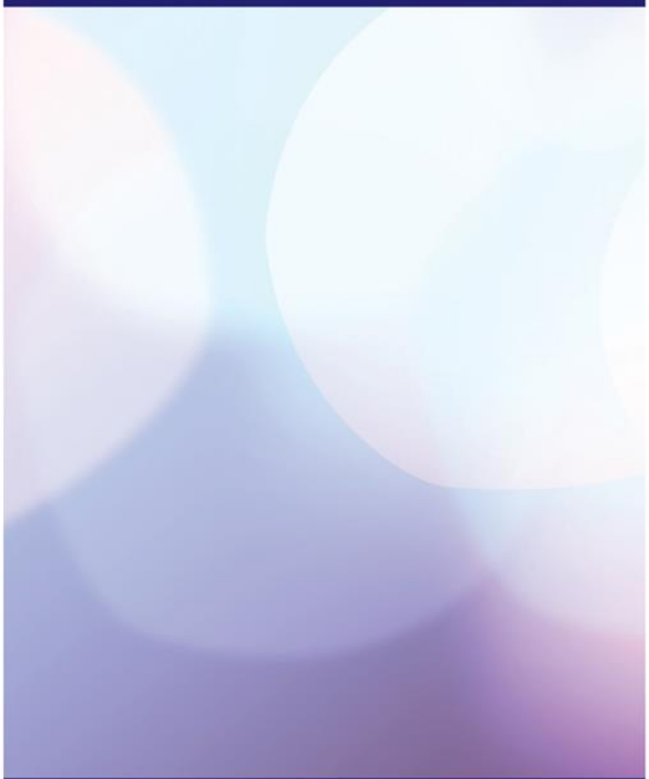

Report for ANACOM

Conceptual approach for a mobile BU-LRIC model – PUBLIC VERSION

12 June 2018

Ref: [2011000-462]

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Contents

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1 Introduction

ANACOM has commissioned Analysys Mason Limited (Analysys Mason) to update the bottom-up long-run incremental cost (BU-LRIC) model for the purpose of understanding the cost of mobile voice termination in Portugal, a model which Analysys Mason itself developed between 2010 and 2012 ('the 2011 model') and updated between 2013 and 2015 ('the 2014 model'). This wholesale service falls under the designation of Market 2[1] (previously Market 7, according to the 2009 European Commission Recommendation on relevant markets).

The model developed has been used by ANACOM to inform its market analysis for mobile termination. The process in place for the development of the BU-LRIC model included a data request and consultation, which gave industry participants the opportunity to contribute at various points during the project. Therefore, this concept paper has been updated to document the model updates implemented to take into account the comments and data provided by the operators for the update of the BU-LRIC model.

In May 2009, the European Commission (the EC, or the Commission) published its Recommendation on the regulatory treatment of fixed and mobile termination rates in the European Union (EU).[2] The May 2009 Recommendation adopts a more specific approach to costing and regulation than previous guidelines. It recommends that national regulatory authorities (NRAs) build 'pure BU-LRIC models', specifically:

- the increment is wholesale traffic only, as opposed to all traffic (as in total service LRIC (TS-LRIC) models or LRAIC+)
- common costs and mark-ups are excluded (e.g. coverage network, initial radio spectrum).

The 2011 and 2014 models developed by ANACOM followed the EC's 'pure LRIC' Recommendation. The 2017 model has been updated, maintaining the same methodology.

This consultation paper describes the modelling approach used in order to implement the EC Recommendation; therefore, in the remainder of this document we present all the modelling principles proposed for ANACOM's bottom-up pure LRIC model, taking into account the following:

- the Recommendation has left some room for further debate on the precise implementation

- older versions of this document were put up for public consultation by ANACOM during the 2011 and 2014 consultation process

1 Commission of The European Communities, *COMMISSION RECOMMENDATION of 9.10.2014 on relevant product and service markets within the electronic communications sector susceptible to* ex ante *regulation*, 9 October 2014.

2 Commission of The European Communities, *COMMISSION RECOMMENDATION of 7.5.2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU*, 7 May 2009 (2009/396/EC).

- the new version of the documentation and model include updated demand forecasts, network parameters and cost inputs.

The conceptual issues addressed throughout this document are classified in terms of four dimensions: operator, technology, implementation and services, as shown in Figure 1.1.

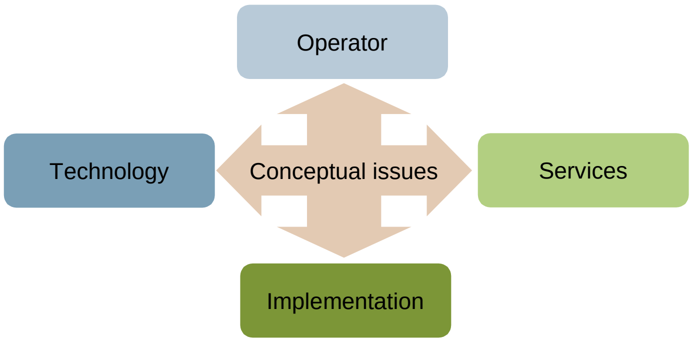


Figure 1.1: Framework for classifying conceptual issues [Source: Analysys Mason, 2017]

Operator

The characteristics of the operator used as the basis for the model represent a significant conceptual decision, with major costing implications:

- The **structural implementation** of the model to be applied. Typically, this question aims to resolve whether top-down models built from operator accounts are used, or whether a more transparent bottom-up network design model is applied. This issue is not debated further in this paper, since the EC Recommendation has defined that a bottom-up approach should be followed.
- The **type** of operator to be modelled – actual operators, average operators, a hypothetical existing operator, or some kind of hypothetical entrant to the market.
- The **footprint** of the operator being modelled – is the modelled operator required to provide national service (or at least to 99%+ of the population), or some specified sub-national coverage?
- The **scale** of the operator – in terms of market share.

Technology

The nature of the network to be modelled depends on the following conceptual choices:

- The **technology and network architecture** to be deployed in the modelled network. This encompasses a wide range of technological issues, which aim to define the modern and efficient standard for delivering the voice termination services, including topology and spectrum constraints.
- The appropriate way to define the **network nodes** and the functionality at these nodes. When building models of operator networks in a

bottom-up manner using modern technology, it is necessary to determine which functionality should exist at the various layers of nodes in the network. Two options here include *scorched-node* or *scorched-earth* approach, although more complex node adjustments may be carried out.

Services Within the services dimension, we define the scope of the services being examined:

- the **service set** supported by the modelled operator
- the traffic volumes
- the way in which **wholesale costs and retail costs** should be accounted for in the model.

Implementation A number of implementation issues are key to producing a final cost model result. They are:

- the **increments** that should be costed
- the **depreciation** method to be applied to annual expenditures
- the **weighted average cost of capital** (WACC) for the modelled operator.

In addition, this paper explains the main design and implementation principles for building a 2G/3G/4G network.

Structure of this document

The remaining sections of this document provide a brief introduction to long-run incremental costing (LRIC), and a discussion of the conceptual issues. It is structured as follows:

- Section 2 introduces the principles of LRIC
- Section 3 deals with operator-specific issues
- Section 4 discusses technology-related conceptual issues
- Section 5 examines service-related issues
- Section 6 explores implementation-related issues.

Furthermore, the report contains the following annexes:

- Annex A presents the proposed economic depreciation principles
- Annex B includes an explanation of the main steps and algorithms used to design and dimension the network
- Annex C includes a glossary of terms used in this report.

2 Principles of long-run incremental costing

This section discusses the main concepts and principles underlying the LRIC methodology for mobile voice termination. It is structured as follows:

- concepts of competitiveness and contestability (Section 2.1)
- long-run costs (Section 2.2)
- incremental costs (Section 2.3)
- efficiently incurred costs (Section 2.4)
- costs of supply using modern technology (Section 2.5).

2.1 Competitiveness and contestability

The 13th Recital[3] of the EC Recommendation is in line with the principle that LRIC reflects the level of costs that would occur in a competitive or contestable market. Competition ensures that operators achieve a normal profit and normal return over the lifetime of their investment (i.e. the long run). Contestability ensures that existing providers charge prices that reflect the costs of supply in a market that can be entered by new players using modern technology. Both of these market criteria ensure that inefficiently incurred costs are not recoverable.

2.2 Long-run costs

Costs are incurred in an operator's business in response to the existence of, or change in, service demand, captured by the various cost drivers. Long-run costs include all the costs that will ever be incurred in supporting the relevant service demand, including the ongoing replacement of assets used. As such, the duration 'long run' can be considered at least as long as the network asset with the longest lifetime. Long-run costing also means that the size of the network deployed is reasonably matched to the level of demand it supports, and any over- or under-provisioning would be levelled out in the long run.

Consideration of costs over the long run can be seen to result in a reliable and inclusive representation of cost, since all the cost elements would be included for the service demand supported over the long-run duration, and averaged over time in some way. In contrast, short-run costs are those which are incurred at the time of the service output, and are typically characterised by large variations: for example, at a particular point in time, the launch of a service or an increase in a service demand may cause the installation of a new capacity unit, giving rise to a high short-run unit cost, which then declines as the capacity unit becomes better utilised with growing demand.

Therefore, in a LRIC model it is necessary to identify incremental costs as all cost elements which are incurred over the long run to support the service demand of the increment.

3 L 124/69 of the Official Journal of the European Union (20 May 2009).

This is in agreement with the 13th Recital of the Recommendation, which recognises that all costs may vary in the long run.

2.3 Incremental costs

Incremental costs are incurred in support of the increment of demand, assuming that other increments of demand remain unchanged. Put another way, the incremental cost can also be calculated as the avoidable costs of not supporting the increment.

Possible definitions for the increment include:

- the marginal unit of demand for a service
- the total demand for a service (e.g. voice service termination)
- the total demand for a group of services
- the total demand for all services in aggregate.

In Figure 2.1, we illustrate where the possible increment definitions interact with the costs that are incurred in a five-service business.

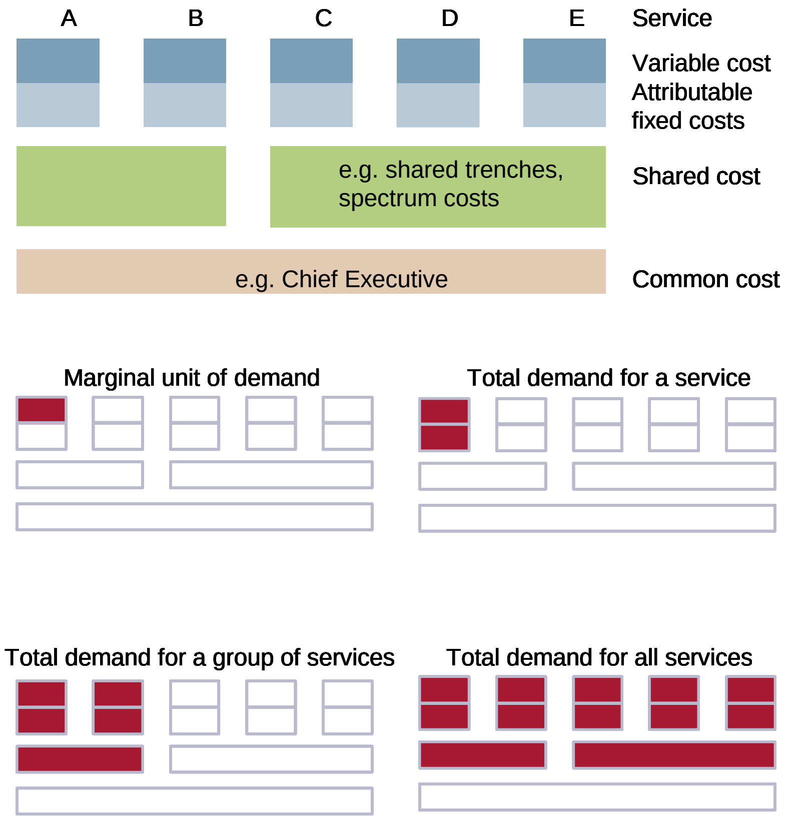


Figure 2.1: Possible increment definitions [Source: Analysys Mason, 2017]

Section 6.1 discusses the definition of the increments that we propose to use in the costing model in more detail.

Evidently, the EC Recommendation of May 2009 favours the second option listed above: the total demand for a service (e.g. voice service termination).

2.4 Efficiently incurred costs

In order to set the correct investment and operational incentives for regulated operators, it is necessary to allow only efficiently incurred expenditures in cost-based regulated prices. In practice, the specific application of this principle to a set of cost models depends significantly on a range of aspects:

- detail and comparability of information provided by individual operators
- detail of modelling performed
- the ability to uniquely identify inefficient expenditures
- the stringency in the benchmark of efficiency which is being applied[4]
- whether efficiency can be distinguished from below-standard quality[5].

The Portuguese operators seem generally active in competitive retail markets, which include both the competitive supply of services to end users, and the competitive supply of infrastructure and services to those operators. Therefore, the *a priori* expectation of inefficiencies in the market may be limited. However, it is still necessary to ensure that there is a robust assessment of efficiently incurred costs.

2.5 Costs of supply using modern technology

A new entrant that competes for the supply of a service in a market will deploy modern technology to meet its needs – since this should be the efficient network choice. This implies four 'modern' aspects: (i) the choice of the network generation (e.g. 2G, 3G or 4G); (ii) the capacity of the equipment; (iii) the price of purchasing that capacity, and the costs of operating it; and (iv) the cost of maintaining the equipment. Therefore, a LRIC model should be capable of capturing these aspects:

- *The choice of technology should be efficient* – Legacy technologies, which are in the process of being phased out, should not be considered modern.

- *Equipment capacity should reflect the modern standard* – In the case of mobile network infrastructure, some network elements are functionally required to have a fixed capacity (e.g. a global system for mobile communications (GSM) transceiver – or TRX – has a capacity of eight channels), whereas other network elements have capacity that increases with new hardware versions and technology generations (e.g. mobile switching centre (MSC) processor capacity), but decreases with the loading of new features[6] – some of which will be deployed for non-voice services. New-generation switches may also be optimised to give improved capacity (e.g. the

4 For example, most efficient in Portugal, most efficient in Europe, most efficient in the world.

5 For example, an operator may appear to be carrying the annual traffic in its network with a relatively low deployment of capacity. However, it may be achieving this with a higher busy-hour blocking probability (e.g. 5%), whereas the 'efficient' benchmark adopted could be 2% (or another figure, as specified in an operator's licence conditions).

6 Much like the power and features of Microsoft Windows PCs over time.

mobile network mobile switching centre server (MSS) only performs *control-plane* switching, whilst the separate media gateway (MGW) switches the *user-plane* voice traffic). Switches may not be simply dedicated to 2G or 3G but switch both 2G and 3G traffic (e.g. using an all-IP core). In contrast, a 4G network is usually deployed as an additional layer that requires some dedicated switches and routers (e.g. IMS for the management of voice over LTE (VoLTE)), and with circuit switch fall-back (CSFB) interfaces to ensure interoperability with the legacy networks.

- *The modern price for equipment* represents the price at which the modern asset can be purchased over time. It should represent the outcome of a reasonably competitive tender for a typical supply contract in Portugal. It is reasonable to assume that operators in Portugal are able to acquire their equipment at typical European prices, and that have a comparable purchasing power to that of their European peers. A data request has been sent to the Portuguese mobile operators in order to obtain their estimate of the unit costs for the different network elements. We complemented the Portuguese data points with European benchmarks in order to come to a final view on the equipment costs in the model.

- *Operation and maintenance costs* should correspond to the modern standard of equipment, and represent all the various facility, hardware and software maintenance costs relevant to the efficient operation of a modern standard network.

The definition of modern equipment is a complex issue. Mobile operators around the world are at different stages of:

- Deploying IP-based core networks, ranging from initial plans to fully deployed

- 3G upgrade: including radio layer augmentation for voice, high-speed downlink packet access (HSDPA) and high-speed uplink packet access (HSUPA), and the extent to which MSS/MGW switching has been rolled out

- 4G network roll-out and service launch: whilst LTE spectrum auctions have already been held in most developed markets, the levels of network roll-out and subscriber take-up still vary quite significantly from one country to another. Whilst LTE data services are already a reality, VoLTE has yet to gain traction in Portugal. However, it appears reasonable to assume that VoLTE will be launched by the Portuguese mobile operators in the next years in light of a number of factors, including: commercial reasons, the higher spectral efficiency of VoLTE with respect to traditional voice, and based on a benchmark on the status of VoLTE on Western European countries that shows that in most Western European countries more than one operator has already launched VoLTE services.

The May 2009 Recommendation states that, in principle, the efficient technological choice on which the cost models for mobile operations should be based are:

- a next-generation based core network
- a combination of 2G and 3G employed in a mobile network.

However, the launch of 4G in recent years means it is now necessary to include it among the efficient technologies in a mobile network.

Therefore, the current efficient technologies applicable to Portugal appear to be:

- a next-generation based core network
- a combination of 2G, 3G and 4G employed in the mobile network.

The technology architecture is discussed in detail in Section 4.1.

3 Operator issues

This section discusses the following aspects of the modelled operator:

- type of operator (Section 3.1)
- network footprint of the operator (Section 3.2)
- scale of the operator (Section 3.3).

3.1 Type of operator

The type of operator to be modelled is the primary conceptual issue, which determines the subsequent structure and parameters of the model. It is also important because of the need to ensure consistency between the choice of operator in the mobile termination model and subsequent cost-based regulation of real players.

The full range of operator choices is:

- **Actual operators** – in which the costs of all actual market players are calculated

- **Average operator** – in which the players are averaged together to define a 'typical' operator

- **Hypothetical existing operator** – in which a hypothetical existing operator is modelled as an existing operator launching services in the Portuguese market in 2006/2007 after having rolled out a network in 2005/2006 (the approximate date at which today's modern technology was deployed) with a modern network architecture, allowing the operator to attain its hypothetical scale around the relevant period of regulation[7]

- **Hypothetical new entrant** – in which a hypothetical new entrant to the market is defined as an operator which enters the market with today's modern network architecture, and acquires a specified target share of the market.

At this stage, we exclude the option to apply actual operators. This is because:

- It would reduce costing and pricing transparency, as well as increasing the risk/complexity of ensuring that identical principles are applied to individual operator models for all three mobile players.

- The EC recommends costing an operator with a minimum efficient scale of 20% – by implication, not an actual operator. In the case of Portugal, this would entail a possible range of market share between 20% (the EC minimum) and 33% (equal market shares for the three network operators).

7 For consistency, these dates are the same as in the previous version of the model.

Therefore, we consider three options for the type of operator to be modelled. The characteristics of these options are outlined in Figure 3.1 below.

