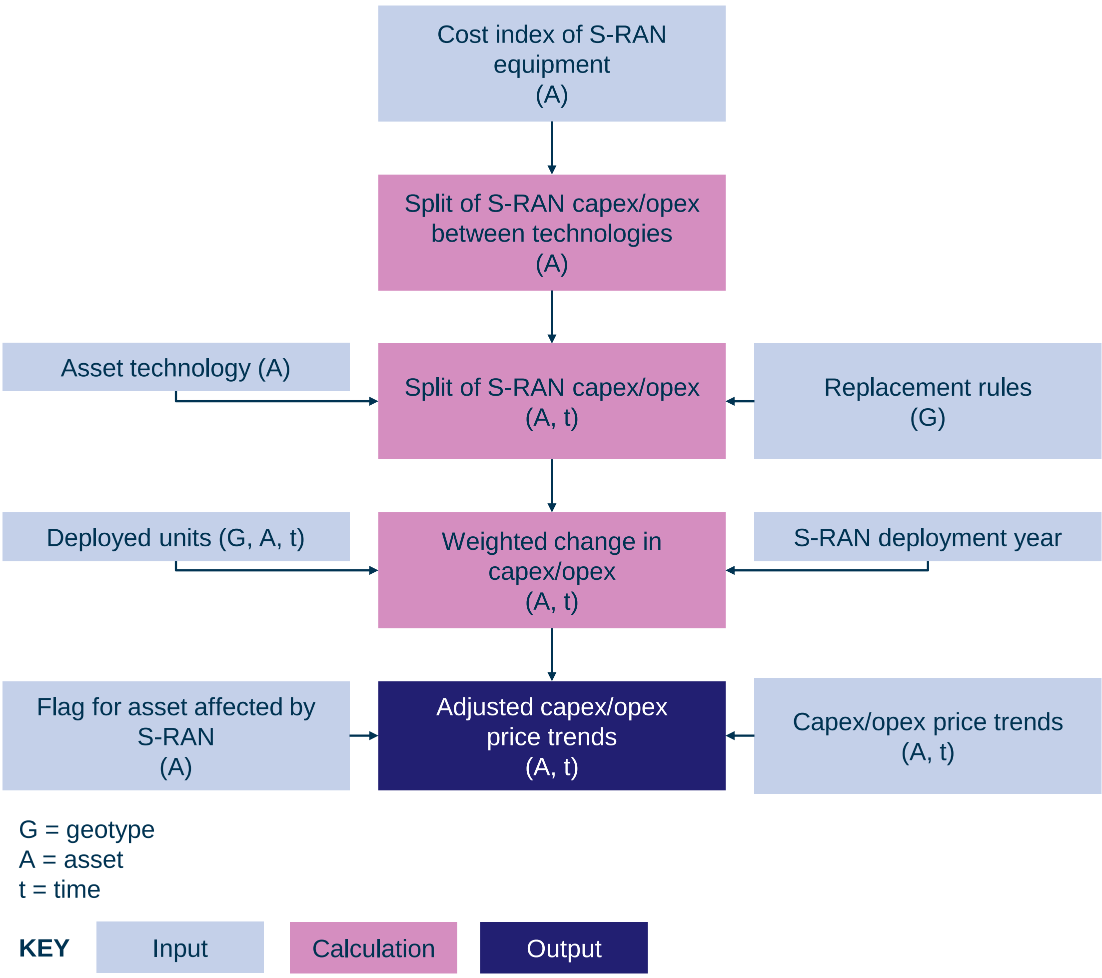
Below we:

- describe the calculations we have included in the 2014 MCT model (Section 4.1.1)
- specify the main assumptions used for this calculation (Section 4.1.2).

4.1.1 Description of new calculations

The calculations relating to the incorporation of S-RAN can be found on the *Unit investment* and *Unit expenses* worksheets of the Cost module. Figure 4.1 illustrates the calculation of S-RAN cost trends in the 2014 MCT model.

Figure 4.1: Calculation of S-RAN cost trends in the 2014 MCT model [Source: Analysys Mason, 2014]



The calculation is designed to derive the year-on-year changes in the cost trends for both capex and opex for those assets that are replaced with S-RAN deployment. For each such asset, this calculation uses the weighted change in capex/opex derived from the number of units deployed by geotype, as well as the split of S-RAN costs that are assigned to the particular asset.

When an asset goes from being a standalone technology to being combined technology, there are three cost aspects to consider. The first is the cost of the new asset in its entirety, which we index back to the cost of the standalone 2G, 3G or 4G assets being explicitly modelled (we refer to this as the 'cost index of S-RAN equipment'). The second aspect is the proportion of the costs of the new S-RAN asset that should be assigned to the 2G, 3G or 4G assets being explicitly modelled (we refer to this as the 'Split of S-RAN costs between technologies'). The third are the capex and opex cost trends of the S-RAN equipment itself, which we add in as a final adjustment at the end of the calculation.

4.1.2 Assumptions used

The following subsections describe the assets affected, as well as the inputs and assumptions used within the S-RAN calculation.

Affected assets

The only assets whose costs are re-evaluated as a result of the deployment of S-RAN are those within the radio layers of the three network technologies, namely:

- 2G base station equipment and transceivers (TRXs)
- 3G base station equipment, additional sectors, additional carriers and HSPA upgrades
- 4G base station equipment and additional carriers.

Cost index of S-RAN equipment

The "cost index of S-RAN equipment" is the ratio of the cost of combined technology equipment to the cost of 2G equipment (i.e. "2G = 1"). We have chosen the 2G equipment to be the single reference point (the 3G or 4G equipment could have equally been chosen). The 2014 MCT model assumes that the capex of "2G+3G+4G" S-RAN equipment is equal to 2.1 times the capex of the 4G equipment (based on operator data submissions), while its opex is equal to 0.7 times the sum of the opex of the three standalone types of equipment (based on studies undertaken by Analysys Mason).[12] When expressed as a multiple of the cost of only the 2G equipment, this gives multiples of 2.40 for capex and 1.91 for opex.

[12] For example, see http://www.analysysmason.com/PageFiles/44117/Analysys_Mason_Building_profitable_network_presentation_Nov2013.pdf

Split of S-RAN costs between technologies

It is assumed that the costs of S-RAN equipment are split across the three radio technologies based on whether they are:

- fixed costs that are specific to the 2G technology
- fixed costs that are specific to the 3G technology
- fixed costs that are specific to the 4G technology
- fixed costs common to all three technologies
- traffic-variable costs across all three technologies.

Operators have been able to provide some cost breakdowns according to this classification.

Fixed technology-specific costs are assumed to be allocated directly to that technology. The fixed common costs and traffic-variable costs of the S-RAN equipment are then assumed to be redistributed amongst the 2G, 3G and 4G assets based on the radio traffic according to two mark-ups as illustrated in Figure 4.2 below.

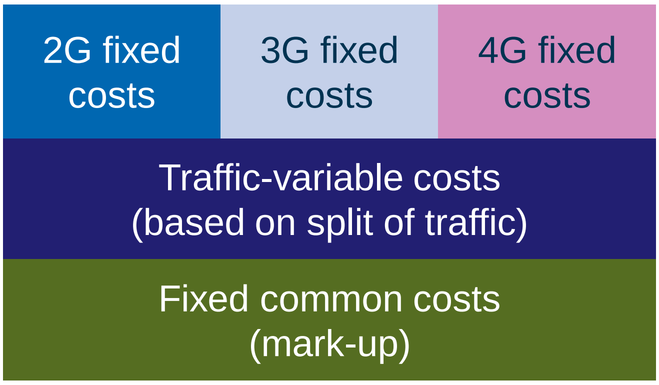


Figure 4.2: Calculation of the split of S-RAN equipment costs between technology generations [Source: Analysys Mason, 2014]

This allows annual cost trend adjustments to be made as the mix of 2G/3G/4G traffic changes over time. The proportions of costs assumed within each category (and their derivation) are described in Annex B.11 of this report.

Replacement rules

The replacement rules define what S-RAN technology combination will be used to replace a standalone technology asset from the point at which S-RAN is deployed. The 2014 MCT model assumes that all network technologies will be upgraded to use a combined 2G+3G+4G S-RAN, or a 2G+3G S-RAN if 4G technology is excluded. Other combinations such as a 3G+4G only S-RAN are not considered in the model.

Initial deployment date and duration of deployment

We specify a year in which S-RAN is assumed to first become available for use. The 2014 MCT model assumes this is 2013/2014. We also assume that the existing radio equipment is completely replaced with S-RAN equipment over three years. Although we note that operators have achieved such a refresh in a year or less (e.g. Telenor in both Hungary[13] and Norway)[14] we consider that it is reasonable to assume longer than a year to reflect complications that may arise from the ongoing implementations of network infrastructure sharing and 4G networks in the UK.

Both inputs can be found on the *Scenarios* worksheet in the Scenario Control module.

Additional cost trends for the S-RAN equipment

We would observe that there should be a negative cost trend in the short- to mid-term to reflect the decrease in cost that S-RAN equipment should experience as the technology matures. This additional cost trend is only present if S-RAN is assumed to be deployed. Separate input trends for capex and opex have been added to the 2014 MCT model in this regard.

Cost trends used in the Economic module

The adjustments made to the cost trends to account for S-RAN deployment are not used within the economic depreciation calculation. These adjustments are divided out of the cost trends prior to their use by the Economic module. This is on the basis that these adjustments should affect the expenditures incurred for S-RAN deployment, but not the economic cost recovery profile.

The exceptions are the "additional cost trends for the S-RAN equipment" described above, which reflect the underlying cost of the equipment and therefore should be included in the Economic module in our view.

4.2 Incorporation of infrastructure sharing

The 2011 MCT model allowed for sharing of passive infrastructure (sites only) using two sets of parameters.

The 2014 MCT model also allows for passive infrastructure sharing using three sets of parameters that are found in the Scenario Control module within the *Parameters* worksheet, and take effect in the *Asset demand for costs* worksheet of the Network module.

The first set of parameters allows the proportion of the hypothetical operator's sites that are shared with another operator to be specified for each of the three current site types (macro, micro and pico) over time.

The second set of parameters splits the sites that are shared with another operator further, into:

- **transformation sites –** those that are transformed from existing single-operator sites to shared-operator sites

13 See http://www.telenor.com/media/articles/2011/telenor-hungary-completes-hipernet-ahead-of-schedule/

14 See http://www.telenor.com/media/press-releases/2011/telenor-norway-opens-europes-most-modern-mobile-network/

- **shared sites –** those that are assumed to be constructed as entirely new physical sites, used by multiple operators.

The third set of parameters defines the unit costs assumed for these assets. Both transformation sites and shared sites are modelled as distinct assets, each incurring a one-off capex and no opex. Transformation sites have different associated unit costs from those of shared sites. Both unit costs were derived as part of the development of the 2011 MCT model.

Since the development of the 2011 MCT model, the UK mobile operators have extended infrastructure sharing to include active infrastructure. Our evidence regarding infrastructure sharing is discussed in Annex B.12 of this report. In light of the evidence gathered, the 2014 MCT model also includes the capability to capture the sharing of active infrastructure, including backhaul transmission and radio electronics.

Below, we:

- describe the calculations we have included in the 2014 MCT model (Section 4.2.1)
- specify the main assumptions used for this calculation (Section 4.2.2).

4.2.1 Description of new calculations

The calculations that incorporate the impact of infrastructure sharing occur in both the Network module and the Cost module. Below, we describe:

- the inputs to be specified, which are located in the Network module
- the calculations made within the Network module
- the calculations made within the Cost module.

At a high level, the new calculations increase both the spectrum and traffic on the modelled network to include that from a second operator sharing the use of the infrastructure. However, we then identify only those costs that the modelled operator would pay for its own traffic, and then recover those costs over the modelled operator’s own traffic using the existing routeing factor table. If we included the other operator’s costs and traffic, then the routeing factor table would have to be adjusted in some way to address this: our implementation avoids this issue. Along with the cost trend adjustments, extra assets have been included to account for the one-off costs incurred when macrosite/microsite/picosites are ‘upgraded’ in order for active infrastructure sharing to occur at those sites.

Inputs

The relevant inputs can be found on the *Scenarios* worksheet of the Network module.

First year of sharing	This input defines the first year in which shared infrastructure is available within the network design.

Sharing settings	Geotype-specific switches are included to allow sharing. These can be specified separately for each of 2G/3G/4G radio equipment. In the 2G case, as soon as one geotype uses shared BTSs, the BSCs are also assumed to be shared. In the 3G case, as soon as one geotype uses shared NodeBs, the RNCs are also assumed to be shared. As soon as one technology is assumed to be shared in a geotype, then the backhaul transmission in that geotype is also assumed to be shared.
Traffic multipliers	There are three sets of inputs, one for 2G, one for 3G and one for 4G. This allows for the increased traffic on the network (from a sharing operator) to be defined over up to a ten-year period. Ten years was chosen as a reasonable maximum period of time over which the migration of the other operator's traffic onto the shared network should be assumed to occur.
Spectrum multipliers	There are three sets of inputs, for 2G, 3G and 4G. This allows the increased spectrum available for the network (from a sharing operator) to be defined over a ten-year period (assumed to be a reasonable maximum period of time for the spectrum resources to be made available to the shared network). This could be interpreted as spectrum sharing/pooling, which does not occur in the UK. However, we believe it is an appropriate modelling simplification that captures the impact of infrastructure sharing deployments since the shared network in the 2014 MCT model will effectively have access to all of this spectrum. In addition, the 2014 MCT model will still only deploy one carrier (from one operator) in geotypes with low traffic levels. In the 2014 MCT model, both the traffic multipliers and the spectrum multipliers are assumed to follow the same migration.

Network calculations

The relevant calculations within the Network module sit within each technology's network designs. To account for the effects of infrastructure sharing, the network is assumed to carry an increased volume of traffic on those technologies and geotypes that are specified as being shared. These increases are defined using the traffic multipliers and inflate the BH radio traffic for the desired technologies and geotypes. An increase in available spectrum is also assumed in these geotypes, using the spectrum multipliers, to reflect the fact that the spectrum holdings of both operators are available for use in the modelled network.

On the *Nw-other* worksheet, the proportion of backhaul capacity that is assumed to be required for the capacity requirements of the modelled operator are also calculated. In particular, we separately calculate the total number of 2Mbit/s (E1)-equivalent circuits required for backhaul to serve the 2G, 3G and 4G installations, respectively. In each year, we then calculate the proportion of total E1-equivalent circuits required for the modelled operator using the following formula:

$$\frac{\left(\dfrac{E1s\ for\ 2G}{2G\ traffic\ multiplier}\right)+\left(\dfrac{E1s\ for\ 3G}{3G\ traffic\ multiplier}\right)+\left(\dfrac{E1s\ for\ 4G}{4G\ traffic\ multiplier}\right)}{Total\ number\ of\ E1\ circuits}$$

The calculation of the site upgrades for infrastructure sharing can also be found on the *Nw-other* worksheet. These calculations uses the sharing assumptions (specified by geotype) to calculate the number of sites being upgraded in each year by geotype, cell type (macro/micro/pico) and site type (2G-only/3G-only/4G-only/2G+3G/2G+4G/3G+4G/2G+3G+4G).

Cost calculations

The calculations within the *Unit investment* and *Unit expenses* worksheets of the Cost module are designed to adjust the cost trends for both capex and opex for those assets assumed to be shared.

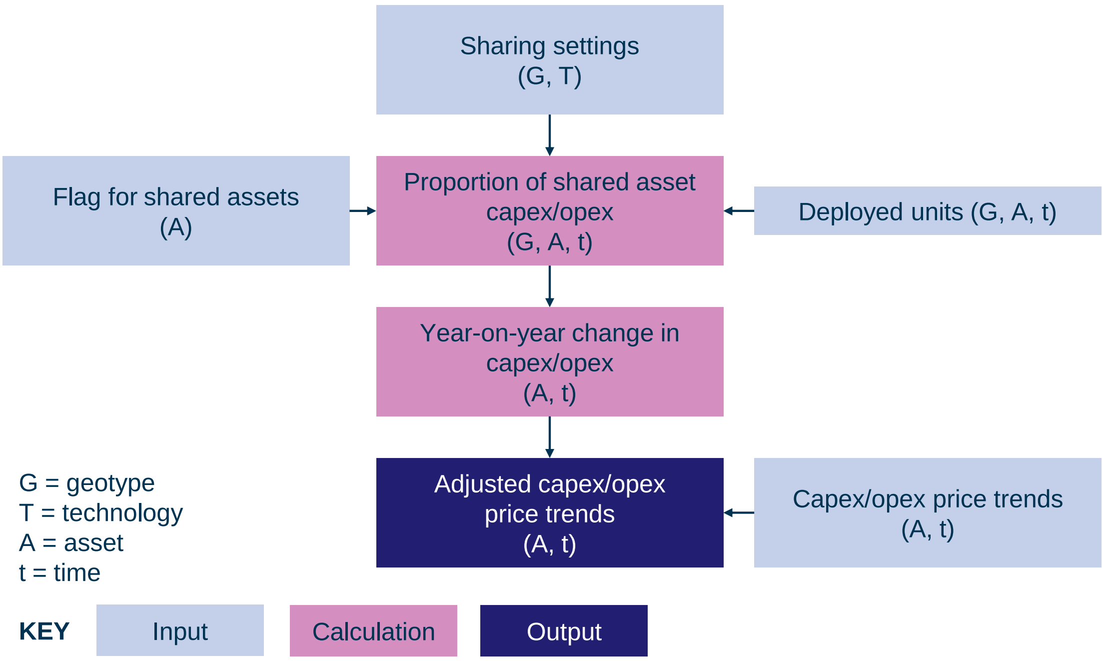
For any of the relevant radio equipment assets, the adjustment to cost trends is derived by applying the following formula:

$$\frac{[(50\%\times Assets\ in\ shared\ geotypes)+(100\%\times Assets\ in\ non\text{-}shared\ geotypes)]}{Total\ assets}$$

For backhaul assets, we assume that the modelled operator pays for transmission on a usage basis. We then use the proportion of backhaul circuits assumed to be for the modelled operator’s traffic (calculated in the Network module) to adjust the cost trends for these assets.