Figure 3.1: Operator choices [Source: Analysys Mason, 2017]

Characteristic	Option 1: Average operator	Option 2: Hypothetical existing operator	Option 3: Hypothetical new entrant
Date of entry	Different for all operators, therefore an average date of entry is not meaningful	Can be set to take into account key milestones in the real networks (e.g. beginning of the phasing of the transition from 2G to 3G)	In this case, the date of entry is inferred from the EC Recommendation, which sets a relation between time and the acquisition of market share
Technology	Different for all mobile operators (e.g. level of roll-out of all-IP core), and so an average mobile operator is not appropriate; the most advanced operators would bear the costs of less-efficient ones (see 'efficiency' section below)	The technology of a hypothetical operator can be specifically defined, taking into account relevant recent technology components of existing networks. In the case where the hypothetical existing operator is modelled as an operator that entered the market in recent years, the EC Recommendation specifies the appropriate technology mix	By definition, a hypothetical new entrant would employ today's modern technology choice. The EC specifies a next-generation network (NGN) mobile core and a mix of 2G and 3G radio technology. However, 4G (long-term evolution, LTE) technology is now available for a new entrant to deploy in Portugal, and so should be taken into account
Evolution and migration to modern technology	All mobile operators currently use modern technology (combined GSM, UMTS, HSPA and LTE networks), but are at different stages of core network roll-out	The evolution and migration of a hypothetical operator can be specifically defined, taking into account the existing networks. Legacy network deployments can be ignored if migration to next-generation technology is expected in the short to medium term or has already been observed in real networks	By definition, a hypothetical new entrant would start with the modern technology. Therefore, evolutionary or migratory aspects are not relevant. However, the rate of network roll-out and subscriber evolution are key inputs into the model
Efficiency	May include inefficient costs through the average	Efficient aspects can be defined. If modelled as a new operator that entered the market in recent years, efficient choices can be made throughout the model	By definition, efficient choices can be made throughout the model
Comparability and transparency of bottom-up network modelling with real operators	The network model of an average operator would only be comparable with an average across the real network operators However, it would be possible to illustrate	In order to compare a hypothetical operator network model with real operators, it would be necessary to transform the actual operator information in some way (e.g. averaging, or re-scaling to reflect the	In principle, the hypothetical new entrant approach is fully transparent in design. However, since none of the real operators is a new entrant, it would not be possible to draw a

Characteristic	Option 1: Average operator	Option 2: Hypothetical existing operator	Option 3: Hypothetical new entrant
	this average comparison in a reasonably transparent way	characteristics of the hypothetical operator). Whilst the hypothetical operator model would be transparent to industry parties, the comparison against real operator information might include additional steps which would need to be explained	like-for-like comparison against real operator network information
Practicality of reconciliation with top-down accounting data	It is not possible to directly compare an average operator with actual top-down accounts. Only an indirect comparison (e.g. overall expenditure levels and operational expenditure (opex) mark-ups) is possible	It is not possible to directly compare a hypothetical existing operator with actual top-down accounts. Only an indirect comparison (e.g. overall expenditure levels and opex mark-ups) is possible	It is not possible to directly or indirectly compare a hypothetical new entrant model with real top-down accounts without additional transformations in the top-down domain (e.g. current cost revaluation). No new-entrant accounts exist

There are four key issues involved in choosing the appropriate option:

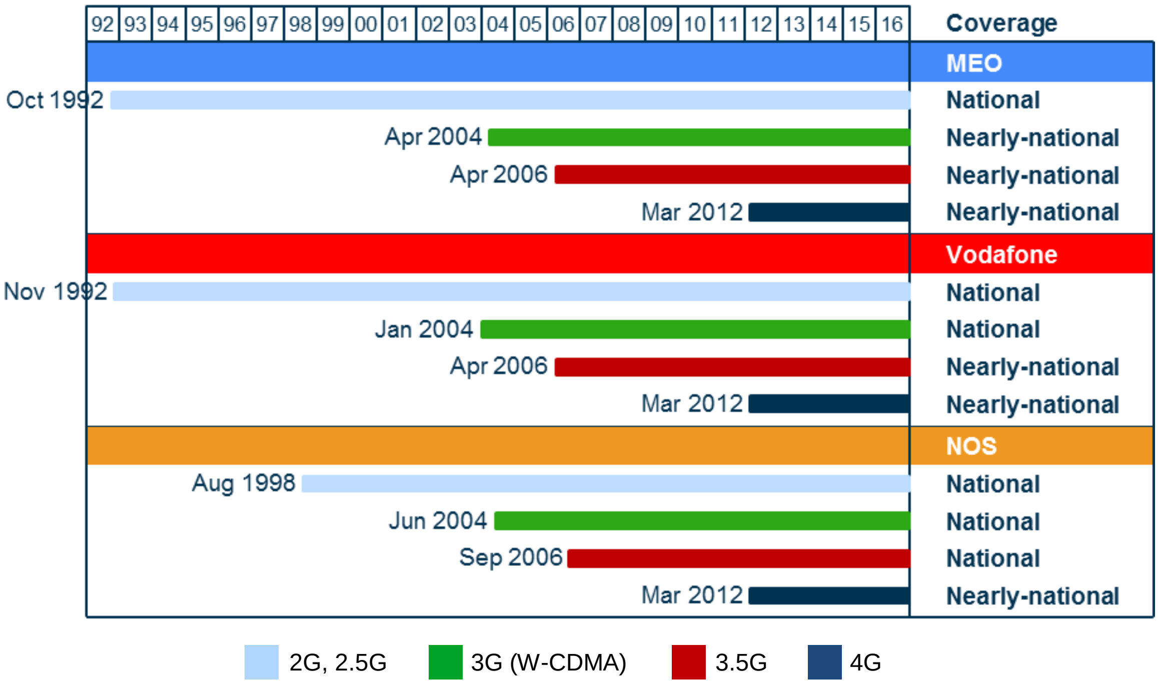
Is the choice appropriate for setting cost-based regulation?

All three options presented above could be considered a reasonable basis on which to set cost-based regulation of wholesale mobile termination services. However, in the case of Option 1, inefficient costs would need to be excluded.

What modifications and transformations are necessary to adapt real information to the modelled case?

Figure 3.1 above summarises the various transformations which are required in the modelling approach. As an example of one of the main transformations (date of entry), Figure 3.2 below illustrates the diversity that exists for dates of entry, in terms of the technology layers in Portugal's networks. For example, a GSM date of entry transformation would be required for all three operator options outlined in Figure 3.1 above, since there are wide variations among the three operators.

Figure 3.2: Timeline comparison for the Portuguese mobile operators [Source: Analysys Mason, 2017]



Are there guidelines which should be accommodated (e.g. EC Recommend-ation)?	The EC Recommendation suggests that an efficient-scale operator should be modelled; however, the precise characteristics of this type of operator are not defined (other than its minimum scale). In principle, all three of the above options can satisfy the efficient-scale requirement.
What flexibility does the model offer in terms of options?	A model constructed for Option 3 would be designed in such a way as to exclude historical technology migrations. It would also be mechanically designed to start its costing calculations in 2013. Therefore, the model for Option 3 can be considered linked to the type of operator modelled. A model constructed for Option 2 can also be used to calculate costs for Option 3 by assuming a modern-equivalent asset (MEA) deployment from the beginning of the period of operation and adjusting the subscriber demand and take-up.

Therefore, Option 2 appears to be the most reasonable and appropriate choice. This view is also supported by the following points:

- The use of a hypothetical existing operator allows the model to be grounded in the reality of Portuguese network operations. In contrast, a hypothetical new entrant model would be more speculative and difficult to populate. As a result, it would have some disadvantages compared to the hypothetical existing operator approach, such as not reflecting real-world technology evolution in recent years

- The proposed methodology is consistent with paragraph 12 of the EC Recommendation, reflecting the level of costs for an operator characterised by reasonably efficient modern technology choices – not necessarily "*the most efficient possible technology choices which might be taken in a 2013 greenfield situation*". As the EC Recommendation notes, it is necessary to be able to identify the relevant technology choices, and we consider it reasonable at the time the new model is designed to refer to actual operators' recent activities, and to capture these in an existing operator model

- The hypothetical existing operator approach ensures consistency with the previous version of the mobile cost model, as well as with the fixed termination cost model that Analysys Mason recently developed on behalf of ANACOM.

Proposed Concept 1: We do not recommend Option 1 (average operators), as it is dominated by historical issues rather than modern and efficient network aspects. We do not recommend Option 3, as it excludes historical technology migrations and consistency with Portuguese operators.

We have based the cost model on Option 2 (hypothetical existing operator) since this enables the model to determine a cost consistent with the existing suppliers of mobile termination in Portugal, such that actual network characteristics over recent time can be taken into account.

However, we consider that such a hypothetical existing operator could be modelled as an operator which started services in 2006/2007, a year after rolling out its network. Reflecting the May 2009 Recommendation, such an operator network would use the technology that an efficient operator at the time of entry would have rolled out, in anticipation of developments during future years, i.e. a combination of 2G, 3G and 4G network and an NGN core.

The modelled operator is therefore:

A mobile operator rolling out a national 900MHz 2G network in 2005/2006, launching 2G services in approximately 2006/2007, and supplementing its 900MHz network with extra 2G capacity in the 1800MHz frequency band until 2022, when the secondary GSM spectrum band is expected to be re-farmed to LTE. This network would also be overlaid with 2100MHz 3G voice and HSPA capacity and switch upgrades (reflecting the technology available in the period 2005–2011), to carry increased voice traffic, mobile data and mobile broadband traffic. Roll-out of a 4G network would be modelled from the beginning of 2012. LTE traffic would be carried on the spectrum bands auctioned at the end of 2011 (i.e. 800MHz for the primary LTE coverage layer, as well as the 2600MHz and 1800MHz bands for secondary and tertiary capacity layers respectively).

The parallel 2G, 3G and 4G networks would continue in operation for the long term, and thus complete migration to 4G network would not be modelled. This is consistent with the information emerged from the data request, which indicates that there is no expectation that operators switch off their 2G and/or 3G networks in the foreseeable future.

To ensure that the hypothetical existing operator reflects the reality of the Portuguese market, the model is calibrated against network and financial data provided by the mobile operators. We focused our calibration efforts on ensuring that the total number of sites and base stations (i.e. BTSs, NodeBs, eNodeBs) produced by the model is consistent with the market numbers as an aggregate. We have also calibrated the cost included in the model with the cost base in aggregate for the market, by referring to total expenditures and book values.

3.2 Network footprint of the operator

Coverage is a central aspect of network deployment. The question of what coverage to apply to the modelled operator can be understood as follows:

- What is the current level of coverage applicable to the market today?
- Is the future level of coverage different from today's level?
- Over how many years does the coverage roll-out take place?
- What quality of coverage should be provided at each point in time?

The coverage offered by a mobile operator is a key input to the costing model. The definitions of coverage parameters have two important implications for the cost calculation:

The unit cost of traffic is affected by the expenditure on coverage roll-out

The rate, extent and quality of coverage achieved determine the network investments and operating costs of the coverage network in the early years. The degree to which these costs are incurred prior to demand materialising represents the size of the 'cost overhang'. The larger this overhang, the higher the eventual unit costs of traffic will be. The concept of a cost overhang is illustrated in Figure 3.3.

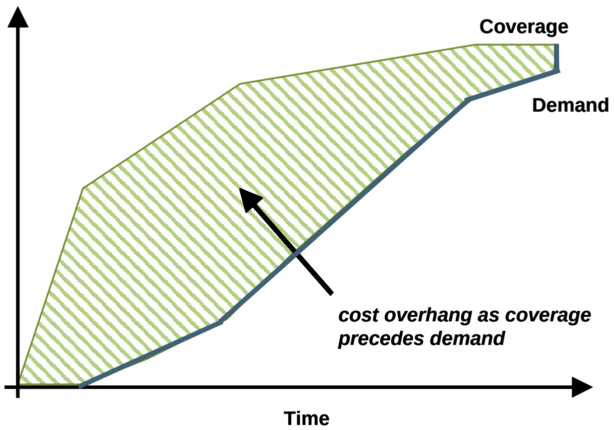


Figure 3.3: Cost overhang [Source: Analysys Mason, 2017]

Identification of network elements that vary in response to traffic

Elements of the mobile networks may (or may not) vary in response to the traffic volumes carried – depending on whether the coverage network has sufficient accompanying traffic capacity for the offered load. This has particular implications during the application of a small wholesale termination traffic increment (see Section 6.1).

Approach

All mobile networks in Portugal currently have almost ubiquitous 2G and 3G outdoor population coverage, as well as significant 4G coverage, and this should be reflected in the model.

Due to building penetration losses, good outdoor coverage does not directly translate into good indoor coverage, and so deep indoor mobile coverage requires additional investment in radio sites. This indoor coverage is delivered by either:

- deploying outdoor macro-site networks to transmit signals through the walls of buildings
- installing a dedicated indoor micro-cell which is typically backhauled to the mobile switch via a fixed link to the building. Indoor micro-cells may be classified as either public access (e.g. in shopping centres) or private access (as in corporate in-building solutions).

These wireless solutions serve traffic which might otherwise be carried to that building by a fixed access method with a dedicated or very high-capacity technology (i.e., with a low marginal cost). It is estimated that up to 60% of mobile voice traffic occurs inside buildings, and at least 30% from home or work.

Because of current end-user expectations, and for the model to reflect current deployment practice and traffic volumes, we have included the current level of indoor coverage within the mobile network footprint principle, calibrated according to the data received by the MNOs.

For a hypothetical existing operator, it appears necessary to have near-ubiquitous 2G coverage responding to the market's needs and standards and consistent with customers' expectations both at the time of launch (2005) and at the current time (2017); conversely, 100% coverage of 3G/4G does not seem necessary, even in light of the adoption of UMTS technology on 900MHz which was done by Vodafone only. 3G and 4G coverage levels will therefore be consistent with current deployments and coverage commitments as set out in the operators' licences. We expect 3G to stay at its current level of 96.9% outdoor coverage of population in the 2.1GHz band (the coverage already takes into account the coverage obligations imposed in the renewal of 2100 MHz band), whereas 4G coverage is projected to reach 95% of population in the 800MHz band in 2020 and 97% by 2030.

It is worth noting the difference between coverage and capacity, as well as the fact that non-traffic-related costs are not to be attributed to the termination traffic; indeed, the definition included in the EC Recommendation states that "the need to provide such coverage to subscribers will cause non-traffic-related costs to be incurred which should not be attributed to the wholesale call termination increment". In our model, the coverage network is deployed based on a specific rate of deployment, independent of traffic, and a capacity network is deployed where the coverage network cannot cope with the voice and data traffic in each geotype.

The minimum coverage level is also similar to that needed to achieve minimum efficient scale (e.g. around 20% market share), as illustrated in Figure 3.4, which shows the relationship between coverage and capacity.

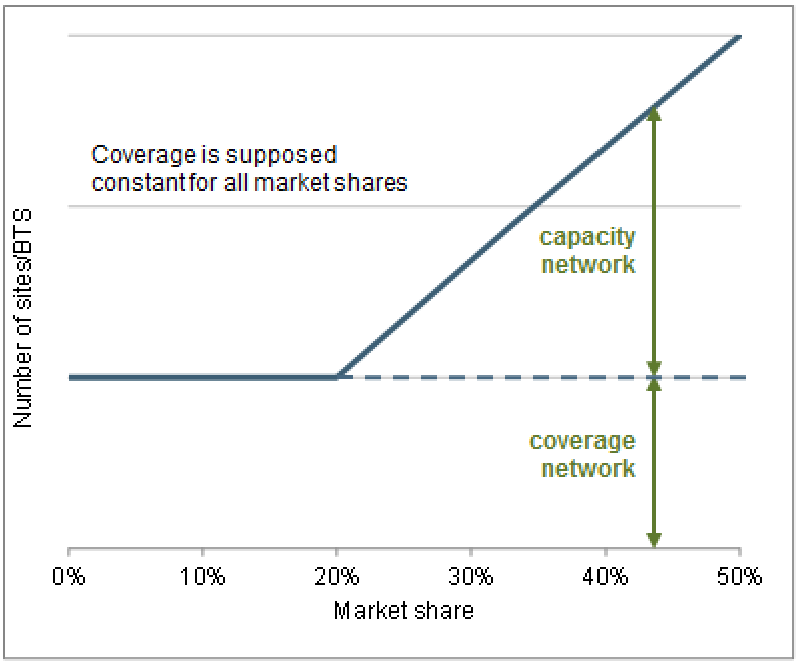


Figure 3.4: Relationship between market share and number of sites of a mobile operator with constant coverage [Source: Analysys Mason, 2017]

Proposed Concept 2: National levels of geographical coverage and coverage regulatory obligations are reflected in the model. In the long run, we expect outdoor coverage to be 99.8% of population for 2G; 96.9% of population for 3G and 97.0% of population for 4G. To develop our coverage model[8] we have used internal estimates and/or calibration of macro- and micro-sites (and/or indoor sites) with operator data[9] if submitted. The model classifies Portuguese *freguesias* into geotypes based on their average population densities. We have adopted a definition of coverage consistent with the expectations of the Portuguese market during the period of 2G and 3G network roll-out.

3.3 Scale of the operator

One of the main parameters that defines the cost (per unit) of the modelled operator is its market share: it is therefore important to determine the market share of the operator and the period over which any market share evolution/growth takes place. The parameters chosen for defining the operator's market share over time influence the overall level of economic costs calculated by the model.

Regarding the scale of the modelled operator, the May 2009 Recommendation[10] indicates a *minimum* value of 20%. However, consistent with ANACOM's desire to reflect a competitive, efficient, cost-

8 Further details of the coverage and capacity calculation are provided in Annex A.

9 Once the coverage calculation has been developed in the model, and loaded up with network traffic, we will be able to compare the modelled numbers of BTSs/(e)Node Bs and TRXs/CE against actual operator data (if submitted). If this comparison process identifies significant differences between the model and reality, further investigation will be required to validate the calculation model (e.g. investigating uncertain model inputs, analysing operator data and differences, identifying relevant benchmarks from other European countries for comparison, or adapting model inputs where appropriate).

10 Commission of The European Communities, *COMMISSION RECOMMENDATION of 7.5.2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU*, 7 May 2009 (2009/396/EC): To determine the minimum efficient scale for the purposes of the cost model, and taking account of market share developments in a number of

based market for the regulated supply of wholesale voice termination, the BU-LRIC model has to take into account the costs of an operator in a fully competitive market. With *n* mobile network operators, each operator will have a *1/n* share of the market in the long term, i.e. a *1/n* share of all standard retail and wholesale services in Portugal.

Furthermore, by modelling an operator that achieves its minimum efficient scale (20%) over a period of six years (2005–2011) and reaches a long-run market share of 33.3% (calculated as 1/*n*, where *n* represents the number of mobile networks throughout Portugal) by 2017, we ensure methodological consistency with:

- the May 2009 Recommendation
- mobile LRIC models developed by other European NRAs
- the previous versions of the mobile termination model
- the fixed termination model recently developed by Analysys Mason on behalf of ANACOM.

A further issue related to the issue of *scale* is the time taken to achieve a steady market share. It is necessary for the model to specify the rate at which the modern network is rolled out, and the corresponding rate at which that modern network carries the traffic volumes of the operator (up to the market share proposed above). There are a number of ways to address this issue when modelling a hypothetical existing operator.

- **Option 1: Immediate scale** – In this option, the modelled operator immediately achieves its market share, and rolls out its network just in time to serve this demand at launch. This approach does not reflect real technology transitions.

- **Option 2: Matching the modern technology transition during the modelled years** – In this approach, the utilisation of the modern technology during recent years is observed for the actual networks and used to define an efficient profile for the hypothetical existing operator. With this option, we observe that mobile networks have not experienced any significant radio technology transition between technology generations in the period 2005–2013 (as it was before in 2005–2009 between 2G and 3G), with 3G and 4G overlays steadily carrying additional traffic.

- **Option 3: Assuming a hypothetical roll-out and market share profile** – In this option, a time period for achieving a target network coverage (footprint) roll-out is specified (e.g. four years), and a time period to achieve full scale (e.g. 20%) is also specified (e.g. four to five years).

- **Option 4: Roll-out and growth based on history** – It is possible to apply roll-out and volume growth profiles which have been obtained directly from (the average of) the actual mobile operators. This approach involves looking back at networks as long ago as the early 1990s, and

EU Member States, the recommended approach is to set that scale at 20% market share. It may be expected that mobile operators, having entered the market, would strive to maximise efficiency and revenues and thus be in a position to achieve a minimum market share of 20%. In case an NRA can prove that the market conditions in the territory of that Member State would imply a different minimum efficient scale, it may deviate from the recommended approach.

therefore would be complex to carry out, with numerous assumptions based on historical information.

Proposed Concept 3: We have modelled an operator that achieves a minimum efficient scale of 20% over a period of six years (2005–2011) and grows to the proposed 33.3% in the long run (achieved in 2017), where the 33.3% reflects the Portuguese mobile market situation calculated as 1/*n*, where *n* represents the number of mobile networks with a significant penetration (equal to three for Portugal as a whole).

Proposed Concept 4: In terms of the time taken to achieve steady market share, we have implemented Option 3, modelling a time period of six years to achieve network coverage (footprint) similar to that of the other Portuguese mobile operators. In many cases, coverage deployments are determined by i) spectrum licences, which often impose coverage obligations on the licensees[11], and ii) the strategic choice of the operator in order to compete and achieve a minimum market share. This is in line with the EC Recommendation, which states that an operator is expected to take three to four years after entry to reach a market share approaching the minimum efficient scale (15–20%).