Figure 4.3 illustrates the calculation of infrastructure sharing cost trends in the 2014 MCT model.

Figure 4.3: Calculation of infrastructure sharing cost trends in the 2014 MCT model [Source: Analysys Mason, 2014]



4.2.2 Assumptions used

The following subsections describe the assets affected, as well as the inputs and assumptions used within the infrastructure sharing calculation.

Affected assets

The assets affected by the deployment of infrastructure sharing are:

- 2G base station equipment and TRXs
- 3G base station equipment, additional sectors, additional carriers and HSPA upgrades
- 4G base station equipment and additional carriers
- backhaul base units and transmission links used for transmission to the core network
- BSC and RNC equipment, except the core-facing ports.

Deployment year

The deployment year is a specified year in which infrastructure sharing becomes available to the network, and is located on the *Scenarios* worksheet of the Network module. The 2014 MCT model assumes this year to be 2013/2014 so as to align with the assumption of the launch of S-RAN deployments.

Traffic multipliers

We assume a profile of traffic multipliers for the first ten years after infrastructure sharing is launched. Using this, and the first-year assumption, gives a traffic multiplier in each year from 1990/1991–2039/2040 for each of 2G/3G/4G. The multiplier will be 100% until at least the first year of sharing.

We propose that the traffic on the network is double its original value (i.e. using a traffic multiplier of 200%) within three years of the first use of infrastructure sharing in the model.

Spectrum multipliers

We assume a profile of spectrum multipliers for the first ten years after infrastructure sharing is launched. Using this, and the first-year assumption, gives a spectrum multiplier in each year from 1990/1991–2039/2040 for each of 2G/3G/4G. The multiplier will be 100% until at least the first year of sharing.

We propose that the spectrum available for each of 2G/3G/4G doubles immediately after the launch of infrastructure sharing.

Sharing settings

Currently we assume that if a technology is shared, then all geotypes have the ability to share infrastructure with the exception of the 'urban' and 'suburban 1' geotypes.

Proportion of shared asset capex/opex

It is assumed that the modelled operator will bear 50% of capex/opex for all shared assets. Within the 2014 MCT model this input can be varied over time, but we currently assume the same proportion in all years.

Savings are achieved in those geotypes where the radio network of the standalone operator is not capacity-driven in all years. This is particularly true for the rural gotypes, where a single coverage layer has a sufficiently large capacity to carry most of the traffic of both operators, meaning that the cost of serving such geotypes falls by almost half.

4.3 Revision of unit costs and cost trends

The 2014 MCT model contains more assets than the 2011 MCT model. These assets require associated unit costs and cost trends. Furthermore, we also revisited the unit costs and cost trends assumed for the assets existing in the 2011 MCT model. We describe each of these below.

4.3.1 Cost inputs for existing assets in the MCT model

The assets summarised below have been assigned new capex (and where appropriate, opex) values based on operator data and benchmark models,[15] as well as appropriate cost trends.

Cost trends in the years prior to 2010/2011 have been left unchanged with the exception of revisions to assumed capacities. In the 2011 MCT model, the cost trends of the following assets were adjusted between 2004/2005 and 2007/2008 to reflect the increased capacity assumed for those assets in the 2011 MCT model compared with the 2007 MCT model:

- 2G MSCs (both processor and software)
- MSC–S and MGW
- HLRs and SMSCs
- 2G and 3G SGSNs and GGSNs
- BSC and RNC base units.

We have included the functionality to adjust the cost trend of these assets again between 2008/2009 and 2012/2013 to reflect further increases in capacity assumed for those assets in the 2014 MCT model compared with the 2011 MCT model. This new functionality can be found on the *Unit investment* and *Unit expenses* worksheets in the Cost module. Ofcom has revised some of

15 Two European models were used to provide benchmark values, namely: France and Sweden.

these capacities, where informed by operator data, as part of its model calibration exercise, as described in Annex 13 of Ofcom's consultation document.

Where we have been able to derive 2012/2013 bottom-up unit costs using the operator data provided, we have then calculated the compound annual growth rate (CAGR) from the modelled value in 2010/2011 to this 2012/2013 bottom-up cost (we calculate the standalone asset cost in this case, meaning that S-RAN and infrastructure sharing adjustments are not being used when recalculating these values). This CAGR is then used as the cost trend for the years 2011/2012 to 2013/2014, after which they remain unchanged from the 2011 MCT model.[16]

Figure 4.4 below summarises the assets for which cost inputs have been revised in this way. The exact values used, and the process by which operator data was processed to obtain them, are detailed in Annex B.13.

Figure 4.4: Summary of existing assets where cost inputs have been revised [Source: Analysys Mason, 2014]

2G assets	3G assets
2G macrocell: equipment (1/2/3 sector)	3G site upgrade: macrocell/microcell
2G microcell: equipment	3G macrocell: equipment
2G macrocell: additional TRXs	3G macrocell: additional sector
2G BSCs	3G RNCs

4.3.2 Cost inputs for new assets in the 2014 MCT model

The assets summarised in Figure 4.5 below have been assigned capex (and where appropriate, opex) based on operator data and benchmark models,[17] as well as appropriate cost trends. The exact values used, and the process by which operator data was processed to obtain them, are detailed in Annex B.13.

Figure 4.5: Summary of sources for cost inputs for new modelled assets [Source: Analysys Mason, 2014]

Asset	Description of cost input sources
3G spectrum licence fees	Derived by Ofcom (see Annex 15)
4G spectrum licence fees	Derived by Ofcom (see Annex 15)
New HSPA upgrades	Extrapolated from the upgrade costs for existing assets
High-speed backhaul	Derived from operator data, or else extrapolated from the costs of existing backhaul assets
4G radio layer	Derived from operator data
Transmission to the core	Derived from operator data
Transmission within the core	Derived from operator data
4G core network	Derived from operator data where possible, otherwise benchmarks

16 Cost trends are assumed to be 0% from 2025/2026 onwards.

17 Two European models were used to provide benchmark values, namely: France and Sweden.

VoLTE network	Derived from operator data where possible, otherwise benchmarks

4.3.3 Forecast cost trends

Cost trend forecasts for new assets have been calculated based on operator response to the s135 notices. Where operators provided at least 2 years of unit cost data from 2012/2013 onwards for a given asset, these costs were converted into real terms and then used to derive a CAGR. For a given asset, these cost trends were then averaged across the operators. We then used those cost trends calculated for assets where at least two operators provided sufficient information.

In the case of capex cost trends, values were derived for sites and site upgrades, base stations across all three technologies, backhaul, BSCs and RNCs. In the case of opex cost trends, values were only derived for high-speed backhaul assets.

In all case, the forecast values derived were used for 2012/2013 and 2013/14 (which are then used to derive the unit costs in 2013/14 and 2014/15 respectively).

4.3.4 Other forecast cost trends

The 2011 MCT model assumed all cost trends were zero until 2020/2021. In the 2014 MCT model, we have extended any forecast cost trends until 2026/2027, with zero cost trends assumed thereafter.

Annex A Other model adjustments

In this annex, we summarise the other adjustments made to the structural calculations of the 2011 MCT model to arrive at the 2014 MCT model, excluding those covered in Sections 2–4 of this report.

HSPA routeing factors

The routeing factors in the 2011 MCT model were such that some HSPA upgrade costs were being recovered by voice. We do not believe that this approach is appropriate and have adjusted the way these costs are recovered in the 2014 MCT model by revising the HSPA upgrade asset subgroups in the Scenario Control module. This correction leads to a 1.6% reduction in the LRIC in 2014/15 in the 2011 MCT model.

Backhaul uplift factors

In the Network module of the 2011 MCT model, uplift factors (called Backhaul.Voice.Uplift.2G and Backhaul.Voice.Uplift.3G on the *Cost drivers* worksheet) were hard-coded for both 2G and 3G voice minutes, which were applied to their routeing factors for certain assets like backhaul.

In the 2014 MCT model, the ratios are now calculated directly from the 2G/3G network designs for the year 2014/2015, replacing the hard-coded values in the 2011 MCT model. The macro used to re-calculate the model now replaces these inputs each time it is set to run.

Cost drivers

The *Cost Drivers* worksheet in the Network module has been adjusted to take into account the re-arrangement of the service list.

Worksheet renaming

The *Network design - XX* worksheets in the Network module have been renamed as *Nw-XX*.

Revision of 3G network design

In the 2011 MCT model, the 3G network was always assumed to be at least as large as the network in the previous year. This has been de-activated on the *Nw-3G*/*Nw-HSPA* worksheets in the Network module.