11 This obligations are *de facto* redundant for Portugal since population coverages reached by operators significantly exceed the obligation thresholds set.

4 Technology issues

This section describes the most important conceptual issues with regard to technology in mobile BU-LRIC models. It is structured as follows:

- choice of modern network architecture (Section 4.1)
- treatment of network nodes (Section 4.2)
- dimensioning of the network and impact of data traffic (Section 4.3).

4.1 Modern network architecture

A mobile BU-LRIC model requires a network architecture based on a specific choice of modern technology. From the perspective of termination regulation, modern-equivalent technologies should be reflected in the model: that is, proven and available technologies with the lowest cost expected over their lifetimes.

Mobile networks have been characterised by successive generations of technology, with the three most significant steps being the transition from analogue to 2G digital (GSM); the expansion to include 3G (UMTS/HSPA)-related network elements and services; and, recently, the development and commercial launch of 4G (namely LTE) networks and services. The mobile network architecture splits into three parts: a radio network, a switching network and a transmission network. Below we discuss the (modern) technology generations to apply to the model.

Radio network generation and technology

Radio networks rely on spectrum bands to carry the traffic load. In Portugal there is almost complete spectrum symmetry among the operators, resulting from how the spectrum assignment process has been managed in the past.

- GSM 900MHz spectrum bands were awarded to the Portuguese operators with a six-year interval between the first and the last operator: Vodafone obtained a GSM licence in 1991; MEO was assigned GSM frequencies in 1992; and NOS obtained a GSM licence in 1997.

- DCS 1800MHz spectrum bands were shared equally among all three mobile operators in the year when NOS entered the market (1997).

- The UMTS 2100MHz spectrum bands were awarded in 2000. Four operators received a licence: Vodafone, NOS, Portugal Telecom (MEO) and OniWay. However, OniWay's licence was revoked in 2003 due to the operator's inability to deploy its network, and its 15MHz of spectrum was distributed equally among the remaining three operators. Deployment obligations were delayed until 2004, for technological and economic reasons.

- LTE 800MHz, LTE 2600MHz and additional frequencies within the 1800MHz band were awarded at the end of 2011. All three existing mobile operators at the time of the auction received spectrum in all three LTE-capable spectrum bands.

There are, however, a few minor asymmetries in the actual frequency assignment among Portuguese operators:

- in the 2G spectrum bands, NOS has 39 2×200kHz channels instead of the 40 channels that Vodafone and MEO each have for GSM 900MHz
- in the 3G spectrum bands, NOS returned its 5MHz of time division duplex (TDD) spectrum in the 2100MHz frequency in February 2009, whereas Vodafone was awarded additional 900MHz spectrum that was used to enhance its UMTS coverage and services
- in the 4G spectrum bands, Vodafone was awarded additional TDD 2600MHz spectrum, whereas NOS and MEO only received FDD frequencies in the same band.

In the model we have also taken into account the fact that the technological restrictions on the use of 900/1800MHz band frequencies were lifted in March 2010, and that these frequencies are now technology neutral (we have modelled 1800MHz spectrum refarming to LTE). Figure 4.1 provides details of the current spectrum allocation in Portugal for all mobile operators.

Figure 4.1: Current spectrum allocation situation in Portugal [Source: ANACOM,[12] Analysys Mason, 2017]

		MEO	Vodafone	NOS
LTE 800MHz	**Frequencies**	2×10MHz	2×10MHz	2×10MHz
	Assigned	1 December 2011	1 December 2011	1 December 2011
	Renewed	N/A[(1)]	N/A	N/A
	Expiration	9 March 2027	9 March 2027	9 March 2027
	Licence cost	EUR90 million	EUR90 million	EUR90 million
	Comments			
	Award system	Auction	Auction	Auction
GSM 900MHz	**Frequencies**	40 channels (16MHz)[(2)]	40 channels (16MHz)[(2)] + 2×5MHz	39 channels (15.6MHz)
	Assigned	16 March 1992	19 October 1991	20 November 1997
	Renewed	16 March 2007	19 October 2006 1 December 2011	N/A
	Expiration	16 March 2022	19 October 2021 9 March 2027	20 November 2012
	Licence cost	Financial allocations pending		
	Comments	The licence was automatically granted to MEO	10 additional channels were provided in 1996 Another 10MHz were assigned	Awarded jointly with 1800MHz licence

12 ANACOM, *Information on multi-band spectrum auction* (12 December 2011), available at http://www.anacom.pt/render.jsp?contentId=1106646#.VIsYJjHF_pV.

		MEO	Vodafone	NOS
		10 additional channels were provided in 1996	during the multi-band auction in 2011	
	Award system	Automatically granted	Public tender	Beauty contest
LTE/GSM 1800MHz	**Frequencies 1710–1785/ 1805–1880MHz**	30 channels (12MHz) + 2×14MHz	30 channels (12MHz) + 2×14MHz	30 channels (12MHz) + 2×14MHz
	Assigned	20 November 1997	20 November 1997	20 November 1997
	Renewed	16 March 2007 1 December 2011	19 October 2006 1 December 2011	1 December 2011
	Expiration	16 March 2022 9 March 2027	19 October 2021 9 March 2027	20 November 2012 9 March 2027
	Licence cost	EUR11 million in 2011 Financial allocations pending for previous assignments	EUR11 million	EUR11 million
	Comments	2×4MHz and 2×5MHz awarded in the 2011 multi-band auction	2×4MHz and 2×5MHz awarded in the 2011 multi-band auction	Awarded jointly with 1800MHz licence 2×4MHz and 2×5MHz awarded in the 2011 multi-band auction
	Award system	Automatically granted	Automatically granted	Beauty contest
UMTS 2100MHz	**Frequencies 1920–1980/ 2110–2170MHz**	-	2×20MHz paired spectrum	2×20MHz paired spectrum
	Frequencies 1900–1920MHz	5MHz unpaired spectrum	5MHz unpaired spectrum	No spectrum
	Assigned	11 January 2001	11 January 2001	11 January 2001
	Expiration	11 January 2016 9 March 2027	11 January 2016 9 March 2027	11 January 2016 9 March 2027
	Licence cost	PTE20 billion per licence fee + annual spectrum fee		
	Comments	Paired spectrum was increased from 2×15MHz to 2×20MHz in December 2003	Paired spectrum was increased from 2×15MHz to 2×20MHz in December 2003	Paired spectrum was increased from 2×15MHz to 2×20MHz in December 2003 In February 2009, NOS returned its 5MHz of unpaired spectrum
	Award system	UMTS frequencies were awarded based on a beauty parade (public tender)		
LTE 2600M	**Frequencies 2500–2690MHz**	2×20MHz paired spectrum	2×20MHz paired spectrum	2×20MHz paired spectrum

	MEO	Vodafone	NOS
		+ 25MHz TDD	
Assigned	1 December 2011	1 December 2011	1 December 2011
Expiration	9 March 2027	9 March 2027	9 March 2027
Licence cost	EUR12 million	EUR15 million	EUR12 million
Comments			
Award system	Auction	Auction	Auction

(1) N/A = not available.

(2) 10 channels were provided in addition to the existing 30 channels in 1996.

Proposed Concept 5: Since all operators have similar spectrum holdings across all bands, it is assumed that the future spectrum holding and coverage network-related costs are symmetrical. We have modelled an operator with:

- 2×10MHz of LTE 800MHz spectrum
- 2×8MHz of GSM 900MHz spectrum
- 2×20MHz of GSM and LTE 1800MHz spectrum
- 2×20MHz of UMTS 2100MHz spectrum
- 2×20MHz of LTE 2600MHz spectrum.

3G networks in Portugal currently carry significant volumes of mobile broadband (HSPA) traffic in their first and (more likely) second carriers; 4G networks carry only mobile broadband (LTE) traffic (since VoLTE has not yet been launched). Therefore, in the *pure BU-LRIC approach*, the 3G spectrum basic licence (2×20MHz) and the 4G ones (see Figure 4.2 below) are also not considered incremental to wholesale termination traffic volumes in the long run.

Figure 4.2: Spectrum awarded during the 2011 multiband auction, by operator [Source: ANACOM, 2011]

Spectrum bands	MEO	Vodafone	NOS
800MHz	2×10MHz	2×10MHz	2×10MHz
900MHz	-	2×5MHz	-
1800MHz	2×14MHz	2×14MHz	2×14MHz
2600MHz	2×20MHz	2×20MHz + 25MHz TDD	2×20MHz

Spectrum payments

The EC Recommendation states that only additional spectrum acquired to provide the wholesale termination service should be taken into account.[13] This is an extension of the EC's principles that only incremental costs of wholesale termination should be taken into account, with common costs excluded. This means that, in many cases, the amounts paid for spectrum would need to be excluded from any cost calculations. The majority of up-front auction fees or beauty-contest obligations in Portugal will have been incurred as a common cost, and thus fall outside the EC proposition.

There are four possible approaches for estimating the cost of 800MHz, 900MHz, 1800MHz, 2100MHz and 2600MHz spectrum applicable to the model:

- **Option 1** – reflect the actual amounts paid by operators for spectrum.
- **Option 2** – reflect the amount which could realistically be paid for spectrum, if the historical reality of spectrum payments had been different. This is mostly relevant in the cases where spectrum assigned through auction mechanisms has raised significant amounts. In such a case, an approach involving benchmarks from recent mobile frequency auctions in other countries could be used.
- **Option 3** – estimate the cost of spectrum from other public sources (not from auctions); for instance, it would be possible to use published price lists on the cost of spectrum, obtained from national regulatory agencies.
- **Option 4** – value the spectrum using an independent forward-looking estimate.

In the case where spectrum costs are estimated from benchmarks of auction prices or from other public sources, the information can be analysed according to five categories:

- paired 800MHz frequencies, for providing a 4G wide-area coverage layer
- paired 900MHz frequencies, typically reflecting the provision of a 2G wide-area mobile coverage
- paired 1800MHz frequencies, for providing 2G and 4G mobile capacity expansion
- paired 2100MHz frequencies, for providing mainly a 3G mobile broadband overlay network
- paired 2600MHz frequencies, for providing a 4G mobile broadband overlay network (mainly for capacity reasons).

We have considered from a theoretical perspective whether any 2G spectrum (and its associated cost) required extending the capacity of the network is sensitive to wholesale traffic termination, and its potential allocation to the wholesale termination service. We have concluded that there is a

13 Extract from the EC Recommendation: "*The costs of spectrum usage (the authorisation to retain and use spectrum frequencies) incurred in providing retail services to network subscribers are initially driven by the number of subscribers and thus are not traffic-driven and should not be calculated as part of the wholesale call termination service increment. The costs of acquiring additional spectrum to increase capacity (above the minimum necessary to provide retail services to subscribers) for the purposes of carrying additional traffic resulting from the provision of a wholesale voice call termination service should be included on the basis of forward-looking opportunity costs, where possible.*"

trade-off between the number of sites deployed and the spectrum owned by an operator. Indeed, each operator must find a balance between owning more spectrum and constructing more sites for capacity.

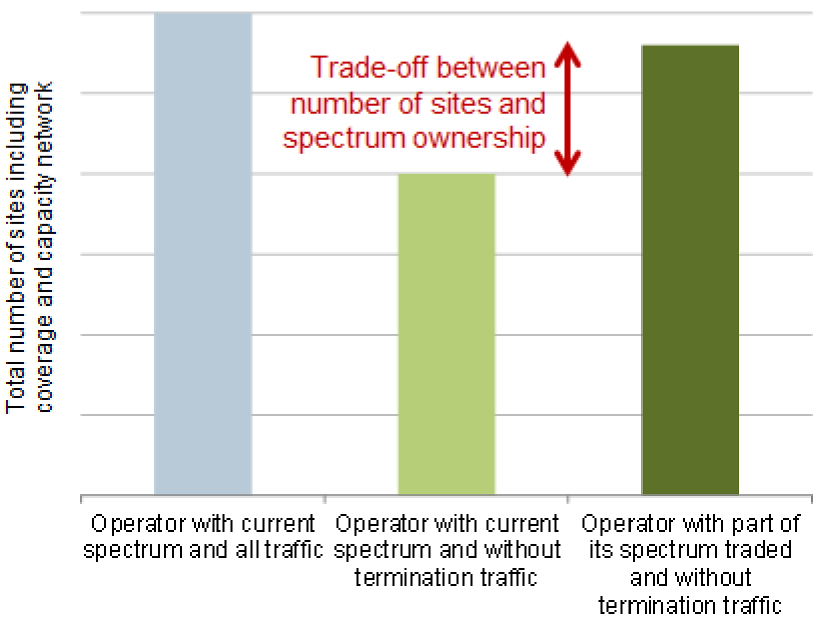


Figure 4.3: Number of sites required for a hypothetical operator for coverage and capacity in different scenarios [Source: Analysys Mason, 2017]

As illustrated in Figure 4.3, given a specific number of sites for an operator, the same operator deploying a network without the termination traffic would have two options:

- retain all of its existing spectrum holding and build a smaller number of sites to address coverage and capacity obligations
- trade part of this spectrum, but construct a larger number of sites with which to make up the capacity lost as a consequence of the spectrum reduction.

We have adopted the first of these two options, as the non-incremental nature of spectrum to wholesale voice termination makes spectrum payments irrelevant in Portugal.

Proposed Concept 6: 2G spectrum is considered non-incremental to wholesale termination traffic in the BU-LRIC model. This is consistent with the EC Recommendation, which states that only additional spectrum acquired to provide the wholesale termination service should be taken into account. Equally, neither 3G nor 4G spectrum is considered incremental in the pure LRIC model.

As such, the value of spectrum has no impact on the results of the pure LRIC model. For the sake of completeness and total costs (not pure LRIC results but LRAIC ones) we model actual amounts paid by Portuguese operators for spectrum in Portugal (including spectrum fees, that were updated to reflect the latest values paid by operators)

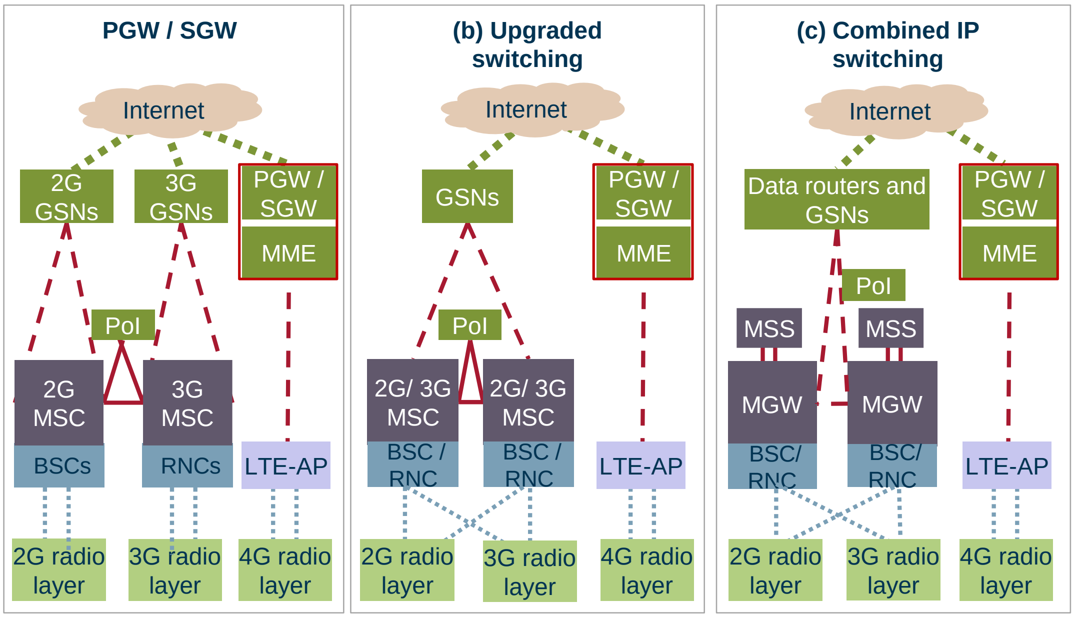
Switching network generation and technology

A single-technology radio network would employ either legacy (single-generation) switches or a next-generation switching structure. The switching network for a combined 2G+3G+4G radio network could be:

- separate 2G, 3G and 4G structures with separated transmission, each containing one or more interlinked mobile switching centres (MSCs), a GPRS serving node (GGSN and SGSN) and points of interconnection (PoIs)
- one upgraded legacy structure with a combined transmission network, containing one or more interlinked MSCs, GSNs and PoIs that are 2G- and 3G-compatible and a separate 4G structure
- a combined 2G+3G switching structure with a next-generation IP transmission network, linking pairs of MGWs with one or more MSSs, data routers and PoIs, separated into circuit-switched (CS) and packet-switched (PS) layers and a separate 4G structure.

The three options are illustrated below in Figure 4.4.

Figure 4.4: Architecture options within the mobile BU-LRIC model [Source: Analysys Mason, 2017][14]



Note: In 4G networks the functionalities of the BSC/RNC are distributed between the eNodeB (i.e. 4G radio layer) and the MME (i.e. 4G core network)

In all these options, 4G is considered as an additional layer working in parallel but separately because it is fully based on a packet-switched (PS) network, whereas both 2G and 3G networks are mainly based on a circuit-switched (CS) architecture (HSPA is a CS–PS hybrid network).

The EC Recommendation suggests that the switching network layer *"could be assumed to be NGN-based*". Mobile switching networks have been evolving for several years now (e.g. Release-99,

[14] For more details on the network equipment, please see Annex B.

Release-4); a new entrant today would deploy the latest technology, whilst actual operators are likely to have been upgrading their networks across these release versions.

Indeed, we are modelling a hypothetical operator, which would have deployed a switching network with the latest technology available at the time of launch. The modelled operator incurs the costs of an entire switching network in its launch years, rather than the ongoing upgrade costs experienced by actual players which have been in the market for many years. The relevant specification is *what type of technology would have been employed by an operator starting to deploy a network from 2005* as indicated in Proposed Concept 1. This operator would deploy the latest, most modern and 'future-proof' technology, consisting of combined IP switching for voice and data traffic. An old hierarchical MSC topology would rapidly become obsolete during the time the operator started its services. The choice of combined IP switching technology is further supported by the fact that at the time the hypothetical operator would have entered the market, the Portuguese operators had already started their migration to a combined IP switching network, which indicates that the modern technology was already available.

> **Proposed Concept 7**: We model 'Option C' above in Figure 4.4 (combined IP switching for voice and data traffic), which represents the most modern switching technology available in 2005 for an efficient operator. We do not model an old hierarchical MSC topology or a migration between technologies for the switching network.

Transmission network generation and technology

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

- base (transmitter) station (BTS) last-mile or (e)NodeB access to a hub
- hub to base station controller (BSC), radio network controller (RNC) or LTE aggregation point (LTE-AP)
- BSC, RNC or LTE-AP to main switching sites (containing MSC, MGW or SGW (serving gateway) if not co-sited
- between main switching sites (between MSC, MGW or SGW).

Typical solutions for providing transmission include:

- leased lines (E1, STM-1 and higher, 100Mbit/s and higher)
- self-provided microwave links (2, 4, 8, 16 or 32Mbit/s, STM-1 microwave links, Ethernet microwave)
- leased fibre network (leased/indefeasible right to use (IRU) dark fibre with either synchronous transfer mode (STM) or Gbit fibre modems)
- owned fibre network in leased ducts.

The choice of mobile network transmission will vary among the actual mobile operators and may change over time. An operator today would most likely adopt a scalable and future-proof fibre-based transmission network in urban areas (though the supply of this network may depend on the prevailing preferences of the operator), whereas in other parts of the country it would most likely use a typical technology mix based mainly on leased lines and microwave links.

The transmission backbone network is assumed to be composed of a national backbone (mostly to interconnect the core network sites) and a number of regional backbone rings to aggregate traffic from sites, BSCs, RNCs and LTE-APs.

It is reasonable to model a modern mobile network transmission architecture. In 2005, this implies a national fibre network backbone for collecting and carrying traffic back to the main switching sites and carrying traffic between the MSCs. The layered core network switches (MSS–MGW, SGW) would typically be based on Gbit/s IP interfaces. The choice between leasing managed STM/Gbit services and self-supply of transmission equipment is likely to vary depending on the strategic decisions and partnerships of each mobile operator (e.g. MEO is likely to lease managed services from its fixed division); however, we have modelled leased dark fibre with self-supplied transmission equipment.

We recognise that real operators use different mixes of leased lines, microwave and fibre in the backhaul part of their transmission networks. We have applied a mix of all those technologies in the model, as presented in Figure 4.5. This consists mainly of fibre complemented with microwave and leased lines for all geotypes.

Figure 4.5: Mix of backhaul technologies per 2G/3G/4G and geotype [Source: Analysys Mason, 2017]

Technology	Geotype	Leased lines	Microwave	DSL	Fibre	Co-location
2G	Dense urban	-	-	10.0%	90.0%	-
	Urban	-	12.5%	1.0%	86.5%	-
	Suburban	2.5%	13.5%	2.0%	82.0%	-
	Rural	2.5%	32.5%	2.5%	62.5%	-
	Indoor	20.0%	-	-	80.0%	-
3G	Dense urban	-	-	10.0%	90.0%	-
	Urban	2.5%	12.5%	1.0%	84.0%	-
	Suburban	2.5%	18.5%	2.0%	77.0%	-
	Rural	2.5%	25.0%	2.5%	70.0%	-
	Indoor	20.0%	-	-	80.0%	-
4G	Dense urban	-	10.0%	-	90.0%	-
	Urban	2.0%	15.0%	-	83.0%	2.0%
	Suburban	2.5%	17.5%	-	80.0%	2.5%
	Rural	5.0%	25.0%	-	70.0%	5.0%
	Indoor	20.0%	-	-	80.0%	20.0%

Proposed Concept 8: We model a national fibre network backbone for collecting and carrying traffic back to the main switching sites and carrying traffic between the MSCs.

The backhaul transmission technology of the efficient operator is modelled as consisting mainly of fibre complemented with microwave and leased lines for all geotypes.

4.2 Network nodes

Mobile networks can be considered as a set of nodes (with different functions) and links between them. When developing deployment algorithms for these nodes it is necessary to consider whether an algorithm accurately reflects the actual number of nodes deployed. The model may be allowed to deviate from the operator's actual number of nodes in the situation where the operator's network is not viewed as efficient or modern in design.

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

Actual network	This approach implements the exact deployment of the real operator without any adjustment to the number, location or performance of network nodes.
Scorched-node approach	This assumes that the historical (number of) locations of the actual network node buildings are fixed, and that the operator can choose the best technology to configure the network at and in between these nodes, to meet the optimised demand of an efficient operator.
Modified scorched-node approach	The scorched-node principle can be reasonably modified in order to replicate a more-efficient network topology than is currently in place. Consequently, this approach takes the existing topology (by node type and number) and applies modifications. In particular, using this principle can mean simplifying the switching hierarchy and changing the functionality of a node (for instance, removing remote BSCs at hub sites and using BSCs co-located with MSCs).
Scorched-earth approach	The scorched-earth approach determines the efficient cost of a network that provides the same services as actual networks, without placing any constraints on its network configuration. It assumes that the network can be perfectly redesigned to meet current criteria. A scorched-earth model may not be very closely related to the actual networks of the operators and could reflect a scenario which might not be realistically achievable (e.g. it may not account for the geography, some buildings may not be fit to host base stations, etc.). At the same time, this approach may introduce a significant amount of complexity to the model (e.g. precise co-ordinates

for each node may be required), and as a result the model may inaccurately calculate the resulting network costs.

We have used a modified scorched-node approach for modelling of the number and type of nodes in mobile networks. This ensures that the network design is modern and reasonably efficient, reflecting, for example, the modern approach to deploying equipment functionality at different nodes in the network. Therefore, we have used the actual node counts of the existing operators, adapted with the functionality relevant to modern network equipment.

When adapting the network design to modern network equipment, two additional elements have to be taken into account:

- a calibration process which aims to ensure the model produces sensible results, even if we do not aim at a strict concordance with existing operator results, which are influenced by historical deployments
- a degree of infrastructure sharing that is compatible with the current situation in Portugal.

Proposed Concept 9: We apply a modified scorched-node approach, incorporating reasonably efficient levels of network deployment and network sharing.

4.3 Dimensioning of the network and impact of data traffic

At a high level, operators dimension their mobile networks based on the expected traffic loading during the busy hour. The number of Erlangs that the network will have to support in the busy hour drives the deployment of the switching network, the network nodes and the number of radio sites.

Traditionally, mobile networks have been dimensioned on the basis of voice traffic in the voice busy hour, because voice was the main factor that determined network load.

However, the roll-out of new technologies such as HSPA (and more recently LTE) and the resulting increase in data consumption have forced mobile operators to rapidly adapt their networks to meet the requirements of higher data traffic.

Mobile operators will follow different strategies based on their specific characteristics and strategic priorities, and this will influence how their network is dimensioned and how traffic is managed.

The network has been modelled and dimensioned by taking into account both voice and data traffic:

- For 2G data, a GPRS channel per sector is reserved exclusively for data transport
- For 3G, separate carriers have been assigned to R99 voice, SMS and data, and HSPA, while the rest of the carriers are used exclusively for data traffic
- For 4G, all traffic currently carried over LTE is data; no prioritisation is assumed for VoLTE traffic when it is launched, in light of the large capacity offered by this new radio access technology.

In all of these three cases we ensure that the reserved spectrum has enough capacity to cope with the existing data traffic requirements for each of the geotypes.

Proposed Concept 10: We dimension the hypothetical existing operator's network on the basis of both voice traffic and data traffic requirements. The 2G network is dimensioned based on voice traffic in the busy hour while reserving a GPRS channel per sector exclusively for data transportation; the 3G network is dimensioned by assigning a carrier for R99 voice, SMS and data, and HSPA in the busy hour, while the rest of the carriers are exclusively used for data transportation; the 4G network is dimensioned based on Mbit/s of traffic (voice, SMS and data) in the data busy hour. In all of the three cases, we ensure that the reserved spectrum has enough capacity to cope with the existing data traffic requirements for each geotype. In layers of the network where serving aggregate traffic is critical (e.g. in the transmission core), it is likely that the driver of network capacity is the combined voice plus data traffic peak load. Core switches may serve voice and data traffic separately (e.g. MSS and GGSN).

5 Service issues

This section discusses the following issues:

- the set of services that need to be included in the model (Section 5.1)
- the evolution of traffic volumes (Section 5.2)
- the rate of migration of voice from legacy to modern technologies (e.g. 2G to 3G, but also 3G to 4G and 2G to 4G; Section 5.3)
- the scope of wholesale/retail costs (Section 5.4).

5.1 Service set

A full list of services must be included in the model, as a proportion of network costs will need to be allocated to these services. This implies that both end-user and wholesale voice services need to be modelled, so that the network is correctly dimensioned, costs are fully recovered from the applicable traffic volumes, and the 'pure' termination LRIC increment can be correctly modelled.

Figure 5.1 contains a more detailed list of the services that are included in the model.

Mobile services
2G, 3G and 4G: Outgoing to on-net, international, fixed and other mobile operators
2G, 3G and 4G: Incoming from on-net, international, fixed and other mobile operators
2G, 3G and 4G: Roaming in origination and termination
2G, 3G and 4G: SMS on-net, outgoing and incoming
MMS
2G packet data (GPRS / EDGE)
3G packet data (Release-99)
3G packet data (HSDPA, HSUPA)
4G packet data (LTE)

Figure 5.1: List of services included in the model [Source: Analysys Mason, 2017]

The traffic profile of the hypothetical existing operator reflects the market average: we have used a hypothetical modelled operator with a traffic profile equal to the average of the market for each service, calculated from data provided by ANACOM. The shape of traffic will remain constant, although total volumes will grow as indicated in Proposed Concept 12.

Different services can be delivered through different networks. Voice and SMS/MMS traffic are carried on the 2G, 3G and 4G networks based on the profile of migration defined in Proposed Concept 13. Voice services over 4G networks will be provided as VoIP traffic (namely VoLTE). The majority of data traffic (low-speed data traffic can be carried over 2G as well) is used to calculate the dimensioning process for the 3G and 4G networks, as it is the key driver in 3G and 4G capacity deployments.

For the dimensioning of the network we have defined a set of conversion factors (which measure the relative use of traffic units of different services) to convert traffic conveyed during the busy hour to busy-hour Erlangs (BHE). Similarly, the conversion factors defined are used to convert all traffic to a common unit (equivalent megabytes) in order to allocate costs to services.[15]

Proposed Concept 11: The service set included in Figure 5.1 is modelled.

5.2 Traffic volumes

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

Given our proposal to adopt an operator with a specified hypothetical market share, the hypothetical existing operator is expected to route the market-average traffic profile.

The average long-term voice traffic per subscriber is assumed to reach 1537 minutes per year in 2025, which is consistent with current market figures and international benchmarks. Wholesale mobile termination traffic (total incoming traffic excluding on-net) is assumed to stabilise in the long term at 19.3% of total mobile voice traffic, in line with current Portuguese figures. A share of incoming traffic equal to 19.3% might appear somewhat low, in light of the modelled operator's market share (initially reaching 20% and eventually 33.3%); moreover, a stable value over time could appear unreasonable. However, the proportion of incoming traffic is relatively homogenous among Portuguese operators, despite large differences in actual market shares. Finally, uncertainty regarding subscriber behaviour makes it difficult to predict the potential evolution of termination traffic as a proportion of total traffic. We therefore maintain a broadly constant proportion of termination traffic over time, which we believe is a plausible and neutral solution.

Figure 5.2 reports the average monthly data traffic per handset and mobile broadband (e.g. dongles, datacards) subscriber for both high-speed 3G and 4G at the end of 2016; these numbers have been calculated from the data published by ANACOM[16] and are comparable with average data traffic per subscriber observed in a number of other European countries. Average data consumption on both uplink (assumed to be 15% of total data traffic) and downlink is assumed to remain constant over the time period of the model, to reflect the uncertainty in the long-term evolution of this traffic.

Figure 5.2: Monthly data traffic per subscriber in 2016 [Source: Analysys Mason elaboration on ANACOM's data, 2017]

Monthly data traffic per subscriber (2016)	Average (DL+UL)
Handset	861MB
Datacard / dongle	9198MB

15 This step is needed in a LRAIC calculation, but not in a *wholesale-termination-only pure LRIC* calculation.

16 Data is publicly available at http://www.anacom.pt/render.jsp?categoryId=520&tab=337754.

It is assumed that the average data consumption will continue to grow both as a result of the migration to 4G and of an increased data usage of 3G SIMs that do not migrate. The average handset data consumption is assumed to reach 3547MB in 2025.

The development of a BU-LRIC model involves a traffic forecasting exercise. We use a traffic forecast that is based on historical information – population, mobile penetration and traffic – provided by the Portuguese operators to ANACOM, as well as on other sources to which a rate of growth has been applied (deduced from forecasts provided by various analysts, such as Analysys Mason Research, GSMA, ITU, EIU or Euromonitor). We assume that all market variables will stabilise after 2025 – including market share, voice and data consumption, etc.

Proposed Concept 12a: The forecast voice traffic profile for the modelled operator is based on the current market-average usage, reaching 1537 minutes per year in 2025, of which around 19.3% is wholesale termination traffic. We have ensured that the forecasts are based on the latest data that the Portuguese operators have made available to ANACOM.

Proposed Concept 12b: The forecast data traffic for the modelled operator is based on the current market-average usage, reaching 3547MB per annum in 2025 for handset users. We have ensured that the forecasts are based on the latest data that Portuguese operators have made available to ANACOM.

5.3 Migration of traffic from legacy mobile generations to the more modern ones

The previous version of the mobile termination cost model already encompassed and modelled the migration of traffic from the 2G radio network to the 3G radio networks. The relatively recent commercial launch of 4G services has added further complexity, which requires a number of factors to be taken into account:

- The voice traffic migration can occur from 2G to 3G, from 3G to 4G and from 2G to 4G
- 4G technologies are IP-native, and then voice traffic has to be routed throughout 4G networks as VoIP (VoLTE for LTE).

Therefore, the migration percentages are the result of many factors, including:

- An increasing number of 3G and 4G phones used on the network (although 4G phones also make 3G calls, and 3G phones also make 2G calls)
- The influence that 3G and 4G device prices have on consumers' decision to migrate to a more modern generation (in light of the current macroeconomic context).

This suggests that the migration of traffic from legacy mobile generations to the more modern ones could follow a number of strategic scenarios ('options') for mobile operators:

- **Option 1 –** maximise investments made in the past for the 2G (and 3G) networks by operating them for as long as possible, delaying expansion of the 3G (and 4G) networks for as long as possible
- **Option 2 –** favour a rapid migration to 3G and 4G networks, to seek refarming of 2G spectrum at an earlier date
- **Option 3 –** migrate progressively from the 2G (and 3G) networks to the 3G (and 4G) networks, allowing amortisation of the 2G (and 3G) network coupled with the development of new services based on the 3G (and 4G) network.

A distinction has to be made between the voice and data traffic generated by a subscriber and the network that actually carries it. For example, the traffic generated by a customer who subscribes to 4G services and owns an LTE-capable handset is not necessarily carried by the 4G network; this traffic can indeed fall back to 3G or even to the 2G network. Therefore, the loading of the 4G network depends on two variables: the number of 4G-enabled SIMs and the percentage of their traffic that is effectively carried over the LTE network. Accordingly, the loading of the 3G network includes a quota of traffic generated by 4G subscribers.[17]

There are three main reasons why traffic might fall back onto lower-generation networks:

- **Coverage gaps** – There are coverage differences among the networks, with 2G able to provide a national coverage layer to ensure the provision of basic voice services. For instance, whenever the signal reception is weak or absent a 4G subscriber is automatically connected to the strongest available signal, regardless of the technology of the SIM card installed
- **Device availability** – Mobile users may not have a handset which is capable of supporting a particular technology, despite having an enabled SIM installed; for instance, there still is a large share of 2G handsets in the market that is not able to connect to the 3G network, and some of the handsets that are sold today are not VoLTE capable. For instance, there is still a considerable amount of handset sales that are basic phones without smartphone capabilities (around 20% for 2017)
- **User experience / capex efficiency** – Mobile operators are interested in maximising the user experience offered to their customers. Depending on their network loading, operators might decide that a certain share of traffic needs to fall back onto other networks in order to avoid overloading capacity-constrained cells. This also enables operators to limit the capex needed to increase capacity on the constrained network, through better utilisation of the capacity already installed for other technologies.

17 The same point also applies to traffic from 4G and 3G subscribers being carried over 2G networks. However, the converse is not true: that is, the traffic generated by 2G subscribers cannot be carried over 3G or 4G (and nor can 3G subscribers have their traffic carried on a 4G network), due to both commercial reasons and device compatibility issues.

In light of the above considerations, we have modelled network traffic used for dimensioning in two steps.

1 Forecast a migration of subscribers from 2G to 3G and to 4G. We have forecast the take-up of 4G in Portugal to be in line with similar European countries, attaining 50% of total subscribers by the end of 2019. In contrast, the 3G share of subscribers is assumed to grow until 2016 and then to start declining, to 20% of the total number of SIMs at the end of 2019.

2 Assume a percentage of voice, messaging and data traffic generated by each subscriber category being carried by 2G, 3G and 4G networks, as per Figure 5.4 below. The option of migrating voice traffic onto the 4G network is also dependent on the roll-out of a VoLTE platform (which is needed for the network to manage IP-native voice traffic).

VoLTE is still somehow a nascent technology, and it is debatable whether it should be included in the mobile termination cost modelling. As a general rule, since it is a new technology, a conservative deployment should be considered. To date, only Vodafone has deployed the technology in Portugal, and so most voice traffic generated by LTE subscribers is carried over 2G and 3G. However, it appears reasonable to assume that VoLTE will be launched by the Portuguese mobile operators in the next years in light of a number of factors:

- Comparatively (with respect to comparable countries, e.g. Western European ones) early launch and take-up of LTE
- Commercial reasons (e.g. HD voice service offerings)
- Higher spectral efficiency of VoLTE with respect to traditional voice, allowing free-up additional spectrum for data[18].

- Based on a 2Q 2017 benchmark, in most Western European countries more than one operator has already launched VoLTE services

In this context, we believe that VoLTE should be included in the updated version of the model, and we assume that the hypothetical existing operator will roll out the technology at the beginning of 2020, since an imminent (i.e. 2018) launch seems unlikely for the Portuguese operators that have not rolled out VoLTE yet.

The EC's 2009 Recommendation made no reference to 4G voice; however, in its March 2015 final decision on the update of the MTR model in the UK, Ofcom explained the inclusion of VoLTE in light of the following points:[19]

- Even though the EC Recommendation did not make any reference to VoLTE, it explains that the cost model "*should be based on efficient technologies available in the timeframe considered*

18 This step implies the 1800 MHz spectrum refarming (from GSM to LTE).

19 Ofcom, *Mobile call termination market review 2015-18*, 18 March 2015, available at http://stakeholders.ofcom.org.uk/binaries/consultations/mobile-call-termination-14/statement/MCT_final_statement.pdf.

by the model" and VoLTE can be considered as an "*efficient technology available in the timeframe considered by the model*", as envisaged by the 2009 EC Recommendation

- Based on stakeholder responses to the June 2014 Consultation, it is appropriate to include VoLTE technology in the 2015 MCT model, as there was evidence of VoLTE being deployed by the MCPs during the control period.

Several European mobile operators have already launched VoLTE as seen in Figure 5.3 below.

Figure 5.3: Status of VoLTE in selected Western European countries [Source: Analysys Mason Research, 2017]

Operator	Country	Status	Launch date
A1	Austria	Launched	November 2015
Proximus	Belgium	Launched	November 2016
TDC	Denmark	Launched	December 2014
Telenor	Denmark	Launched	November 2015
Elisa	Finland	Launched	Nov 2016
DNA	Finland	Launched	Mar 2015
Bouygues	France	Launched	Nov 2015
Orange	France	Launched	Jan 2016
T-Mobile	Germany	Launched	Jan 2016
Telefónica (O2)	Germany	Launched	Apr 2015
Vodafone	Germany	Launched	May 2015
T-Mobile	Hungary	Launched	Apr 2017
TIM	Italy	Launched	Dec 2015
Vodafone	Italy	Launched	Jul 2015
KPN	Netherlands	Launched	Nov 2016
T-Mobile	Netherlands	Planned for 2H 2017	
Tele2	Netherlands	Launched	Mar 2016
Vodafone	Netherlands	Launched	Nov 2016
Telia	Norway	Launched	Oct 2016
Telenor	Norway	Launched	Nov 2015
T-Mobile	Poland	Launched	Nov 2016
Vodafone	**Portugal**	**Launched**	**Sep 2015**
Orange	Spain	Launched	Nov 2016
Telefónica (Movistar)	Spain	Launched	Mar 2017
Vodafone	Spain	Launched	Jul 2015
Tele2	Sweden	Planned 2H 2017	
TeliaSonera	Sweden	Launched	Apr 2017
Swisscom	Switzerland	Launched	Jun 2015
EE(BT)	UK	Launched	Feb 2016
Telefónica (O2)	UK	Launched	Mar 2017
Vodafone	UK	Launched	Soft launch May 2017

The rate of adoption of VoLTE services largely depends on the availability of compatible handsets, as explained above. Most of the devices currently available in the market already support VoLTE (all main hardware vendors such as Samsung, Apple, LG, HTC, Xiaomi have mid-range devices with VoLTE). Therefore, the rate of adoption of VoLTE will depend on the increase of smartphone penetration in Portugal.

In light of these points we assume that an operator will be able to migrate 40% of the voice (and messaging) traffic generated by its 4G subscribers to VoLTE two years after the commercial launch (i.e. in 2022). This share is projected to continue increasing over time.