Radio network inputs

In the 2G/3G network designs, the following inputs have been set to be time series rather than single-year inputs:

- 2G/3G blocking probabilities
- 2G 1800MHz spectrum allocation
- 2G sector re-use
- maximum TRX per 2G BTS.

2G BTS physical capacity inputs

On the *Params - 2G* worksheet of the Network module, the maximum number of TRXs per BTS has been increased from 2011/2012 onwards to reflect improvements in the physical capacity of 2G base stations. The macrocell capacities have been increased from 4 to 6. The assumed sector re-use is now calculated explicitly from 2011/2012 onwards. Both revisions were made in order to address comments from BT in relation to the January workshop for the 2014 MCT model (as described in Annex C) and were reconsidered based on a comparison of the assumptions in cost models in other jurisdictions (e.g. the Netherlands).

The 1800MHz spectrum allocations for 2G networks have also been reduced, from 2×30MHz to 2×20MHz from 2012/2013 onwards, with the 2×10MHz spectrum refarmed for 4G use.

Currency The 2011 MCT model calculated in real-terms 2008/2009 GBP. The 2014 MCT model calculates in real-terms 2012/2013 GBP.

Inflation The 2011 MCT model converted to nominal currency using a retail price index (RPI) for inflation. The 2014 MCT model instead uses a consumer price index (CPI)[18] for inflation.

Extension of lists In order to accommodate the additional assets modelled, the national asset list in the 2014 MCT model has been increased to 150 entries, while the asset list by geotype has been increased to 650 entries. The utilisation factor lists have also been extended on the *Utilisation* worksheet in the Network module.

Capex mark-up As part of the finalisation of the 2011 MCT model, an uplift was applied to the capex cost trends in the years 2004/2005 to 2008/2009. For the 2014 MCT model, the implementation of this mark-up has been refined so that is not applied to new assets (i.e. it is only applied to the assets carried over from the 2011 MCT model).

Site calculations In the 2014 MCT model, the site calculation has been adjusted on the *Nw-other* worksheet so that the number of sites in a geotype cannot fall over time.

Cost recovery of 2G/3G core network In the final version of the 2011 MCT model, an adjustment was included in the Network module to the network element output of the assets related to the 2G/3G core network, to reflect the fact that the asset was being used by a proportion of 2G traffic between 2007/2008 and 2010/2011 (in parallel with the legacy 2G MSCs).

In the 2014 MCT model, we have extended this network element output adjustment to the 2G MSC assets to reflect the fact that they carry only

18 See http://www.ons.gov.uk/ons/rel/cpi/consumer-price-indices/november-2013/consumer-price-inflation-reference-tables.xls

some of the 2G traffic in these years.

We have made additional refinements to the service costing calculation in the Economic module to reflect these adjustments to the network element output (effectively to adjust the routeing factors used in this period of years for these particular assets). These adjustments have no impact on the model outside of the period 2003/2004-2010/2011.

Adjustment of NodeB processing parameters

In the 2011 MCT model, a set of inputs called "NodeB processing parameters" were included in the Scenario Control module to allow the implied channel elements per carrier (and thus capacity per carrier) to change over time. In the 2011 MCT model, these were set to 1, so that they had no effect on the model outcome. In the 2014 MCT model, these values have been retained as 1 up to 2012/13, but then increased to 1.4 from 2014/15 onwards. These values were finalised as part of the model calibration.

Annex B Overview of s135 responses

Section 135 (s135) notices were issued by Ofcom to EE, H3G, Telefónica (O2) and Vodafone for the purposes of gathering evidence to inform the 2014 MCT model. Section 135 notices were issued on the following dates:

- 8 November 2013
- 14 February 2014
- 18 March 2014.

This annex sets out how the operator data has been used to justify the modelling revisions incorporated in the 2014 MCT model. We describe the data provided by each operator in response to s135 requests and set out our conclusions on the implications for the 2014 MCT model. In particular, we describe our findings in relation to:

- HSPA backhaul (Section B.1)
- high-speed backhaul (Section B.2)
- cell breathing (Section B.3)
- transmission *to* the core network (Section B.4)
- transmission *within* the core network (Section B.5)
- other network design inputs (Section B.6)
- 4G radio network (Section B.7)
- 4G spectrum allocations (Section B.8)
- 4G core network (Section B.9)
- VoLTE network (Section B.10)
- S-RAN implementation (Section B.11)
- infrastructure sharing (Section B.12)
- unit cost inputs (Section B.13).

Confidential data within this annex has been redacted and is indicated by square brackets and the scissor symbol ‘[✂…]’.

Where a table has a ‘[✂]’ in the top left-hand corner, this indicates that all data in the table is confidential and has been redacted prior to widespread distribution, leaving only the column and row headings.

Where a table has a ‘[✂]’ in a column, this indicates that all data in that column is confidential and has been redacted prior to widespread distribution.

B.1 HSPA deployments

The relevant questions in the s135 notice dated 8 November 2013 were Q5.1 (in particular) and Q5.11. In the following subsections we provide an overview of the operator data submitted in response to these two questions and the proposals we have made based on this evidence.

B.1.1 Overview of data

Figure B.1 shows the proportion of NodeBs activated at the different HSPA speeds in 2013/2014 for each of the four operators.

HSPA speed [✂]	EE[19]	H3G	Vodafone	Telefónica
No HSPA activated				
3.6Mbit/s				
7.2Mbit/s				
14.4Mbit/s				
21Mbit/s				
42Mbit/s				

Figure B.1: Proportion of NodeBs activated at different HSPA speeds in 2013/2014 [Source: operator data, 2013]

As can be seen in the table above, all operators use speeds up to and including 42Mbit/s. [✂]. No operator currently uses an HSPA speed of 84Mbit/s, and no operator has indicated if/when this may occur.

Figure B.2 shows the proportion of NodeBs activated at the different HSPA speeds in 2011/2012 for the four operators.

HSPA speed [✂]	EE	H3G	Vodafone	Telefónica
No HSPA activated				
3.6Mbit/s				
7.2Mbit/s				
14.4Mbit/s				
21Mbit/s				
42Mbit/s				

Figure B.2: Proportion of NodeBs activated at different HSPA speeds in 2011/2012 [Source: operator data, 2013]

Figure B.3 shows the proportion of NodeBs activated at the different HSPA speeds in the 2011 MCT model for 2010/2011 as well as 2013/2014.

19 Data shown for EE are [✂].

HSPA speed	2010/2011	2013/2014
No HSPA activated	0%	0%
3.6Mbit/s	0%	0%
7.2Mbit/s	67%	0%
14.4Mbit/s	33%	100%
21Mbit/s	0%	0%
42Mbit/s	0%	0%

Figure B.3: Proportion of NodeBs activated at different HSPA speeds in the 2011 MCT model [Source: 2011 MCT model]

B.1.2 Proposals

In the 2011 MCT model all sites were activated for HSPA. This still appears reasonable in the context of the operator data, as [✂].

A large proportion of operator sites use 42Mbit/s by 2013/2014. We believe this should be reflected within the 2014 MCT model by deploying 42Mbit/s everywhere by 2014/2015.

B.2 High-speed backhaul

The relevant question in the s135 notice dated 8 November 2013 was Q5.2. The s135 notice dated 14 February 2014 asked more specific questions about this part of the network. In the following subsections, we give an overview of the operator data provided in response to these questions and the proposals we have made based on this evidence.

B.2.1 Overview of data

All operators have provided data on this topic and indicated that they use both self-supply Ethernet backhaul as well as leased Ethernet. All operators have also given the proportions of their backhaul that fall into these two categories.

[✂]

B.2.2 Proposals

From the data given relating to the proportion of traffic carried by the various methods of backhaul, the split of traffic between leased Ethernet and owned microwave was calculated as an average of operator data provided.

The speeds of the extra high-speed backhaul options were based on the submission of [✂] and are proposed to be 100Mbit/s, 300Mbit/s and 500Mbit/s. Their associated opex and capex were initially calculated based on a logarithmic relationship derived from the lower speeds, but then updated with operator data where it was available (see Section B.13).

B.3 Cell breathing

No data was provided by operators in relation to this revision. Our proposals have been driven by discussions relating to the approach used in the 2011 MCT model.

B.4 Transmission to the core network

The relevant question in the s135 notice dated 8 November 2013 was Q5.9. The s135 notice dated 14 February 2014 asked more specific questions about this part of the network. In the following subsections we give an overview of the operator data provided in response to these questions and the proposals we have made based on this evidence.

B.4.1 Overview of data

[✂]

Figure B.4 below shows the operator data from the s135 notice dated 14 February 2104 pertaining to transmission to the core network, as a result of more specific questioning. These responses affirmed that 1,000Mbit/s was an appropriate speed for this additional transmission. For the 2014 MCT model, we have assumed that the proportion of high-speed links reaching a remote site is the average of the four operator data points (44%).