Figure 5.4: Percentage of voice and messaging traffic assumed to be carried by each network (2G, 3G and 4G) in 2025 [Source: Analysys Mason, 2017]

	Voice			Messages		
	2G network	3G network	4G network	2G network	3G network	4G network
2G subs	100.0%	-	-	100.0%	-	-
3G subs	10.0%	90.0%	-	10.0%	90.0%	-
4G subs	13.8%	11.3%	74.9%	13.8%	11.3%	74.9%

The share of data traffic generated by 4G subscribers that is carried by the 4G network is assumed to increase over time along with the increase in coverage and availability of LTE-capable handsets. As shown in Figure 5.5, however, we do not expect this share to reach 100%.

Figure 5.5: Percentage of data traffic assumed to be carried by the network assumed in the model in 2025 [Source: Analysys Mason, 2017]

	Low-speed data			High-speed data		
	2G network	3G network	4G network	2G network	3G network	4G network
2G subs	100%	-	-	-	-	-
3G subs	-	100%	-	-	100%	-
4G subs	-	-	-		5%	95%

Proposed Concept 13a: We understand that the overall strategy of existing operators in Portugal is to migrating traffic from 2G to 3G and to 4G progressively. Hence we modelled the hypothetical existing operator to follow a similar migration path as that described in Option 3.

Proposed Concept 13b: We model a hypothetical existing operator which migrates 50% of the subscriber base and 91% of high-speed data traffic (i.e. HSPA and LTE) to 4G by 2019.

Proposed Concept 13c: We assume the commercial launch of VoLTE in 2020 and model a migration that reaches 40% of the voice and messaging traffic generated by 4G subscribers in 2022 (two years later).

5.4 Wholesale or retail costs

The BU-LRIC model is intended to calculate the costs of a wholesale market. As such, we consider only those costs that are relevant to the provision of the wholesale network termination service.

When developing the model, we have considered all incremental costs that are associated with the provision of wholesale termination traffic services and that are incremental to wholesale traffic at the margin (i.e. avoidable). For instance, the billing platform is likely to be driven by the number of call data records (CDRs) it can handle on a single day. If the addition of wholesale termination traffic means that the billing platform needs to be upgraded, the resulting avoidable costs will be taken into account when calculating the MTR. The model also includes the regulatory fees that operators have to pay to ANACOM on an annual basis, consistently with what has been implemented in the fixed interconnection model. All retail costs have been excluded.

Proposed Concept 14: Only wholesale network costs are included. Retail costs are excluded. We consider all incremental costs that are associated with the provision of wholesale termination traffic services and that are incremental to wholesale traffic (i.e. avoidable). Common business overheads costs are not added to the cost of termination in the pure LRIC approach because they are common costs which do not vary with the increment of wholesale termination.

6 Implementation issues

This section presents a number of implementation issues that need to be considered:

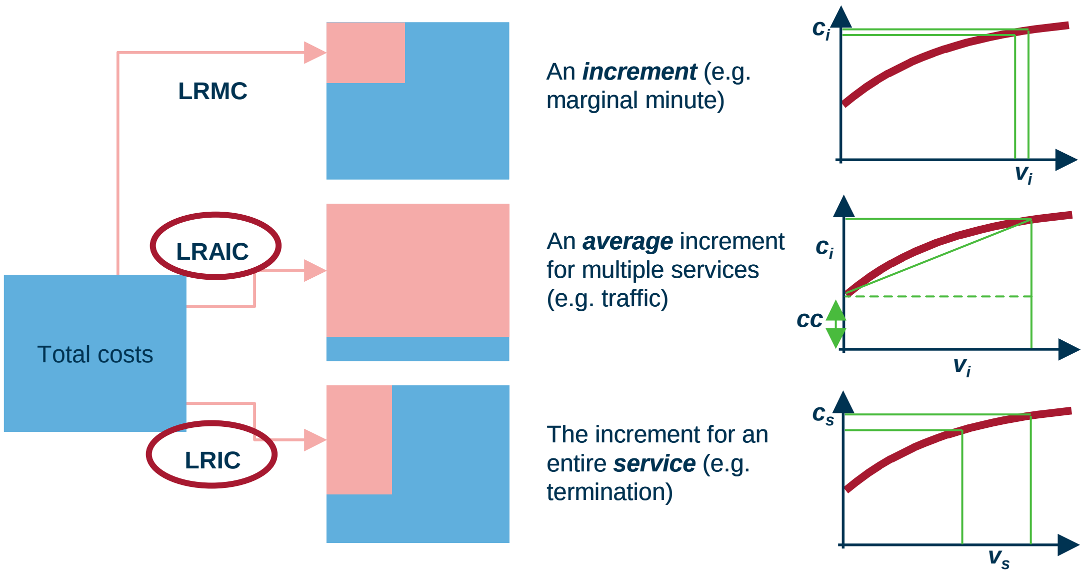
- choice of service increment (Section 6.1)
- depreciation method to be applied (Section 6.2)
- WACC to be applied (Section 6.3).

6.1 Choice of service increment

The long-run incremental cost of an 'increment' of demand is the difference between the total long-run cost of a network which provides all service demand including the increment, and a network which provides all service demand except the demand of the specified increment.

Three common incremental cost approaches are illustrated in Figure 6.1 below.

Figure 6.1: Increment approaches [Source: Analysys Mason, 2017]



Long-run incremental costing (LRIC, which we describe as 'pure' LRIC in the case recommended by the EC where common costs are not included) is consistent with the May 2009 Recommendation, which considers the increment to be all traffic associated with a single service. Based on the avoidable cost principle, incremental costs are defined as the costs which are avoided when not offering the service. By building a bottom-up cost model which contains network design algorithms it is possible to use the model to calculate the incremental cost: by running it with and without the increment in question, and thus it is possible to determine the cost increment.

The voice termination unit costs are then calculated by dividing that cost increment by the total service volume (see Figure 6.2).

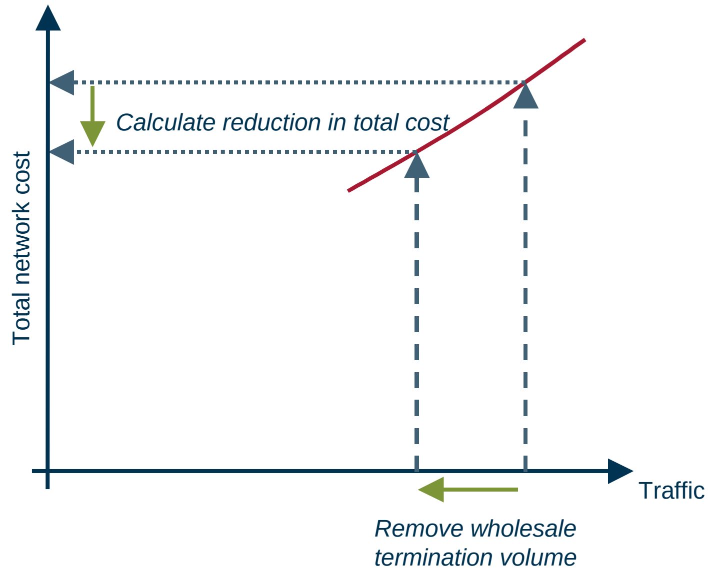


Figure 6.2: Calculation of the incremental cost of termination traffic [Source: Analysys Mason, 2017]

In the working document which accompanied its May 2009 Recommendation, the EC noted (at page 14) the following: *"In practice, the majority of NRAs have implemented LRIC models which are akin to LRIC+ or a fully allocated cost (FAC) approach, resulting in an allocation of the whole of a mobile operator's cost to the different services"*. The EC goes on to argue that (pure) LRIC is a more appropriate approach to calculate the cost of termination services.

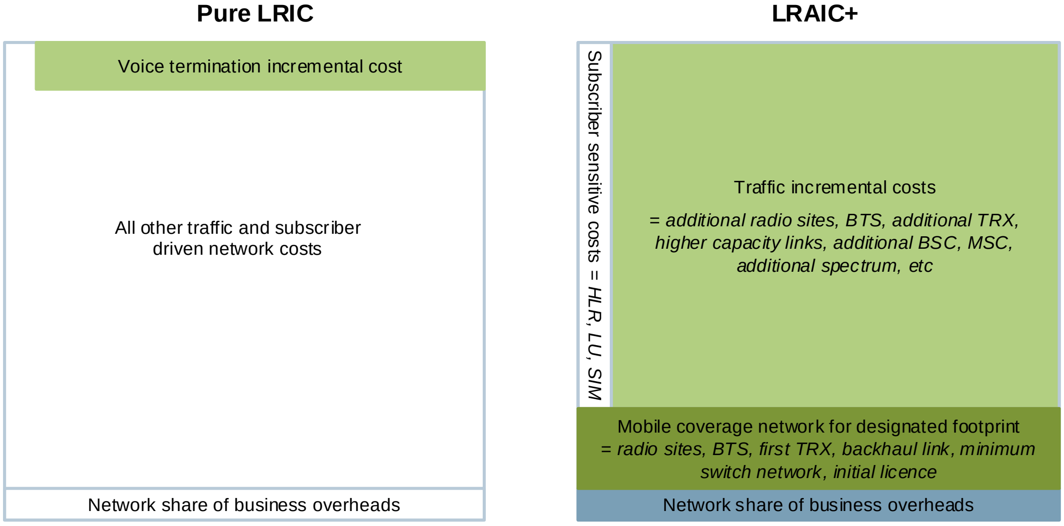
The *pure BU-LRIC* approach is consistent with the EC Recommendation of May 2009, which specifies the following approach for the calculation of the incremental costs of wholesale mobile termination:

- The relevant increment is the wholesale termination service, which includes only avoidable costs. Its costs are determined by calculating the difference between the total long-run costs of an operator providing all services and the total long-run costs of an operator providing all services except voice termination.
- Non-traffic related costs, such as subscriber-related costs, should be disregarded.
- Costs that are common, such as network common costs and business overheads, should not be allocated to the wholesale voice termination increment.

In light of this approach, when developing the model we considered all the incremental costs that are associated with the provision of wholesale voice termination traffic services. This has been taken into account in the modelling exercise through the implementation of the algorithm specified in Proposed Concept 15.

In Figure 6.3 below, the area shaded green on the left-hand side of the diagram illustrates the costs included in the unit cost of voice termination traffic in the pure LRIC methodology; by way of comparison, the coloured areas on the right-hand side represent the costs included in the LRAIC+ methodology.

Figure 6.3: Pure LRIC and LRAIC+ cost allocations (LRAIC+ for comparison purposes) [Source: Analysys Mason, 2017]



The model calculates LRAIC+ results (for information only), in addition to pure LRIC.

It is also important to note that the model represents an operator with long-run levels of utilisation for its network elements (rather than short-run utilisations), reflecting the average utilisation levels that efficient operators may have in their networks in order to cope with current and foreseeable increases in traffic demand. In this context, the wholesale termination increment is a ‘long-run’ increment rather than a short-run increment; therefore, on average it will reflect the long-run utilisation, rather than the short-run under-utilisation which occurs at various/ongoing times in the network.

In addition, the operator does not deploy its network instantaneously; instead, for each element a planning period algorithm is defined and implemented in the model (representing the time between the initial decision to deploy a new network element and its effective activation). This algorithm ensures that network elements are deployed following a realistic schedule to meet the operator’s traffic demand needs.

Proposed Concept 15: Pure LRIC as required by the EC Recommendation is modelled. LRAIC+ is also modelled for information purposes.

6.2 Depreciation method

There are four main potential depreciation methods for defining cost recovery:

- historical cost accounting (HCA) depreciation
- current cost accounting (CCA) depreciation
- tilted annuities
- economic depreciation.

Economic depreciation is the recommended approach for regulatory costing. Figure 6.4 shows that only economic depreciation considers all potentially relevant depreciation factors that should be taken into account when developing a regulatory cost model.

Figure 6.4: Factors considered by depreciation methods [Source: Analysys Mason, 2017]

	HCA	CCA	Tilted annuity	Economic
MEA cost today		✓	✓	✓
Forecast MEA cost			✓	✓
Output of network over time			-[20]	✓
Financial asset lifetime	✓	✓	✓	✓[21]
Economic asset lifetime			✓	✓

The primary factor in the choice of a depreciation method is whether the network output is changing over time. In a mobile network, traffic volumes have risen significantly over recent years and mobile broadband volumes are currently growing strongly. Accordingly, tilted annuities may produce a significantly different result from that obtained when using economic depreciation. Furthermore, the EC recommends that economic depreciation be used wherever feasible.

Having previously built several regulatory models similar to the one considered in this Concept Paper, we believe it is important to understand the implications of using economic depreciation in a pure LRIC calculation and the potential problems that might be caused by its use. One potential problem arises when the avoidable increment of demand is not a uniform proportion of the demand over time. This situation may result in (undesirable) increased inter-temporal effects, which means that although costs may be (overall) lower without wholesale voice termination, cost recovery is also moved in time according to the profile of demand without wholesale termination applying to each network element. With data services more important in the later years, this can mean that unconstrained economic costs without wholesale termination are postponed further into the future relative to the all-service calculation. As such, unconstrained pure incremental costs can be very low in later years.

To avoid this, our approach to pure LRIC is calculated from the (net present value) difference in network expenditures arising from the removal of the wholesale voice termination traffic, constrained over time so that the underlying equipment price trends apply also to the pure LRIC components of cost. It is reasonable that the calculated pure LRIC is directly constrained by the underlying equipment price trends. We calculate this constrained pure LRIC of wholesale termination using economic depreciation, as illustrated in Figure 6.5.

20 An approximation for output changes over time can be applied in a tilted annuity by assuming an additional output tilt factor of x% per annum.

21 Economic depreciation can use financial asset lifetimes, although strictly speaking it should use economic lifetimes (which may be shorter, longer or equal to financial lifetimes).

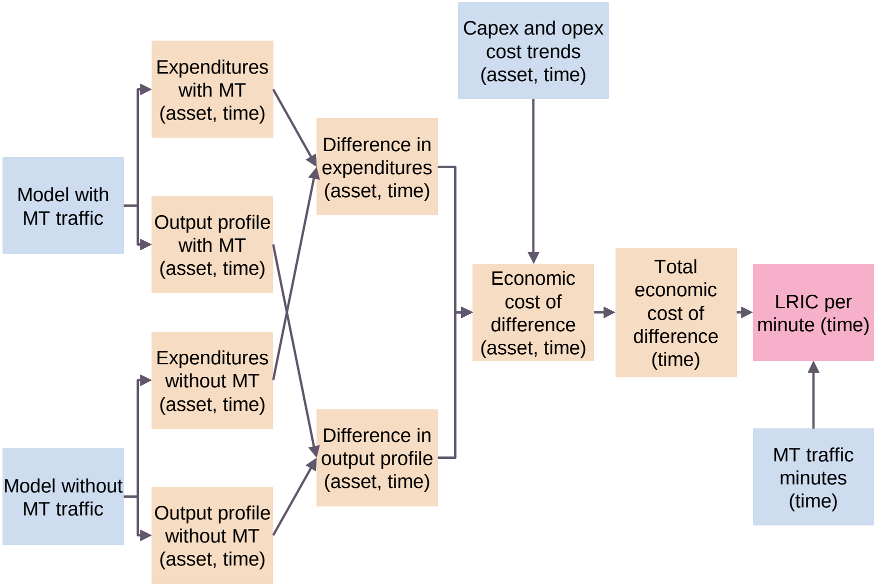


Figure 6.5: Application of economic depreciation to the pure LRIC of mobile termination (MT) [Source: Analysys Mason, 2017]

In order to give a better view of the economic depreciation algorithm, we have included an illustrative example in Annex A.

Time series

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

- allows the consideration of all costs over time, providing the greatest clarity within the model as to the implications of adopting economic depreciation
- provides greater clarity as to the recovery of all costs incurred from services
- provides a wide range of information with which to understand how the costs of the modelled operator vary over time and in response to changes in demand or network evolution
- can also include additional forms of depreciation (such as accounting depreciation) with minimal effort.

The timeframe can be equal to the lifetime of the operator, allowing full cost recovery over the entire lifetime of the business. However, the lifetime of an operator is impractical to identify. Hence, we would propose that the timeframe should be at least as long as the longest asset lifetime used in the model.

In the case of mobile BU-LRIC models developed by other NRAs in the past, the longest asset lifetimes have often been set to 20–40 years (e.g. for sites, switch buildings and fibre infrastructure), so a modelling timeframe of 40 years is often used in order to reflect at least one full period of a long-lived asset. A longer time period also ensures that any terminal value becomes negligible and can potentially be ignored.

If we were to assume a zero terminal value after a much shorter period (e.g. 20 years), this would:

- increase the costs of wholesale voice termination charges by a material amount, given the remaining long-life capex still to be recovered at that point
- allow the operators to effect a cost-free exit from the market at that point (all expenditures having been fully recovered)[22]
- imply that the value of the business was zero beyond 20 years.

As such, modelling full cost recovery within a relatively short period (e.g. 20 years) would in our view involve an overly conservative assessment of the risk of obsolescence, and would not reflect the shareholder value and investment incentives for long-term presence in the market.

A 45-year LRIC model is not intended to forecast accurately and precisely over such a long period of time (e.g. about technology evolution and traffic forecasting). This will be an uncertain exercise due to new technology developments, the introduction of new services, changing consumer behaviours, etc.

We model a 'steady state' for the market from 2025 onwards, which ensures that cost recovery can continue in perpetuity, subject to ongoing MEA equipment price declines and the WACC.

The extended time period allows for the full recovery of all investments as well as removing the need for a terminal value of the business (which would itself also require assumptions on revenue and cost growth rates).

We therefore believe that a model with a timeframe of 45 years, which forecasts the development of the Portuguese market up to 2025 and assumes a steady state thereafter, and adopts an economic depreciation methodology is reasonable for the next regulatory review period and will reduce the potential effect of unforeseeable market evolution after 2025.

Proposed Concept 16: Economic depreciation is applied to the wholesale voice termination incremental expenditures; this is the same methodology applied and accepted in other pure LRIC models developed by Analysys Mason and recommended by the EC.

Proposed Concept 17: The model uses a timeframe of 45 years in order to reasonably calculate the costs of long-lived assets, and ignore any remaining terminal value thereafter. A timeframe of 45 years also corresponds to three complete 15-year spectrum licences, which is consistent with the current duration of individual spectrum usage licences in Portugal. The model forecasts the situation for the Portuguese market up to 2025 and defines a steady state for the market from that year onwards, thus minimising the potential effect of market evolution once steady state is reached.

6.3 WACC

The cost model requires a cost of capital (WACC) to be specified.

22 i.e. 20 years before with respect to an exit after a 40-year period.

ANACOM has consulted upon the cost of capital for MEO. There are a number of documents that are of particular relevance to the BU-LRIC project:

- ANACOM's Decision regarding the methodology to be used in the determination of MEO nominal WACC[23]
- ANACOM's Decision on the value of WACC for MEO for 2017[24]:

These documents refer to the fixed telecoms business, not pure mobile business. Nevertheless, our review of these documents suggests that the methodology set is based on standard best practice, and it was straightforward to adapt this methodology for the BU-LRIC project. The main requirement was to select a group of benchmark 'pure play mobile' operators to replace the set of fixed operators used to establish a representative equity beta and optimal gearing. The approach followed is the same as in the previous version of the model.

We decided to maintain the 'pure play mobile' benchmark sample defined in the previous iteration of the model, i.e. MTS, Mobistar, Telenor ASA, TeliaSonera AB, Vodafone Group and Mobile Telesystems OJSC.

The WACCs of the mobile businesses of MEO, Vodafone and NOS (if it were possible to measure these directly) are inevitably different from one another, because of variations in effective tax rates, company beta and gearing ratios among the operators, and because of different mixes of products sold and market segments addressed. However, because we are modelling a hypothetical operator the BU-LRIC model uses a single WACC, rather than specific individual WACCs for each of MEO, Vodafone and NOS.

Regarding the value of WACC over time, although a constant WACC for 45 years is unrealistic, it is not reasonable to try to calculate the WACC for each of the 45 years. As explained in other parts of this document, we must ensure that the model produces coherent and consistent results for the next regulatory period: this means that calculation of the WACC has to take into account information that is available regarding this period, typically two or three years.

The model works in real, pre-tax terms (as opposed to nominal, post-tax terms, which is the convention employed for statutory financial purposes).

Therefore, the proposed WACC is suitable for determining a single pre-tax WACC for the hypothetical existing Portuguese mobile operator.

Proposed Concept 18: The model simulates the effect of inflation by expressing costs and revenues in real (inflation-adjusted) terms and using the corresponding 'real terms' WACC.

23 Available at https://www.anacom.pt/render.jsp?contentId=1184468

24 Available at https://www.anacom.pt/render.jsp?contentId=1413470

Proposed Concept 19: The model includes a 'pre-tax' WACC.

Proposed Concept 20: The 'pre-tax' WACC is determined using the same methodology as in the 2014 model update: an analogous methodology to that already set out by ANACOM for Portugal Telecom (MEO) – but using 'pure play mobile' or 'mainly mobile' international benchmarks to arrive at the values for some of the parameters, such as beta and gearing.

Annex A Details of economic depreciation calculation

An economic depreciation algorithm recovers all efficiently incurred costs in an economically rational way by ensuring that the total of the revenue[25] generated across the lifetime of the business is equal to the efficiently incurred costs, including cost of capital, in present value terms. This calculation is carried out for each individual asset class, rather than in aggregate. Therefore, asset-class specific price trends and element outputs are reflected in the components of total cost.

Present value calculation

The calculation of the cost recovered through revenue generated needs to reflect the value associated with the opportunity cost of deferring expenditure or revenue to a later period. This is accounted for by the application of a discount factor on future cashflow, which is equal to the WACC of the modelled operator.

The business is assumed to be operating in perpetuity, and investment decisions are made on this basis. This means that it is not necessary to recover specific investments within a particular time horizon (for example, the lifetime of a particular asset), but rather throughout the lifetime of the business. In the model, this situation is approximated by explicitly modelling a period of 45 years, which is consistent with a right of use of spectrum of 15 years and two potential renewals. At the discount rate applied, the present value of the Euro in the last year of the model is fractional and thus any perpetuity value beyond a large number of years is regarded as immaterial to the final result.

Cost recovery profile

The net present value $NPV = 0$ constraint on cost recovery can be satisfied by (an infinite) number of possible cost recovery trends. However, it would be impractical and undesirable from a regulatory pricing perspective to choose an arbitrary or highly fluctuating recovery profile.[26] Therefore, the costs incurred over the lifetime of the network are recovered using a cost-recovery path that is in line with revenue generated by the business. In a contestable market, the revenue that can be generated is a function of the lowest prevailing cost of supporting that unit of demand, thus the price will change in accordance with the costs of the MEA for providing the service.[27] Therefore, the shape of the revenue line (or cost-recovery profile) for each asset class is modelled as a product of the demand supported (or output) of the asset and the MEA price trend for that asset class.

[25] Strictly cost-oriented revenue, rather than actual received revenue.

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

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

Capital and operating expenditure (capex and opex)

The efficient expenditure of the operator comprises all the operator's efficient cash outflows over the lifetime of the business, meaning that capex and opex are not differentiated for the purposes of cost recovery. As stated previously, the model considers costs incurred over the lifetime of the business to be recovered by revenue over the lifetime of the business. Applying this principle to the treatment of capex and opex leads to the conclusion that both should be treated in the same way, since they both contribute to supporting the revenue generated over the lifetime of the operator.

Details of implementation

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

$$PV(expenditures) = PV(revenues)$$

The **revenue** which the operator earns from the service in order to recover its expenditures plus the cost of capital employed is modelled as a function of $Output \times MEA\ price\ trend$, where:

- *Output* is the service volume carried by the network element
- *MEA price trend* is the input price trend for the network element which thus proportionally determines the trend of the "revenue" that recovers the expenditures (effectively, the percentage change to the revenue tariff that would be charged to each unit of output over time).

Output is discounted because it reflects the (future) revenue stream from the network element. Any revenue recovered in the years after a network element is purchased must be discounted by an amount equal to the WACC in order that the cost of capital employed in the network element is also returned to the mobile operator.

This leads to the following general equations:

$$Revenue = \alpha \times (output \times MEA\ price\ trend)$$

$$Revenue = constant \times output \times MEA\ price\ trend$$

Using the relationship from the previous section:

$$PV(expenditures) = PV(constant \times output \times MEA\ price\ trend)$$

More specifically, since:

$$PV(expenditures) = PV(constant \times output \times MEA\ price\ trend)$$

then the *constant* is just a scalar which can be removed from the PV as follows:

$$PV(expenditures) = constant \times PV(output \times MEA\ price\ trend)$$

Rearranging:

$$constant = \frac{PV(expenditures)}{PV(output \times MEA\ price\ trend)}$$

This *constant* is thus the unit price in the first year, and the yearly access price over time is simply:

$$yearly\ access\ price\ over\ time = constant \times MEA\ price\ index$$

This yearly access price over time is calculated separately for the capital and operating components in one step in the model.

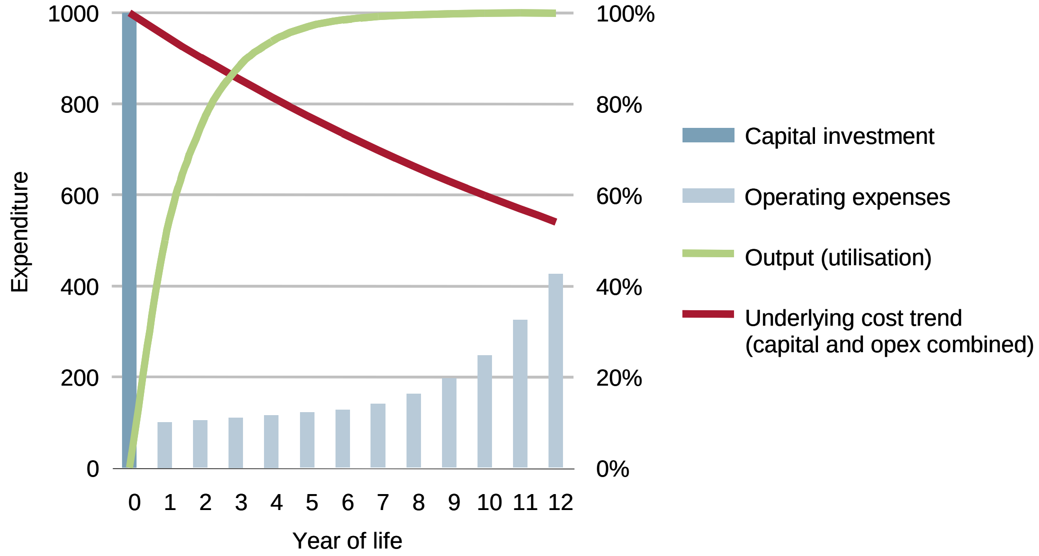
Calculating economic depreciation

The economic depreciation calculation can be expressed as: 'What time series of prices, consistent with trends in the underlying costs of production and the assumed contestability of the market, yield an expected NPV of zero over the period of interest?':

- An NPV of zero ensures that the prices are cost based, as they would have to be in a fully competitive market, neither under- nor over-recovering total costs (including a return on capital employed) over the lifetime of the project.
- Consistency of prices with trends in the underlying costs of production and assumed contestability of the market ensures that those prices are reflective of those that a (hypothetical) new entrant into the market at each point in time would charge.

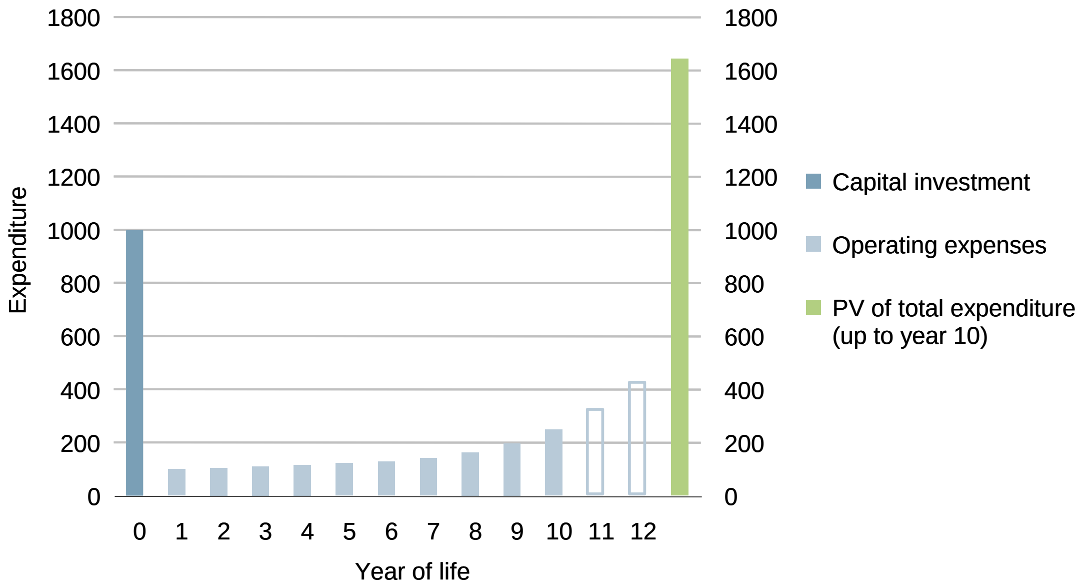
The inputs to the calculation are illustrated in Figure A.1.

Figure A.1: Economic depreciation inputs [Source: Analysys Mason, 2017]



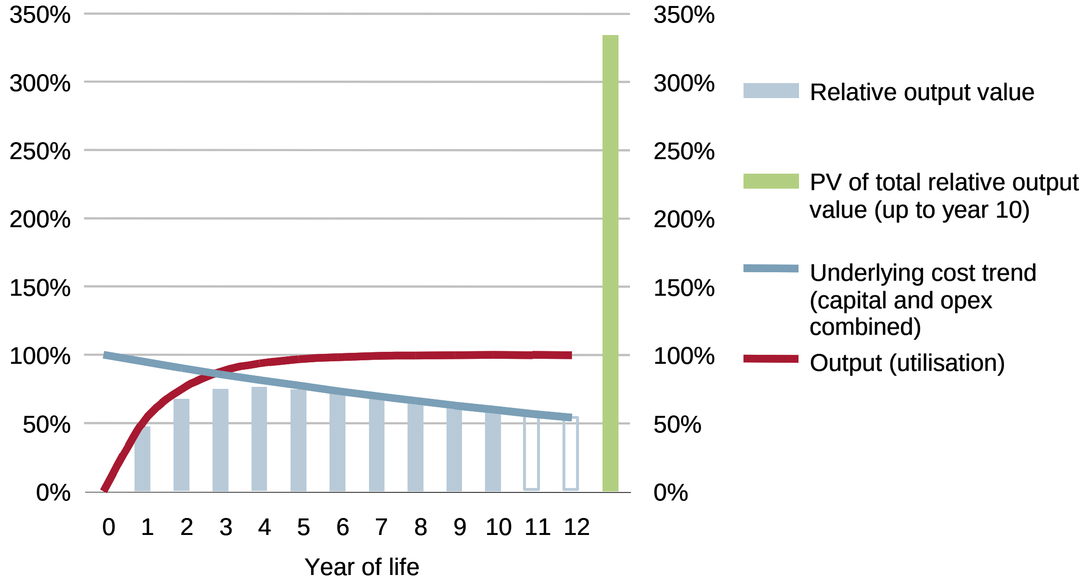
The present value (PV) of total expenditure, over say ten years, is calculated as shown in Figure A.2.

Figure A.2: PV of total expenditure over ten years [Source: Analysys Mason, 2017]



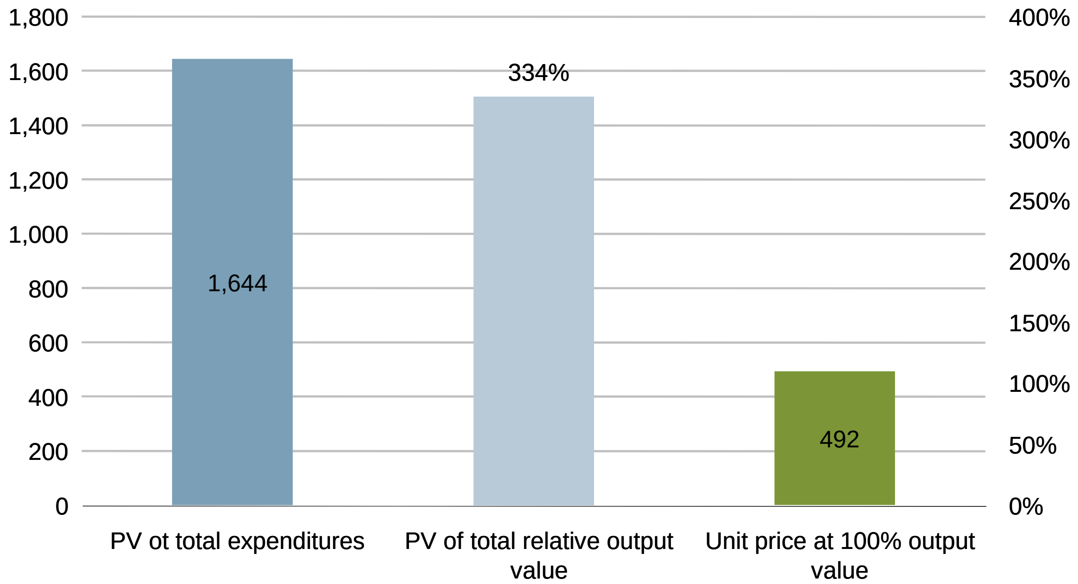
Then the PV of total *relative output value* is calculated over the same ten-year period. Relative output value is the product of asset utilisation multiplied by the (declining) price trend, and a relative measure of the revenue which can be earned from the asset. This is illustrated in Figure A.3.

Figure A.3: PV of total relative output value over ten years [Source: Analysys Mason, 2017]



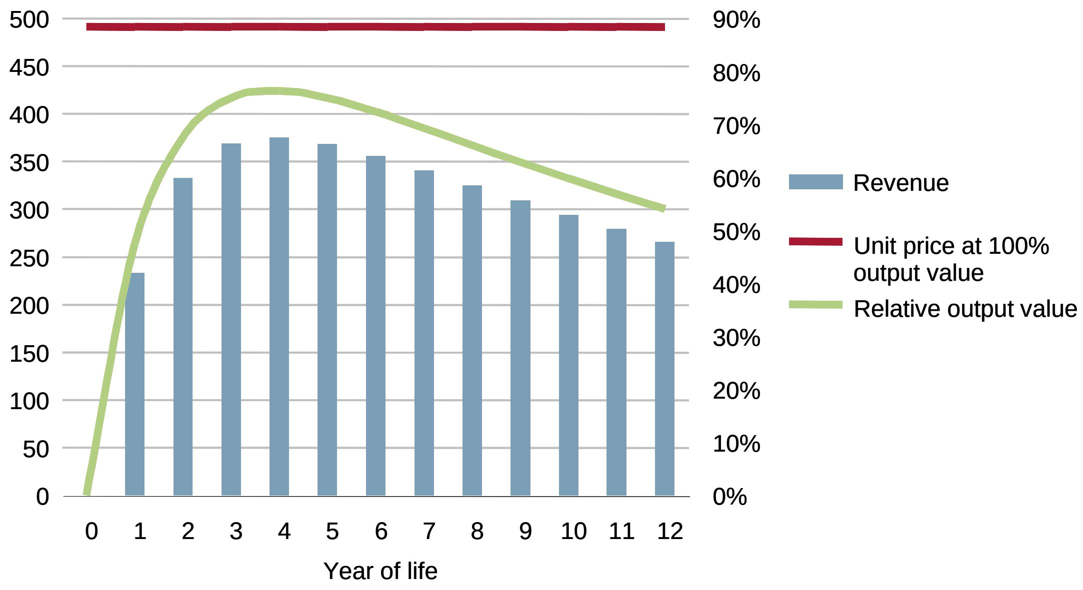
If we divide the PV of total expenditures by the PV of total relative output value, we obtain the measure of *unit price* at 100% of output value – i.e. revenue, or cost, per minute.

Figure A.4: Calculation of unit price [Source: Analysys Mason, 2017]



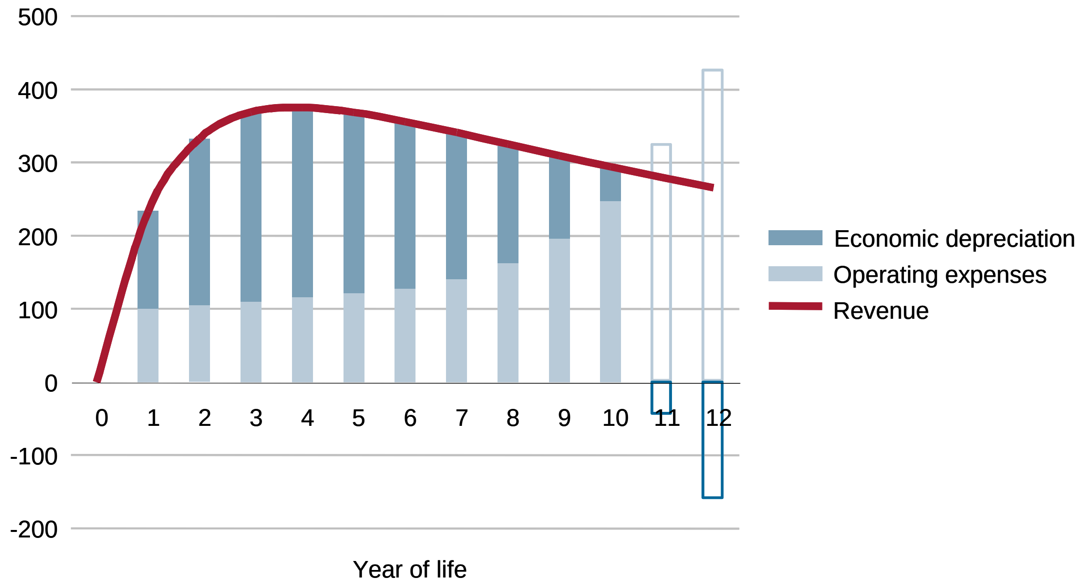
This unit price is then multiplied by the profile of relative output value to give overall output value, or revenue, as shown in Figure A.5.

Figure A.5: Calculation of revenue [Source: Analysys Mason, 2017]



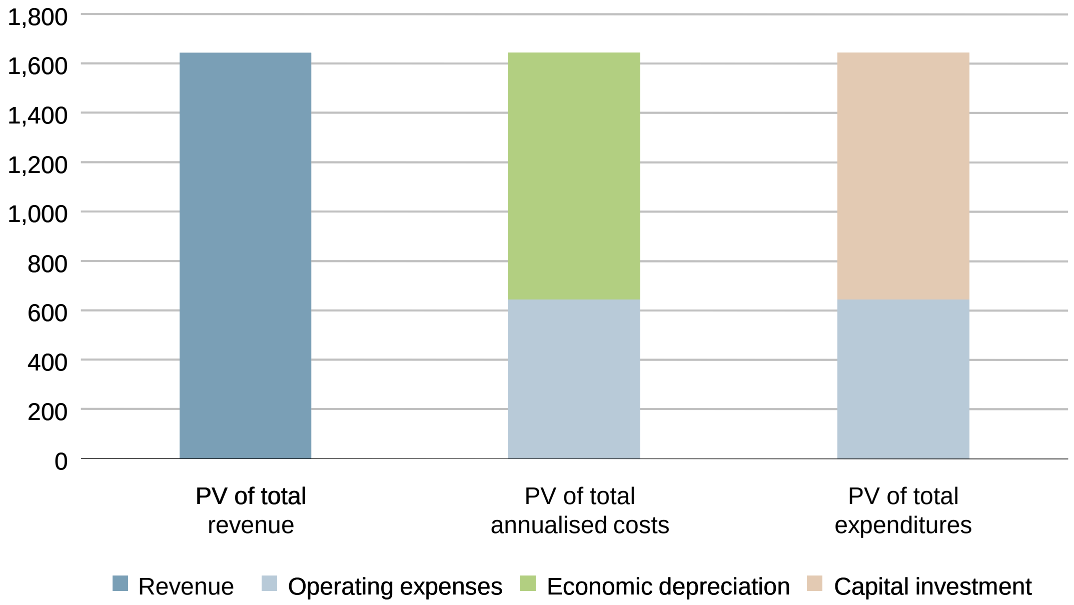
Economic depreciation specifically is the difference between revenues and operating expenditures, although it is often used to describe the overall depreciation profile (i.e. the recovery of costs through revenues). The economic lifetime of the asset is determined by when the asset operating expenditures exceed the revenues which can be earned from the asset – in this example, ten years. It is possible to determine the economic lifetime endogenously through iteration (e.g. by checking whether opex exceeds revenues in the eleventh year) or exogenously by making an external assumption (e.g. the economic lifetime of this asset will be *x* years). The overall economic depreciation profile is shown in Figure A.6.