Figure B.4: Operator data pertaining to transmission to the core network [Source: Operator data, 2014]

Quantity [✂]	EE	H3G	Vodafone	Telefónica
Proportion of high-speed backhaul links that reach a remote site				
Capacity of high-speed backhaul hub/link (Mbit/s)				

B.4.2 Proposals

Based on the information provided by all four operators in response to the s135 notice dated 14 February 2014, we have assumed that a fixed proportion of backhaul links require transmission from remote hubs to the core network.

B.5 Transmission within the core network

The relevant question in the s135 notice dated 8 November 2013 was Q5.9. In the following subsections, we give an overview of the operator data provided in response to this question and the proposals we have made based on this evidence.

B.5.1 Overview of data

Responses to Q5.9 from [✂] confirm that operators are now using core transmission links based on high-speed Ethernet. Figure B.5 and Figure B.6 illustrate the core network points for [✂]. Operators indicated that these were current deployments, but also expected some consolidation of these locations in the future.

In particular, operators indicated an average of 16 core network locations in their responses to the s135 notice dated 8 November 2013 [✂].

Figure B.5: Core points for [✂]

[✂]

Figure B.6: Core points for [✂]

[✂]

B.5.2 Proposals

Based on these submissions, it was considered that 16 core node locations were appropriate for the UK (consistent with the 2011 MCT model). Of these, it was considered from the maps above that there should be three in the Greater London area, one in Wales and one in Scotland. We describe how these node locations were defined in Section 2.4 of this report.

B.6 Other network design inputs

The relevant questions in the s135 notice dated 8 November 2013 were Q5.1b/c.

Figure B.7 shows the operator data provided for a number of network design inputs. This operator data was then averaged in order to obtain values that could be used in the 2014 MCT model.

Figure B.7: Operator data pertaining to network design inputs revised using responses from the s135 notices [Source: Operator data, 2013]

Quantity	EE [✂]	H3G [✂]	Vodafone [✂]	Telefónica [✂]	Average
Average call duration (2G incoming)					1.84
Average call duration (2G on-net)					1.98
2G call attempts per					1.55

Quantity	EE [✂]	H3G [✂]	Vodafone [✂]	Telefónica [✂]	Average
successful call					
GPRS data rate					33.4[20]
Proportion of GPRS data in the downlink					77%
Proportion of BSC–MSC traffic which traverses the core network					63%
Proportion of BSC–SGSN traffic which traverses the core network					99%
Proportion of SGSN–GGSN traffic traversing the core network					100%
Proportion of MSC–MSC traffic which traverses the core network					100%
Average call duration (3G incoming)					1.80
Average call duration (3G outgoing)					1.81
Average call duration (3G on-net)					1.97
3G call attempts per successful call					1.32
Proportion of data traffic in the downlink					88%
Proportion of RNC–MGW traffic which traverses the core network					75%
Proportion of RNC–SGSN traffic which traverses the core network					100%
Proportion of SGSN–GGSN traffic which traverses the core network					100%
Traffic overhead RNC–SGSN					3%
Traffic overhead SGSN–GGSN					3%
Minimum number of switch sites					10.67
Maximum number of switch sites					15.67
Capacity of a VMS					22,333,333

20 The data from the operators indicated a wide range of values in this case. As part of Ofcom's calibration, 20kbit/s was assumed in the 2014 MCT model, which lies within this range of values.

Quantity	EE [✂]	H3G [✂]	Vodafone [✂]	Telefónica [✂]	Average
(subscribers)					
Capacity of an SMSC (messages/s)					5,780
Capacity of HLR (subscribers)					4,250,000

B.7 4G radio network

The relevant question in the s135 notice dated 8 November 2013 was Q5.5d. More specific questions were then asked in the s135 notice dated 14 February 2014. In the following subsections we give an overview of the operator data provided in response to these questions and the proposals we have made based on this evidence.

B.7.1 Overview of operator data

Here we give an overview of the operator data relating to the 4G network design, in particular:

- the cell radii for the frequencies being used
- the assumed capacity per sector per carrier
- the assumed coverage roll-out
- other network design inputs.

Cell radii

► *800MHz*

Figure B.8 shows the information received from operators to the s135 notice dated 8 November 2013 relating to cell radii used to provide 4G at 800MHz by geotype. For comparison, it also shows the cell radii used in the 2011 MCT model for both 1800MHz and 2100MHz.

Figure B.8: Cell radii using 800MHz by geotype (km) [Source: Operator data, 2013]

Geotype	EE [✂]	H3G [✂]	Vodafone [✂]	Telefónica [✂]	2011 MCT model 1800MHz	2011 MCT model 2100MHz
Urban					1.10	0.79
Suburban 1					2.10	1.44
Suburban 2					2.10	1.78
Rural 1					4.00	3.60
Rural 2					4.33	4.16
Rural 3					5.33	4.80
Rural 4					8.33	7.50
Highways					5.33	4.80
Railways					4.33	3.90

► *1800MHz*

Figure B.9 shows the information received from operators to the s135 notice dated 8 November 2013 relating to cell radii used to provide 4G at 1800MHz by geotype. For comparison, it also shows the cell radii used in the 2011 MCT model for both 1800MHz and 2100MHz.

Figure B.9: Cell radii using 1800MHz by geotype (km) [Source: Operator data, 2013]

Geotype	EE [✂]	H3G [✂]	Vodafone [✂]	Telefónica [✂]	2011 MCT model 1800MHz	2011 MCT model 2100MHz
Urban					1.10	0.79
Suburban 1					2.10	1.44
Suburban 2					2.10	1.78
Rural 1					4.00	3.60
Rural 2					4.33	4.16
Rural 3					5.33	4.80
Rural 4					8.33	7.50
Highways					5.33	4.80
Railways					4.33	3.90

► *2600MHz*

Figure B.10 shows the information received from operators to the s135 notice dated 8 November 2013 relating to cell radii used to provide 4G at 2600MHz by geotype. For comparison, it also shows the cell radii used in the 2011 MCT model for both 1800MHz and 2100MHz.

Figure B.10: Cell radii using 2600MHz by geotype (km) [Source: Operator data, 2013]

Geotype	EE [✂]	H3G [✂]	Vodafone [✂]	Telefónica [✂]	2011 MCT 1800MHz	2011 MCT 2100MHz
Urban					1.10	0.79
Suburban 1					2.10	1.44
Suburban 2					2.10	1.78
Rural 1					4.00	3.60
Rural 2					4.33	4.16
Rural 3					5.33	4.80
Rural 4					8.33	7.50
Highways					5.33	4.80
Railways					4.33	3.90

Assumed capacity per sector per carrier

The assumed capacity per sector per carrier has been derived as an average of operator data. Figure B.11 shows the operator data provided. As can be seen in the table below, this was in some cases for cells with multiple carriers and sectors. Before averaging, each of these data points was normalised to obtain its ‘one-carrier, one-sector’ equivalent.

Figure B.11: Throughput data provided by operators [Source: Operator data, 2013/2014]

Operator [✂]	Description [✂]	Value (Mbit/s) [✂]	Value for 1 carrier and 1 sector (Mbit/s) [✂]
Average	**1 carrier, 1 sector, any frequency**		**31**

Assumed coverage roll-out

All operators provided data on historical and projected 4G area and population coverage to varying levels of detail. However, each operator provided information using its own geotype definition which did not match that used in the MCT model. Figure B.12 shows the operator data for the 4G area coverage for the years provided, as well as the operator average.

Operator [✂]	2013/2014	2014/2015	2015/2016
EE			
H3G			
Vodafone			
Telefónica			
Average			

Figure B.12: 4G area coverage data provided by operators [Source: Operator data, 2013]

Other 4G network design inputs

There are a few other parameters relating to the 4G network design that have been derived based on operator data. Figure B.13 shows the operator values submitted and the calculated average (to be used in the 2014 MCT model).

Figure B.13: Operator data pertaining to 4G radio network design inputs [Source: Operator data, 2013]

Quantity	EE [✂]	H3G [✂]	Vodafone [✂]	Telefónica [✂]	Average
Proportion of data traffic in the downlink					87%
Effective Mbit/s as a proportion of peak Mbit/s					26%
Downlift for data traffic in the 4G radio network					10[21]

B.7.2 Proposals

In this subsection we set out our conclusions for:

- the cell radii for the frequencies being used
- the assumed capacity per sector per carrier
- the assumed coverage roll-out
- other network design inputs.

Cell radii

The data provided by operators for the three frequencies, as shown in the previous section, is not sufficiently complete to make any direct conclusions regarding cell radii in both the 800MHz and 2600MHz frequency bands. As such, values for cell radii in these frequency bands were obtained by using the operator data to calculate a ratio between 1800MHz and 800MHz radii, as well as the equivalent ratio between 1800MHz and 2600MHz cell radii. The average ratio of 1800MHz radii to 800MHz radii was 0.7, while the average ratio of 1800MHz radii to 2600MHz radii was 1.5.

Using these multipliers and the established cell radii for 1800MHz in the 2011 MCT model, cell radii by geotype for 800MHz and 2600MHz were then derived for use in the 2014 MCT model.