Figure A.6: Economic depreciation profile [Source: Analysys Mason, 2017]



It can be confirmed that the calculation is overall NPV zero: the PV of revenues should equal the PV of expenditures and the PV of total cost recovery. This is illustrated in Figure A.7.

Figure A.7: NPV zero confirmation [Source: Analysys Mason, 2017]



Variants of economic depreciation exist; for example:

- operating expenditures can also be "depreciated", treating them as a (PV of) expenditures just like capital investment and recovering them from the profile of revenue according to operating expenditure price trends
- the calculation can be performed over a range of asset vintages by amalgamating the timeframe of expenditures into a single, overall, expenditure present value
- under the assumption of **constant output**, the economic depreciation profile equates to a **tilted annuity**.

Annex B Network design and dimensioning

This annex provides an overview of the main aspects of the design and dimensioning for the BU-LRIC model.

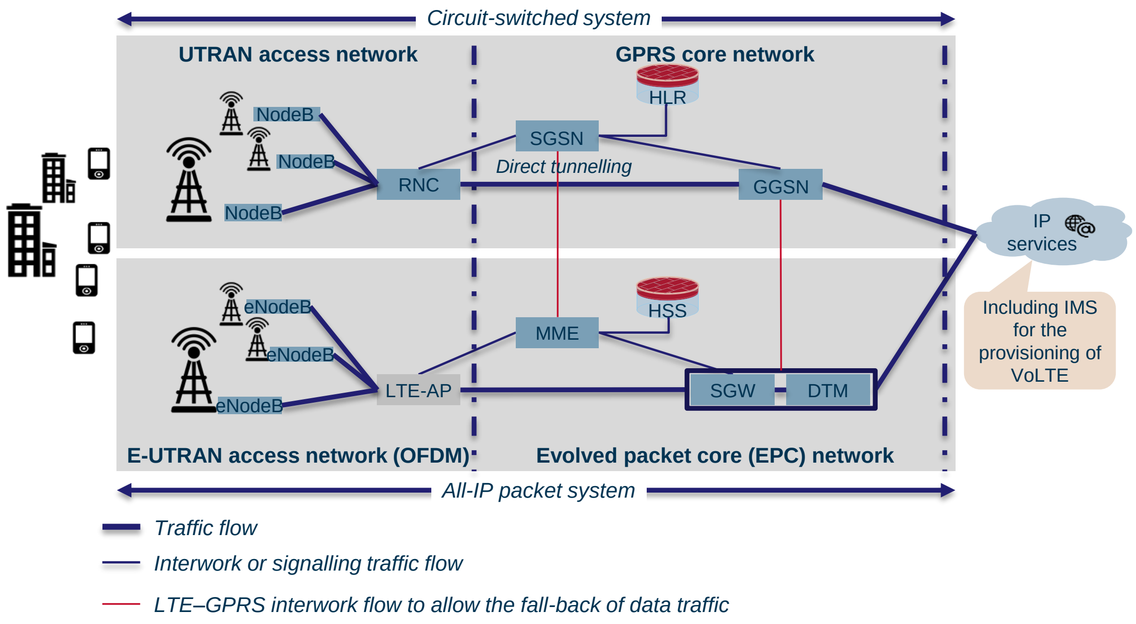
B.1 Network design

The 2G and 3G networks do not differ from those represented in the previous model. We have modelled a theoretical LTE network as an overlay of the existing networks, in line with international common practice,[28] which also appears to reflect the networks actually rolled out by Portuguese operators.

Figure B.1 illustrates the main components of the all-IP LTE network we have modelled and the interfaces with the existing GPRS network to ensure network interoperability. The 4G network can be split between the:

- E-UTRAN (orthogonal frequency division multiplexing (OFDM)) access network
- evolved packet core (EPC) core network.

Figure B.1: Illustration of the modelled data networks [Source: Analysys Mason, 2017]



28 Telecom Italia, *Notiziario Tecnico: speciale LTE, perché? Sostenibilità, tecnologie e uso delle nuove reti*, Q3 2013, available at http://www.telecomitalia.com/content/dam/telecomitalia/it/archivio/documenti/Innovazione/MnisitoNotiziario/2013/2-2013/NT2-2013.pdf; Alcatel-Lucent, *Introduction to Evolved Packet Core*, available at http://www3.alcatel-lucent.com/wps/DocumentStreamerServlet?LMSG_CABINET=Docs_and_Resource_Ctr&LMSG_CONTENT_FILE=White_Papers/Intro_EPC_wp_0309.pdf; Alcatel-Lucent, *The LTE Network Architecture*, available at http://www.cse.unt.edu/~rdantu/FALL_2013_WIRELESS_NETWORKS/LTE_Alcatel_White_Paper.pdf.

B.2 Demand modelling, definition of geotypes and dimensioning algorithm

Coverage requirements are defined in terms of population and area coverage. Coverage is often quoted in terms of the percentage of population covered (as per licence obligations). More useful to a mobile network designer is the geographical area covered (disaggregated by area type):

- converting population coverage into area requirements usually involves detailed demographics
- a number of area types will be defined that effectively capture the broad range of radio environments in Portugal
- urban, suburban and rural are the minimum number of geotypes recommended to properly model coverage; for example, as shown in Figure B.2 it may be possible to cover 90% of the population by covering perhaps 60% of the land area, comprising all urban, all suburban, and some rural areas.

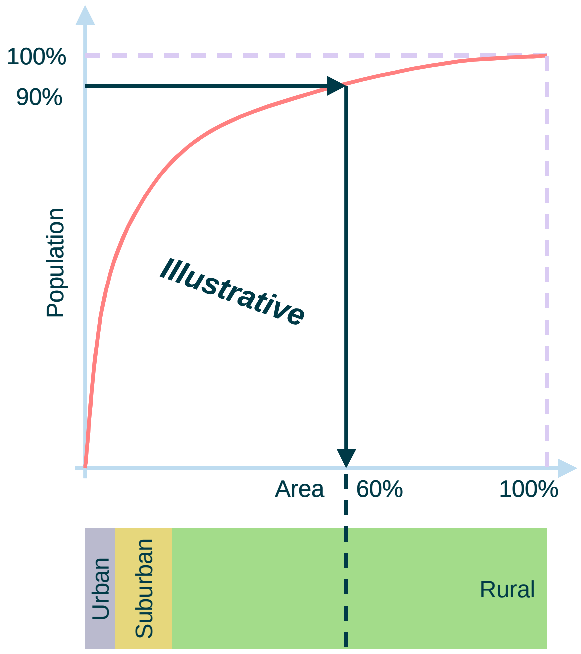


Figure B.2: Population distribution by geotype [Source: Analysys Mason, 2017]

We consider five geotypes: dense urban, urban, suburban, rural and micro/indoor. Geotypes are defined according to population density. The areas that belong to a certain geotype share common radio propagation profiles. As an example, the dense urban geotype usually includes areas where population is very concentrated in tall multi-dwelling units, which will require the network deployment in those areas to be made up of cells with smaller radii. The suggested definition of geotypes for the Portuguese mobile cost model are summarised in Figure B.3 below.

Figure B.3: Split of area and individuals between geotypes [Source: Analysys Mason, 2017, based on data from the 2011 Portuguese census]

Geotype	Density (d) threshold (pop/km^2)	Area (km^2)	Population
Dense urban	d > 14 000	11	173 944
Urban	1100 < d < 14 000	1445	4 060 643
Suburban	100 < d < 1100	15 453	4 207 139
Rural	d < 100	75 230	1 839 635

In order to better understand the distribution of geotypes across Portugal, a MapInfo dataset of Portuguese *freguesias* has been used to assign each *freguesia* to a geotype. This has been done by sorting *freguesias* in descending order by population density and allocating them to geotypes based on the cumulative area in the sorted list.

The model has been updated to take account of the latest data published by the 2011 census.[29] In order to calculate the density of the *freguesias* there are two options in terms of the population metrics that can be used:

- resident population
- individuals.

We opted for the second one since we believe it is the most appropriate driver for mobile usage.

Demand over time will be a key input in order to properly dimension the network. A simple diagram of the way in which total traffic can be calculated is provided in Figure B.4 below.

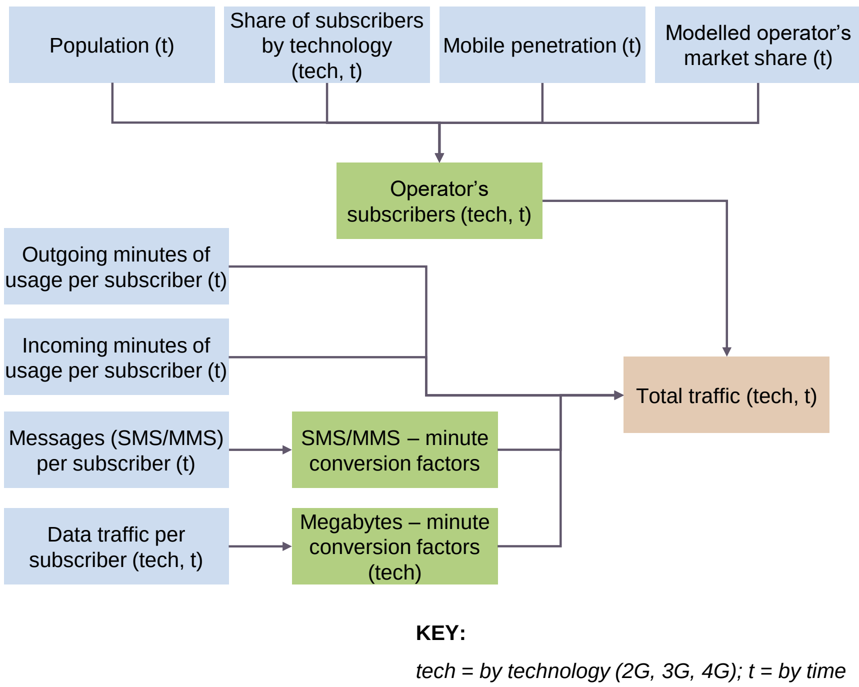


Figure B.4: Methodology for the calculation of total traffic [Source: Analysys Mason, 2017]

[29] Available at mapas.ine.pt/download/index2011.phtml.

The remainder of this section explains the typical algorithms used to calculate the number of elements required to meet the service and coverage requirements for a 2G/3G/4G network.

Figure B.5 provides a key to the diagrams used in the rest of this annex.

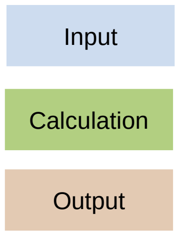


Figure B.5: Key for diagrams [Source: Analysys Mason, 2017]

B.2.1 Radio network: site coverage requirements

The coverage networks for each technology and spectrum band (primary GSM 900MHz, primary UMTS 2.1GHz and primary LTE 800MHz) are calculated separately within the model.

2G

We assume that the operator uses the 900MHz spectrum for coverage purposes. The number of macro-sites deployed at 900MHz has to be sufficient to meet the coverage requirements, which are defined as a given area (km²) for each geotype.

The inputs to the coverage site calculations are as follows:

- primary spectrum
- total area covered over time by technology and geotype
- cell radii for coverage, by geotype and technology
- proportion of primary spectrum sites available for overlay over time, by geotype.

Figure B.6 below outlines the model algorithm for the calculation of 2G sites deployed.

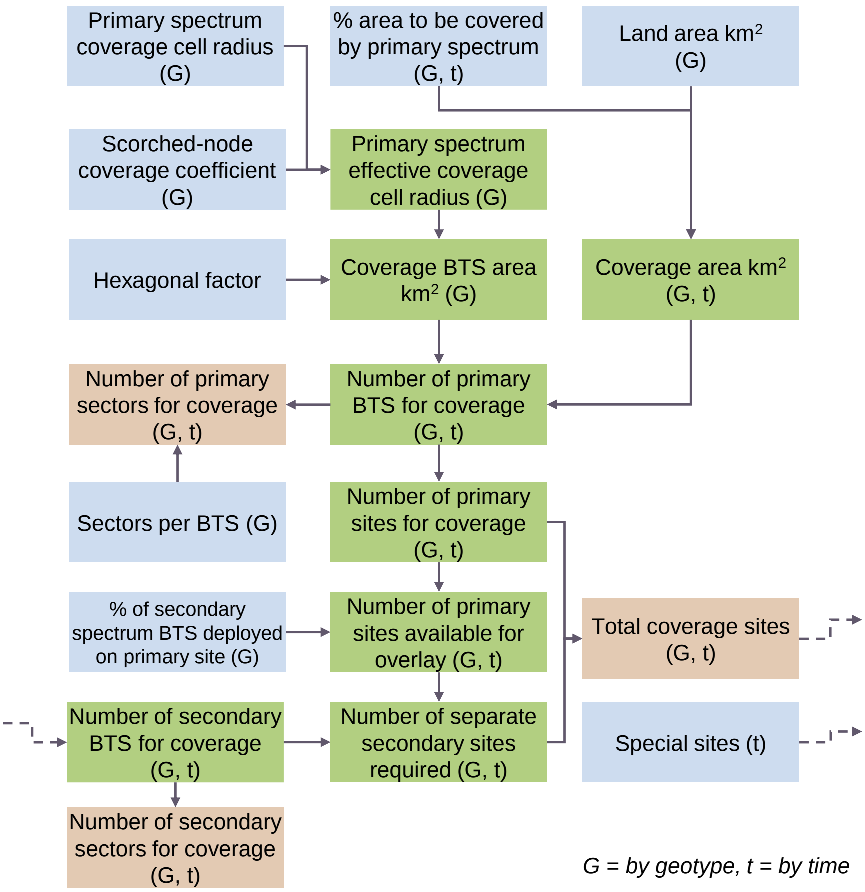


Figure B.6: 2G coverage algorithm [Source: Analysys Mason, 2017]

The coverage sites for the primary spectrum are calculated first. The area covered by a BTS in a particular geotype is calculated using the effective BTS radius. A scorched-node coverage coefficient (SNOCC) is used to account for practical limitations in deploying sites which result in sub-optimal locations. The total area covered in the geotype is divided by this BTS area to determine the number of primary coverage BTSs (and therefore sites) required. The calculation of the number of secondary coverage BTSs includes an assumption regarding the proportion of secondary BTSs that are overlaid on the primary sites.

In addition, special indoor sites can be modelled as an estimate, based on data provided by the operators or as a separate capacity layer.

All sites are usually assumed to be tri-sectored. However, there can be exceptions to this network design principle.

In the case of Portugal, all operators have access to 900MHz primary spectrum, and so secondary 1800MHz spectrum would only be deployed as a capacity overlay (until re-farming to LTE).

3G

For 3G, the operator uses its spectrum in the 2.1GHz band.

The same methodology used to derive 2G coverage sites is used to derive the initial number of coverage sites required for 3G, as shown in Figure B.7 below. All 3G coverage NodeBs are assumed to be tri-sectored as well, since this is normal operator practice. An assumption on cell loading is required for 3G due to the cell-breathing effect for W-CDMA technology.

The 3G network is an overlay network and does not typically need to fill every gap of population coverage. As a result, its SNOCCs may be higher than the corresponding 2G SNOCCs.

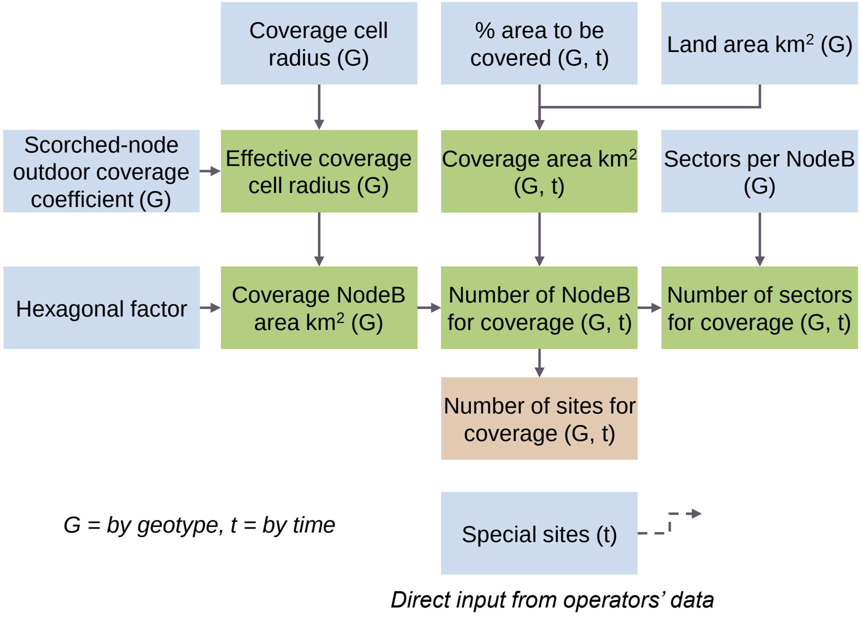


Figure B.7: 3G coverage radio network dimensioning [Source: Analysys Mason, 2017]

4G

The modelling of 4G coverage follows the same methodology adopted for 2G and 3G, with 800MHz being the primary spectrum used for coverage purposes. Therefore, the number of macro-sites deployed at 800MHz has to be sufficient to meet the coverage requirements, which are defined as a given area (km²) for each geotype. Unlike the situation with 2G, however, there are two overlay spectrum bands: LTE 1800MHz and LTE 2600MHz.

The inputs to the coverage site calculations are as follows:

- primary spectrum
- total area covered over time by technology and geotype
- cell radii for coverage, by geotype and technology
- proportion of primary spectrum eNodeBs available for primary overlay over time, by geotype
- proportion of secondary spectrum eNodeBs available for secondary overlay over time, by geotype.

Figure B.8 below outlines the model algorithm for calculating the number of 4G sites deployed.