Assumed capacity per sector per carrier

Evidence provided by each of the operators show no significant variation in the throughput by frequency, so we have assumed a single value across all frequencies. As to the value itself, [✂] indicate a throughput per sector per carrier of around [✂]Mbit/s, whereas the [✂] data indicates a throughput per sector per carrier of around [✂]Mbit/s. We have specifically confirmed the descriptions of the data that all four operators provided in their submissions that we set out in Figure B.11 above. We have taken an average of the values provided, which leads to a value closer to those provided by [✂].

21 Using the logarithmic relationship established for HSDPA upgrades, and an assumed throughput of 93Mbit/s (for a 3-sectored eNodeB with a capacity of 31Mbit/s per carrier per sector, as described in Annex B.7.2) leads to a downlift factor of 10.04, which is in close agreement with both our initial estimate and [✂] response.

Assumed coverage roll-out

The assumed 4G area coverage is calibrated to the operator data provided (and outlined in Annex B.7.1). In subsequent years, we assume a coverage roll-out following that of the 2G network with a delay of 19 years. We have made our forecast coverage for 2015/2016 less aggressive than the average forecast of the operators since matching this level of coverage would appear to require extensive rural coverage, which we believe is unlikely to be feasible. This roll-out is shown in Figure B.14.

Geotype	2013/2014	2014/2015	2015/2016
Urban	100.00%	100.00%	100.00%
Suburban 1	100.00%	100.00%	100.00%
Suburban 2	10.00%	100.00%	100.00%
Rural 1	5.00%	40.00%	90.00%
Rural 2	5.00%	30.00%	45.00%
Rural 3	5.00%	30.00%	45.00%
Rural 4	5.00%	30.00%	45.00%
National	**6.93%**	**36.58%**	**57.38%**
Operator values	**[✂]**	**[✂]**	**[✂]**

Figure B.14: 4G coverage roll-out profile [Source: Analysys Mason, 2014]

Operators were unable to provide 4G coverage data for highways and railways. Therefore, we assume that the 4G coverage here mimics 2G coverage (i.e. the first quarter of 4G coverage in these geotypes is the same as the first quarter of 2G coverage in these geotypes, and so on). This is equivalent to the 4G coverage being the same as the 2G coverage, delayed by 20½ years.[22]

We note that Telefónica has an obligation on its spectrum holdings to achieve 98% population coverage by the end of 2017 (i.e. Q3 2017/2018). The model achieves 98.3% population coverage by the end of this quarter. The 2014 MCT model therefore deploys coverage broadly consistent with this obligation.

Other 4G network design inputs

For most inputs, in the absence of any operator data in the s135 responses, we have assumed that the inputs are the same as those used in the 3G network design. In particular, this is assumed for the following:

- voice call data rate (radio, core, interconnect)
- average SMS/MMS capacity usage
- average call durations (incoming, outgoing and on-net)
- call attempts per successful call

22 We observe that, in the 2011 MCT model (and the 2014 MCT model), the site sharing assumptions lead to an increased level of assumed 3G coverage, on the basis that more extensive rural coverage at 2100MHz frequencies becomes economically viable with site sharing, Since the 4G coverage forecast is based on 2G coverage (which is more extensive) and primarily uses 800MHz frequencies for coverage, we consider this to be sufficient enough. Therefore, the site sharing assumptions do not lead to an additional increase in the assumed 4G coverage.

- ringing time per call.

B.8 4G spectrum usage

The relevant question in the s135 notice dated 8 November 2013 was Q5.4e. In the following subsections we give an overview of the operator data provided in response to this question and the proposals we have made based on this evidence.

B.8.1 Overview of data

Figure B.15 summarises the information that we received in response to the s135 notice dated 8 November 2013 relating to the planned usage of the three 4G frequencies.

Figure B.15: Operator uses of 4G spectrum [Source: Operator data, 2013]

Operator [✂]	800MHz	1800MHz	2600MHz
EE			
H3G			
Vodafone			
Telefónica			

B.8.2 Proposals

From this data, it is proposed that coverage should be deployed on 1800MHz in urban and suburban geotypes, while 800MHz is proposed to provide coverage in rural and highway/railway geotypes. Capacity would then be deployed on 2600MHz nationwide, 800MHz in urban and suburban geotypes, while 1800MHz would provide capacity in rural and highway/railway geotypes.

B.9 4G core network

The relevant question in the s135 notice dated 8 November 2013 was Q5.6. Further questions were then asked in the s135 notice dated 14 February 2014. In the following subsections we give an overview of the operator data provided in response to these questions and the proposals we have made based on this evidence.

B.9.1 Overview of data

[✂] provided no data on 4G core networks. [✂] provided network design information, while [✂] provided network design information but no capacities.

[✂] indicated that it would have a specific data traffic management system (called [✂]), which has a capacity of about [✂]. The other operators did not indicate such a system is used.

[✂] indicated that they have an HSS, though [✂] did not. We have revised the HLR to be dimensioned by only 2G/3G subscribers and have dimensioned a separate HSS for 4G.

B.9.2 Proposals

We have added the following assets to enable a 4G core network to be built:

- MME
- SGW
- MME software
- data traffic manager
- HSS.

B.10 VoLTE network

The relevant question in the s135 notice dated 8 November 2013 was Q5.8. Further questions were then asked in the s135 notice dated 14 February 2014. In the following subsections we give an overview of the operator data provided in response to these questions and the proposals we have made based on this evidence.

B.10.1 Overview of data

[✂]

[✂]

[✂]

We have confirmed that the 2014 MCT model is consistent with this.

B.10.2 Proposals

We have included a reference design within the 2014 MCT model.

B.11 S-RAN implementation

The relevant question in the s135 notice dated 8 November 2013 was Q5.11. Further questions were then asked in the s135 notice dated 14 February 2014 and the s135 notice dated 18 March 2014. In the following subsections, we give an overview of the operator data provided in response to these questions and the proposals we have made based on this evidence.

B.11.1 Overview of data

Figure B.16 summarises the operator data given in relation to S-RAN deployments.

Figure B.16: Overview of operator data in relation to S-RAN deployments [Source: Operator data, 2014]

Operator [✂]	First s135 response	Second s135 response
EE		
H3G		
Vodafone		
Telefónica		

In the s135 notice dated 18 March 2014, we asked for an estimate of the split of costs of S-RAN equipment based on whether they are:

- fixed costs that are specific to the 2G technology
- fixed costs that are specific to the 3G technology
- fixed costs that are specific to the 4G technology
- fixed costs common to all three technologies
- traffic-variable costs across all three technologies.

[✂].

We have calculated distributions of capex from the data we have received as shown below.

Figure B.17: Distribution of capex costs indicated by operators [Source: Operator data, 2014]

Category	Case 1 ([✂]])	Case 2 ([✂]])	Case 3 ([✂])	Case 4 ([✂])	Values used
Fixed 2G costs					10%
Fixed 3G costs					10%
Fixed 4G costs					10%
Fixed common costs					20%
Traffic variable costs					50%

The values we have set in the 2014 MCT model are based on the range of values indicated by these four cases, with less emphasis placed on the low demand cases. This is because the split of costs should reflect the higher levels of traffic that will be carried by this equipment in the long-term.

No quantitative data was received on the split of opex. However, a qualitative datapoint was received from [✂]

Based on this information, we would therefore conclude that 0% of S-RAN macrocell opex should be considered traffic-variable in the 2014 MCT model. We have then renormalised the split of the remaining capex categories to derive the split of opex (giving 20%, 20%, 20%, 40% and 0%).

B.11.2 Proposals

We have added functionality for S-RAN to be considered within the 2014 MCT model at the cost-level based on the operator data submitted. We have included options for a 2G+3G or 2G+3G+4G S-RAN, depending on whether 4G is to be assumed active in the modelling. The operators have different strategies on the use of the S-RAN in their networks, but there is evidence of the use of both (i) S-RAN on a national basis and (ii) use of 2G+3G+4G S–RAN. Since this would most likely lead to the most significant gains, we would therefore propose to implement a 2G+3G+4G S-RAN nationwide.

Their respective effects on capex are derived from information provided on operator unit costs, while the effects on the opex are estimated by Analysys Mason.

For the capex calculation, in their responses to the s135 notice dated 14 February 2014, [✂] provided unit costs for standalone 4G equipment, 2G+3G equipment and 2G+3G+4G equipment. For each operator, we have calculated the ratio for these costs, which we have then used in the 2014 MCT model. The values of these ratios are shown below.

Figure B.18: Calculation of ratios of S-RAN to standalone equipment [Source: Analysys Mason, 2014]

Ratio	[✂] (2d.p.)	[✂] (2d.p.)	[✂] Average (1d.p.)
2G+3G+4G macrocells as a proportion of a 4G macrocell			
2G+3G macrocells as a proportion of a 4G macrocell			

B.12 Infrastructure sharing

The relevant questions in the s135 notice dated 8 November 2013 were Q8.13 and Q5.11f. In the following subsections, we give an overview of the operator data provided in response to these questions and the proposals we have made based on this evidence.

B.12.1 Overview of data

[✂]

Figure B.19: Illustration of asset sharing in the H3G/EE sharing agreement [Source: Operator data, 2013]

[✂] Asset	2G	3G	4G (800MHz)	4G (1800MHz)

[✂] Asset	2G	3G	4G (800MHz)	4G (1800MHz)

B.12.2 Proposals

The 2011 MCT model assumed that some sites were shared with another operator. In the 2014 MCT model we have also assumed that other assets are shared with another operator.

In particular, the s135 responses indicate that:

- [✂]

In our view, this indicates a mixed picture for all networks. For simplicity, we have proposed that each technology be shared everywhere except the ‘urban’ and ‘suburban 1’ geotypes. Importantly, there is precedent for each technology to be shared based on the actual cases in the UK. While we recognise that operators have made different commercial decisions on how to proceed on this aspect of network rationalisation, network sharing should lead to efficiency gains and therefore we would suggest that it is reasonable to assume sharing of all technologies within the 2014 MCT model.

B.13 Unit cost inputs

The relevant questions in the s135 notice dated 8 November 2013 were Q8.1–Q8.6. Further questions were then asked in the s135 notice dated 14 February 2014. In the following subsections, we give an overview of the operator data provided in response to these questions and the proposals we have made based on this evidence.

B.13.1 Overview of data

All operators responded to these questions with data to varying degrees of detail. Due to these variations in the completeness of the data sets received, post-processing was required in order to derive values for the 2014 MCT model. These steps, as well as their results, are described within this subsection.

From the information provided in response to s135 notice dated 8 November 2013 and the s135 notice dated 14 February 2014 it was the 2012/2013 value that was of primary interest. This value is then used to calculate either:

- for existing assets (using the responses to the s135 notice dated 8 November 2013), a CAGR to be used as a cost trend between 2009/2010 to 2011/2012
- for new assets (using the responses to the s135 notice dated 14 February 2014), the direct value of the 2012/2013 unit cost.

All values have first been converted into real 2012/2013 GBP. For some assets, the unit cost values were quoted for a capacity different from that assumed in the 2014 MCT model. The unit cost values were then scaled according to the ratio of the operator's capacity and the modelled capacity.

Given the incomplete nature of some of the submissions, data from several years has been used in conjunction to obtain these values. Specifically, data from 2012/2013, 2013/2014 and 2014/2015 has been used in accordance with the following rules to obtain 2012/2013 data. For each operator and asset:

- if 2012/2013 values are present, then this is used directly
- if 2013/2014 and 2014/2015 values are present, then we calculate the real-terms trend between these values and use it to extrapolate the 2012/2013 value
- if only one of the 2013/2014 or 2014/2015 values is present, then a 2012/2013 value is calculated based on a benchmarked real-terms cost trend.[23]

Following this processing for individual operator data, the values are then averaged across all operators where values could be derived. The final values being used within the 2014 MCT model are set out in the following subsection.

B.13.2 Proposals

Figure B.20 shows the CAGRs calculated by applying these rules to the information provided in response to the s135 dated 8 November 2013. Only assets where two or more operator data points were available were used. In a handful of cases, where the unit costs of an operator are significantly above or below the range of the other operators, they have been excluded from the average. This is documented below in the column on the right.

Figure B.20: Unit cost CAGRs calculated from responses to the s135 notice dated 8 November 2013 [Source: Analysys Mason, 2014]

Asset	Quantity of interest	Real CAGR	Comments
Macrocell: sites	Capex	–22%	–
2G macrocell: equipment (1 sector)	Capex	–42%	–
2G macrocell: equipment (2 sector)	Capex	–41%	–
2G macrocell: equipment (3 sector)	Capex	–30%	–
2G microcell: equipment	Capex	–18%	–
2G macrocell: additional TRXs	Capex	–32%	–
2G BSCs	Capex	+6%	–
3G site upgrade: macrocell	Capex	–8%	–
3G site upgrade: microcell	Capex	–24%	–
3G macrocell: equipment	Capex	–39%	–
3G macrocell: additional sector	Capex	–13%	–
3G RNCs	Capex	+11%	[✂]

23 This benchmarked cost trend is firstly based on the costs of similar assets provided by that operator and otherwise based on real-terms cost trends assumed in the French and Swedish cost models.

The CAGRs above mean that the modelled capex for these assets - when excluding adjustments for asset sharing, S-RAN deployments and top-down calibration - is consistent with the unit capex values derived from the operator responses to the s135 notices.

Figure B.21 shows the unit costs calculated by applying these rules to the information provided in response to the s135 dated 14 February 2014. Again, only assets where two or more operator data points were available were used. In a handful of cases, where the unit costs of an operator are significantly above or below the range of the other operators, they have been excluded from the average. In a small number of cases, we have extrapolated a unit cost using another method. Instances of both are documented in the table below in the column on the right.

Figure B.21: Unit costs calculated from responses to the s135 notice dated 14 February 2014 [Source: Analysys Mason, 2014]

Asset	Quantity of interest	Unit cost (GBP)	Comments
4G macrocell: equipment (3 sector)	Capex	25,000	–
4G microcell: equipment	Capex	18,400	–
Additional carrier for a 4G macrocell	Capex	14,100	–
Site upgrade for a 4G macrocell	Capex[24]	19,100	–
Leased Ethernet (100Mbit/s)	Capex/opex	13,200/4,900	–
Leased Ethernet (300Mbit/s)	Capex	13,200	Capex assumed to be the same as 100Mbit/s based on [✂]
Owned microwave (100Mbit/s)	Capex/opex	16,200/1,500	Capex based on 300Mbit/s value and average of cost trends of [✂] data[25]
Owned microwave (300Mbit/s)	Capex/opex	15,500/1,500	–
High-speed backhaul hub	Capex/opex	22,900/3,900	Capex assumed to be the same as the high-speed leased backhaul link (1,000Mbit/s) capex, based on [✂]
High-speed leased backhaul link (1,000Mbit/s)	Capex/opex	22,900/6,600	–
MME	Capex	2,200,000	–
Serving Gateway (SGW)	Capex	4,700,000	–
MME software	Capex	400,000	–
Call server (CS) hardware	Capex	3,000,000	–

24 [✂] indicates an increase in site opex of approximately [✂], but it provides the only such data points on this unit cost.

25 That is, the trend between 100Mbit/s and 300Mbit/s costs from the operators is averaged and used to adjust the 300Mbit/s cost.

Annex C Operator comments on the Network and Cost modules

Figure C.1 and Figure C.2 outline the comments made by each operator and its subsequent treatment within the MCT model in response to the October 2013 and January 2014 workshops, respectively.

Figure C.1: Summary of comments made by operators following the October 2013 workshop on the MCT model and treatment of issues raised [Source: Operators and Analysys Mason, 2014]

Operator comment	Treatment of comment
EE	
EE considers that all network operators are likely to be operating combined 2G, 3G and 4G networks over the course of the next charge control period	A 4G network is being included as well as 4G small cells in the relevant geotypes
With respect to S-RAN, allocation of costs between technologies will need to be justified in relation to economic efficiency and ensuring technology/competitive neutrality	The cost breakdown data received from the operators to s135 dated 18 March 2014 has been used to inform the allocation of costs between technologies
The impact of VoLTE over the next charge control period will be complex and so should be treated with care	A VoLTE network has been included within the 4G network design as an option and can be updated as information becomes available
TELEFÓNICA	
It is not clear at this stage which technologies might disappear and by when. On that basis, it might be prudent to assume that 2G, 3G and 4G will co-exist for some time to come	The model continues to assume that the three technologies persist, although the networks can be de-activated in the model if that is deemed efficient
H3G	
H3G considers both 2G and 3G will be in use for the foreseeable future	The model continues to assume that the three technologies persist, although the networks can be de-activated in the model if that is deemed efficient
Care should be taken when considering shared assets with respect to capacity assumptions. Sharing of the asset entails a sharing of the capacity	The implementation in the 2014 MCT model explicitly assumes that radio/backhaul network elements are dimensioned based on the traffic from both the modelled operator's network and whoever else is sharing the infrastructure

Figure C.2: Summary of comments made by operators following the January 2014 workshop and treatment of issues raised [Source: Operators and Analysys Mason, 2014]

Operator comment (reference)	Treatment of comment
H3G	
H3G commented, by way of numerical examples, that the model appears to assume that 4G radio technology is at least 50 times more efficient than 3G radio technology	This is effectively due to voice being carried within the data layer, as well as the vastly increased capacity of 4G base stations compared to 3G base stations, as well as the 3G unit cost being increased due to the 3G network utilisation falling in the long term
The model assumes that a 3G network is maintained until 2039/2040 and, via the economic depreciation calculations, into perpetuity. However, the model also assumes that no 3G capex is incurred beyond 2015/2016, even if 3G assets become life expired	The functionality causing this effect in the Draft MCT model was an attempt to capture the effect of the 3G network design not responding to reductions in traffic (see Annex A). The effect has been turned off in the 2014 MCT model and the 3G network design has also been refined to reduce in size as 3G traffic declines
The model forecasts a temporary increase in 2G macrosites between 2011/2012 and 2014/2015 driven by the assumed fallback of 4G data demand in areas of limited 4G coverage during the early years of 4G deployment	Ofcom has revisited this treatment of 4G fallback, as described in Annex 11 of Ofcom's consultation document
[✂]	The reasons for including S-RAN in the 2014 MCT model are outlined in Annex 11 of the Ofcom's consultation document
EE	
[✂]	The radio blocking probability has been updated to 1% for both the 2G and 3G network designs from 2011/2012 onwards
EE considers that the approach taken in the draft model to implement active RAN sharing (i.e. applying a 50% capex share adjustment) may need further refinement to better reflect the commercial models in relation to 4G networks	The incorporation of network sharing has been refined in the 2014 MCT model, as described in Section 4.2 of this report
[✂]	Our approach to implementing S-RAN is explained in Section 4.2 of this report
BT	
BT suggests that the model should consist of a modern multi-mode network built in 2011 and fully loaded by 2015 (page 4)	This approach is used in other countries, especially in Scandinavia, but the approach used by Ofcom for many years is of an operator established in the 1990s
BT notes that the model currently assumes that an operator has two 3G carriers for the lifetime of the model. In reality, Telefónica is the only operator to have two carriers in its network (in the primary 2100MHz 3G bands). BT suggest this is increased to at least three carriers, potentially to four further in the future (page 7)	The number of available carriers within the model has been adjusted to increase to three from 2012/2013
A higher-than-expected proportion of main switch site costs is attributed to 4G voice. This is due to	The main switch site costs are allocated to all generations of voice together, as in the 2011 MCT

Operator comment (reference)	Treatment of comment
the legacy network replacement costs being increasingly allocated to 4G voice in later years (page 8)	model. The 2G and 3G networks are still assumed to carry some voice in the long term, and some 2G/3G voice assets must therefore be retained in the long run. The proportion of costs allocated to voice has been reduced in the 2014 MCT model, by adjusting the capacities for some of the assets, as well as reducing the minimum asset deployments
Currently, consideration of S-RAN is only included in the Cost module. It is suggested that the effect of S-RAN should be included in the Network module as well (page 9)	The implementation of S-RAN is still confined to the Cost module for reasons described in Section 4.1 of this report
The draft model appears insensitive to infrastructure-sharing assumptions; this is due to the capacity adjustments made in conjunction with the relevant cost adjustments, where one cancels the other out (page 9)	The implementation of infrastructure sharing in the 2014 MCT model has been changed in response to this comment. The new implementation is described in Section 4.2 of this report

Annex D Network diagrams

Figure D.1 illustrates the modelled 2G/3G network, primarily established in the 2011 MCT model.

Figure D.1: Illustration of modelled 2G/3G network [Source: Analysys Mason, 2014]

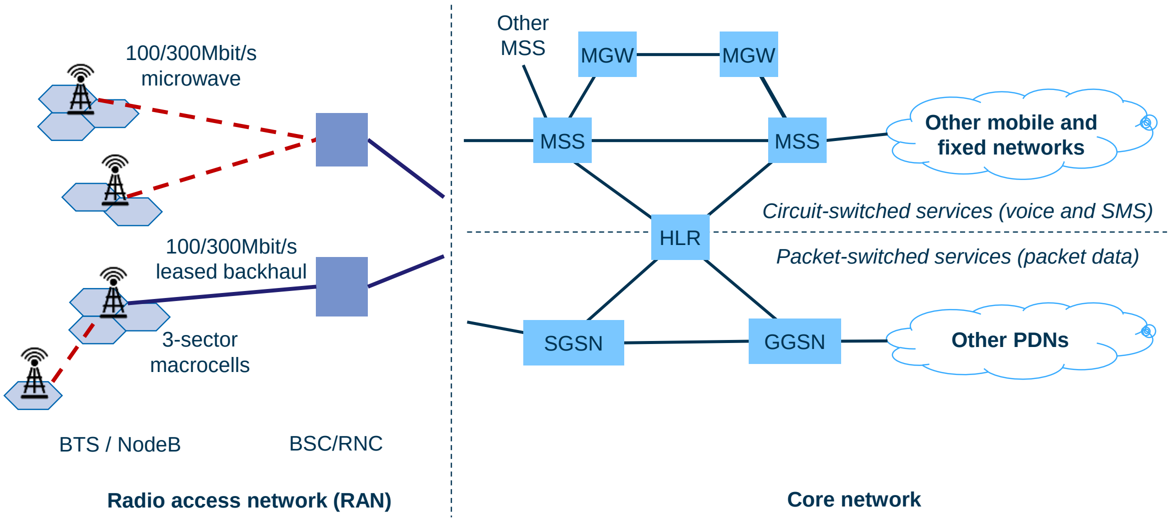
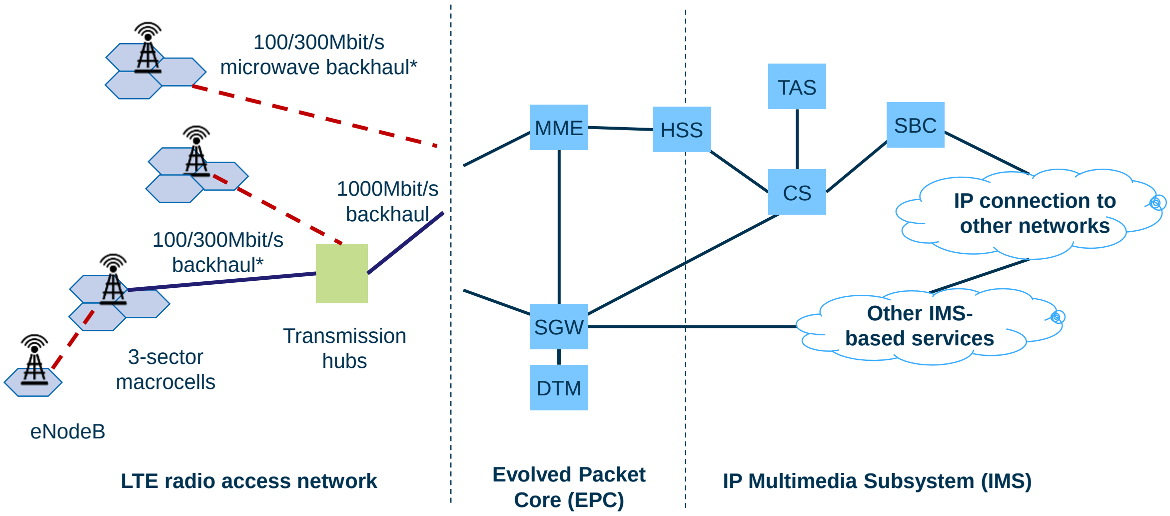


Figure D.2 illustrates the modelled 4G network developed for the 2014 MCT model.

Figure D.2: Illustration of modelled 4G network [Source: Analysys Mason, 2014]



* Backhaul links to radio network sites are deployed based on total throughput (from 2G, 3G and 4G base stations). Therefore, the links illustrated in Figure D.2 will also be used to link the 2G/3G base stations in Figure D.1, and vice versa.

Annex E Expansion of acronyms

ALF	Annual licence fee
BH	Busy hour
BHCA	Busy hour call attempts
BSC	Base station controller
BT	British Telecom
BTS	Base transmitter station or base station
CAGR	Compound annual growth rate
CPI	Consumer price index
CS	Call server
CSCF	Call session control function
DNS	Domain name system
DTM	Data traffic manager
EC	European Commission
EE	Everything Everywhere
ENUM	Electronic numbering
EPC	Enhanced packet core
ETSI	European Telecommunications Standards Institute
EU	European Union
GBP	Great British Pound
GGSN	Gateway GPRS support node
GPRS	General packet radio service
GSM	Global system for mobile communications
HLR	Home location register
HS(D)PA	High-speed (downlink) packet access
HSS	Home subscriber server
IMS	IP multimedia subsystem
IP	Internet Protocol
ITU	International Telecommunication Union
LMA	Last-mile access
LRIC	Long-run incremental cost
LTE	Long-term evolution
MB	Megabyte
MBNL	Mobile Broadband Network Ltd
MCT	Mobile call termination
MEA	Modern equivalent assets
MGW	Media gateway
MME	Mobility management entity
MMS	Multimedia messaging service
MSC	Mobile switching centre
NMS	Network management system
PDP	Packet data protocol
PGW	Packet data network gateway
RAN	Radio access network
RNC	Radio network controller
RPI	Retail price index
SBC	Session border controller
SGSN	Serving GPRS support node
SGW	Serving gateway
SMS	Short message service
SMSC	Short messages serving centre
TAS	Telephony application server
TRX	Transceiver
VMS	Voice mail system