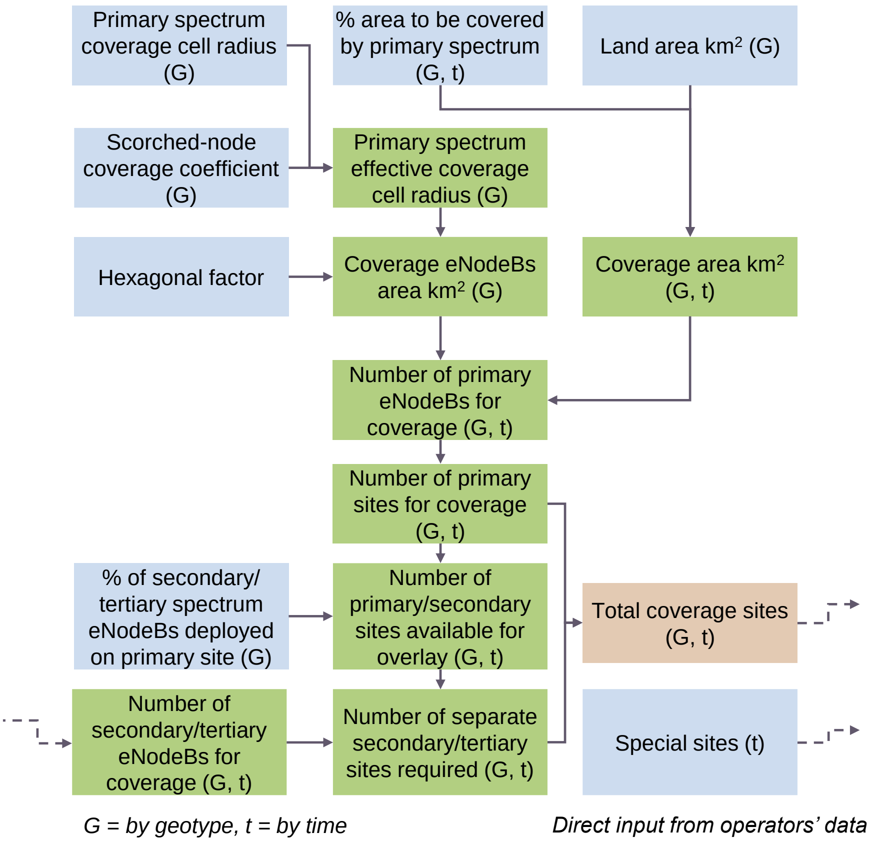


Figure B.8: 4G coverage algorithm [Source: Analysys Mason, 2017]

The coverage sites for the primary spectrum are calculated first. The area covered by an eNodeB in a particular geotype is calculated using the effective eNodeB radius. An SNOCC is used to account for practical limitations in deploying sites which result in sub-optimal locations. The total area covered in the geotype is divided by this eNodeB area to determine the number of primary coverage eNodeBs (and therefore sites) required. The same methodology is used to calculate the number of secondary and tertiary coverage eNodeBs.

In addition, special indoor sites can be modelled as an estimate based on data provided by the operators or as a separate capacity layer.

B.2.2 Radio network: site capacity requirements (2G, 3G and 4G)

The capacity requirements for each spectrum band and technology are calculated separately within the model. In all cases two steps are required, to calculate:

- the capacity provided by the coverage sites
- the number of additional sites (including secondary spectrum overlays, if available) required fulfilling capacity requirements.

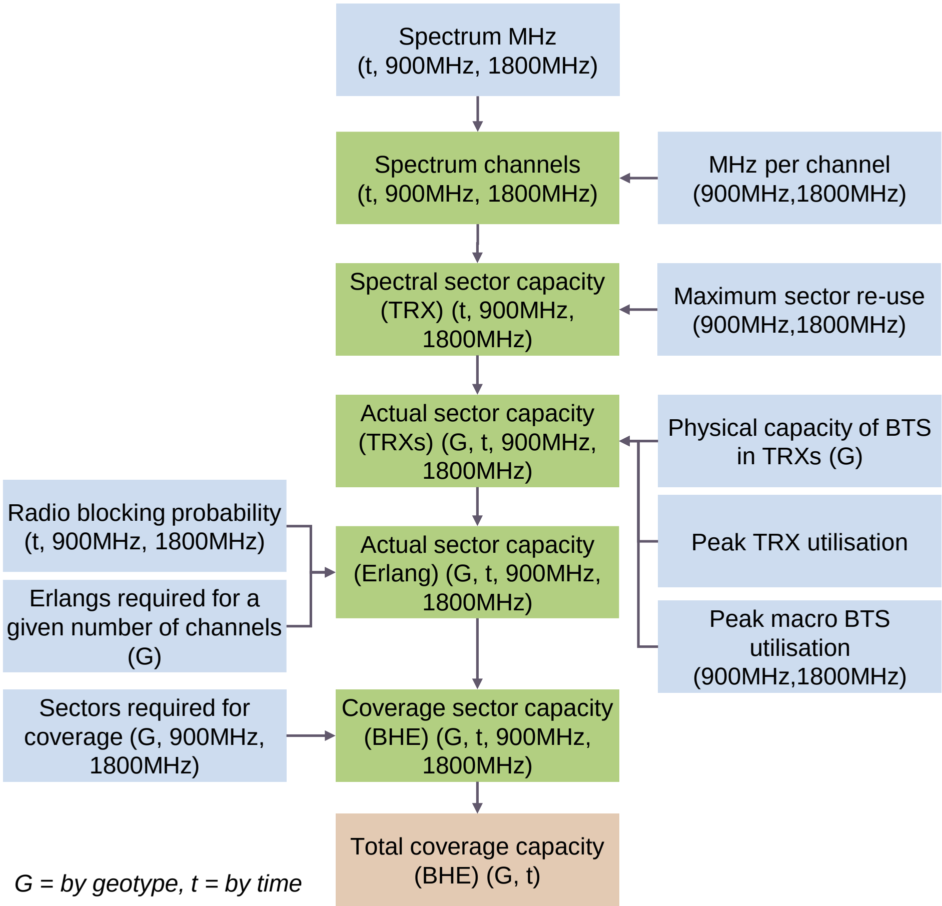
However, the differences between 2G, 3G and 4G technologies mean that slightly different inputs are required, as explained below.

2G capacity requirements

► *Step 1: Capacity provided by the sectorised coverage sites*

We have explained above how the number of coverage BTSs is derived by geotype, and technology, over time. The calculation of the busy-hour Erlang (BHE) capacity provided by the sites deployed for coverage purposes is shown in Figure B.9 below.

Figure B.9: Calculation of the BHE capacity provided by the coverage network [Source: Analysys Mason, 2017]



The coverage capacity is calculated separately for each technology and spectrum band. For a given technology, before the capacity requirements of the network are calculated, the Erlang capacity for the allocated spectrum is determined.

The inputs to this calculation are:

- availability of spectrum
- spectrum re-use factor
- blocking probability
- BTS capacity (in terms of TRXs).

The spectral capacity per sector is the number of TRXs that can be deployed per sector given a certain maximum spectrum re-use factor. The minimum between physical capacity and spectral capacity of a sector is the applied capacity.

The sector capacity in Erlangs is obtained using an Erlang B conversion table, and channel reservations for signalling and GPRS are also made. In calculating the effective capacity of each sector in the coverage network, an allowance is made for the fact that BTSs and TRXs will in fact be under-utilised:

- Under-utilisation of BTSs occurs because it is not possible to deploy the full physical TRX complement in every BTS, since BHE demand does not occur uniformly at all sites. Alternatively, an operator may specifically choose to provide capacity using additional sites rather than additional TRXs.
- Under-utilisation of TRXs occurs because the peak loading of each cell at its busy hour is greater than at the network-average busy hour. In addition, BHE demand does not occur uniformly in a certain number of sectors.

New technologies such as adaptive multi-rate (AMR) enable the radio network to increase sector capacity by a percentage, and this percentage can also be applied to calculate the effective sector capacity. This is possible due to the increased compression factor that is applied to voice traffic. A voice call may then be transmitted at half the rate of a normal call by using AMR-HR (AMR half rate).

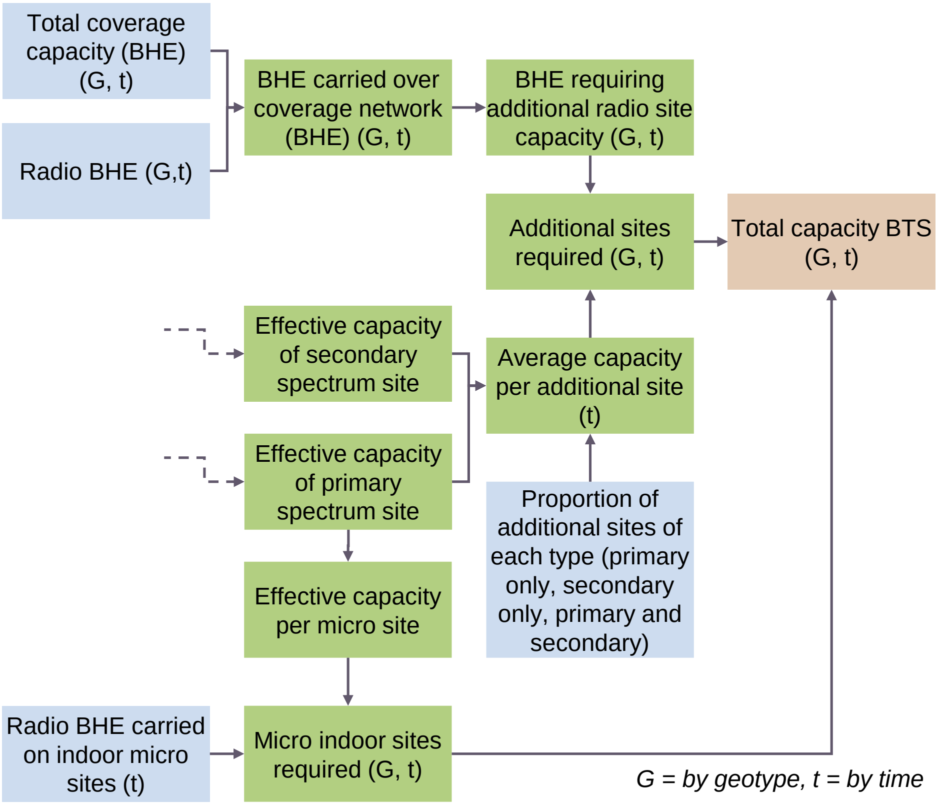
The sector capacity (in Erlangs) is then multiplied by the total number of sectors in the coverage network to arrive at the total capacity of the network.

► *Step 2: Calculation of the number of additional sites required to fulfil capacity requirements*

It is assumed that an operator can deploy capacity BTSs on new sites, and in overlays on existing sites. In reality, it is not uncommon for operators to simultaneously deploy new dual sites (GSM 900 and DCS 1800) when they want to install new capacity and improve patchy coverage or increase in-building penetration.

The additional new sites required to fulfil capacity requirements are computed after calculating the capacity of the coverage networks, as shown in Figure B.10.

Figure B.10: Calculation of the BHE capacity provided by the coverage network [Source: Analysys Mason, 2017]



Three types of GSM site are dimensioned according to the spectrum employed:

- primary-only sites
- secondary-only sites
- dual sites.

The total BHE demand is aggregated by element and then allocated by geotype. GPRS traffic is excluded on the assumption that it is carried in a packet data channel reservation. Once the total capacity of the coverage network is known, it is possible to determine the BHE demand that cannot be carried by the coverage network, broken down by geotype.

Assuming that all new sites are fully sectorised, the total effective capacity of a fully sectorised BTS for both primary and secondary spectrum is calculated. It is then assumed that new 2G sites will be deployed if different types of spectrum are available: primary, secondary and primary with secondary. These parameters are used with the effective BTS capacities to calculate the weighted average capacity per additional site by geotype. The total BHE demand not accommodated by the coverage networks is then used, along with this weighted average capacity and the split of new sites by site type, to calculate the number of additional sites by site type and geotype required accommodating the remaining BHE.

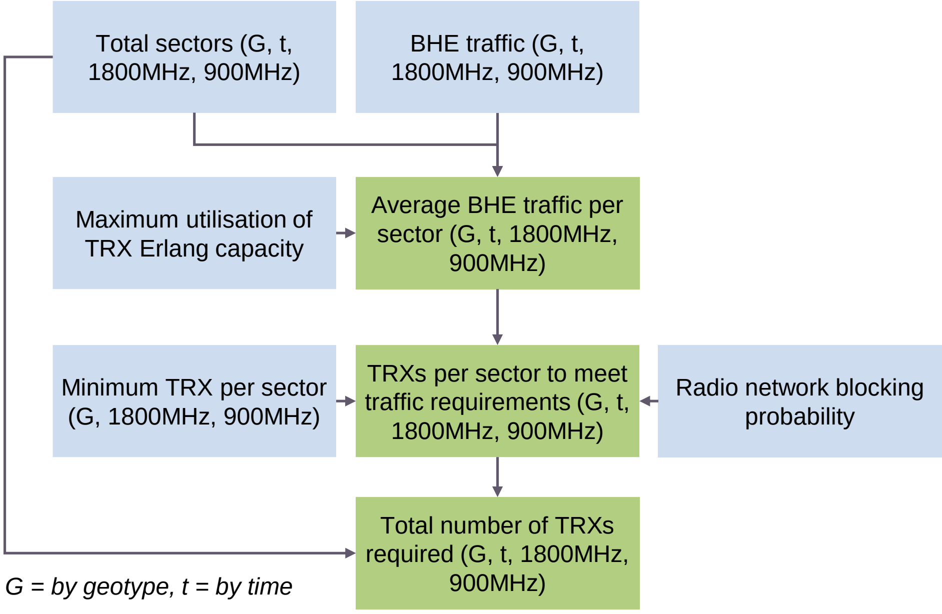
► *Step 3: Calculation of the number of TRXs required*

The number of TRXs required in each sector (on average, by geotype) to meet the demand is calculated:

- taking into consideration the maximum TRX utilisation percentage
- converting the Erlang demand per sector into a channel requirement using the Erlang-B table and the assumed blocking probability
- excluding signalling and GPRS channel reservations
- assuming a minimum number of one or two TRXs per sector.

The total number of TRXs required is obtained by multiplying the number of sectors by the number of TRXs per sector, as shown in Figure B.11 below.

Figure B.11: Calculation of TRX requirements [Source: Analysys Mason, 2017]

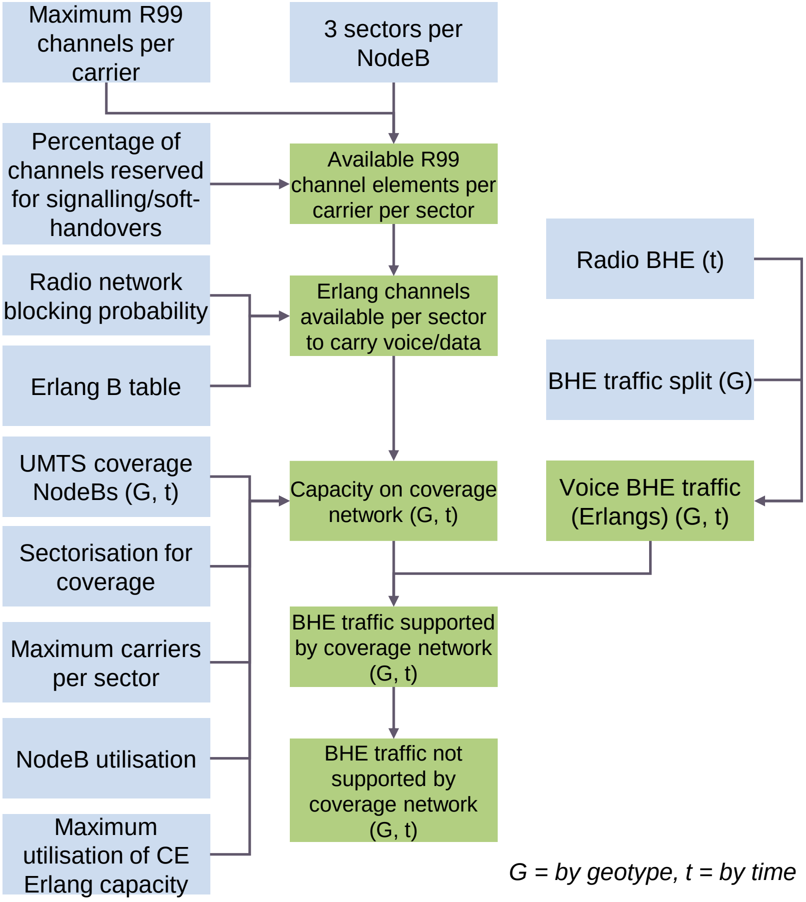


3G capacity requirements

► *Step 1: Capacity provided by the sectorised coverage sites*

Figure B.12 below illustrates the methodology used to derive the capacity of the 3G network.

Figure B.12: Calculation of the BHE capacity not met by the 3G coverage network [Source: Analysys Mason, 2017]



The following assumptions about specific 3G modelling inputs have been made based on the typical values of the UMTS standard:

- three sectors per NodeB
- 5MHz per UMTS carrier
- a maximum physical capacity of *n* channel kits per carrier per sector, across all geotypes
- pooling of channel elements at the NodeB
- 16 or 64 channel elements per channel kit
- one channel element required to carry a voice call, and four to carry a video call
- 20% to 30% additional channel elements are occupied for signalling/soft-handover purposes. This only applies to voice, video and PS data; HSDPA does not use soft handover.

The calculation ensures that all offered traffic – voice, data and video – is carried with a guarantee of available bandwidth. This represents the situation where delivery of 'best-efforts' data traffic is undertaken without compromising the user's experience of the service during the busy hour. The degree to which operators may allow degradation in packet data service during the busy hour is a network strategy/quality decision, especially when HSDPA services are available to enable more-efficient delivery of downlink traffic.

The number of 3G coverage sites calculated earlier in the model is multiplied by the maximum BHE voice capacity per carrier and by the number of carriers per site to derive the capacity in the coverage network by geotype. As with 2G capacity requirements, an allowance is made for the fact that NodeB and channel kit capacity is less than 100% utilised:

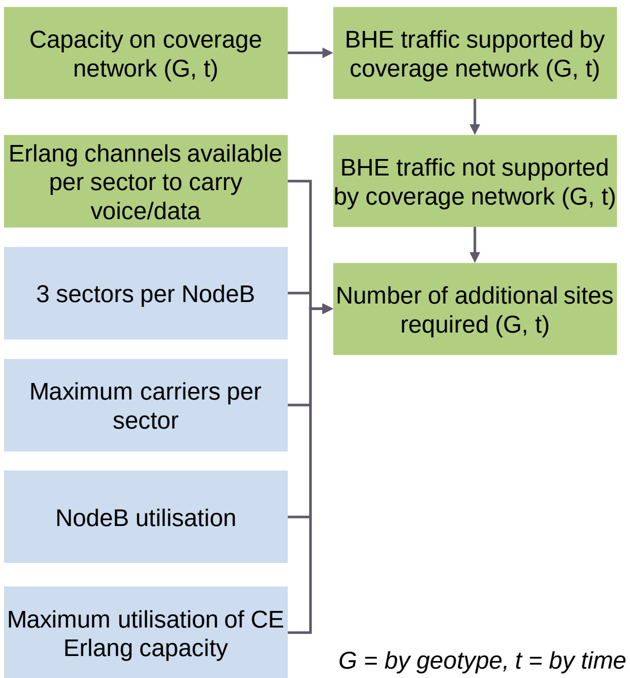
- Under-utilisation of NodeBs occurs because BHE demand is not uniform at all sites
- Also, BHE demand does not occur uniformly in a certain number of NodeB sectors.

Special indoor sites are assumed to provide additional capacity as if they were an omni-sector site.

► *Step 2: Calculation of the number of additional sites required to fulfil capacity requirements*

Having calculated both the 3G BHE and the capacity of the coverage network by geotype, the BHE demand that cannot be accommodated by the coverage network by geotype is derived, and the number of additional sites calculated, as shown in Figure B.13 below.

Figure B.13: Calculation of the additional sites required to fulfil capacity requirements [Source: Analysys Mason, 2017]



This calculation essentially uses a three-stage algorithm:

- *Stage 1* – if the 3G BHE demand in a geotype can be accommodated by the coverage network for that geotype, then no further carriers or sites are added to the network.

- *Stage 2* – if the 3G BHE demand in a geotype cannot be accommodated by the coverage network for that geotype, then another carrier is added to the BTS in that geotype so that the remaining 3G BHE demand can be accommodated.

- *Stage 3* – if all 3G coverage BTSs in that geotype have been overlaid with additional carriers before satisfying BHE demand, then the number of additional sites required in that geotype to accommodate unmet demand from Stages 1 and 2 is calculated. These additional sites are assumed to be deployed fully overlaid, i.e. with all carriers used.

Micro indoor sites are modelled as an additional layer of 2-sector capacity sites.

It should be noted that the 3G coverage network has significant capacity (having been implicitly designed to cope with (e.g. up to 50%) load for cell-breathing purposes), and the need for additional sites for capacity only arises in high-traffic situations.

► *Step 3: Calculation of the number of 3G channel kits and carrier deployment*

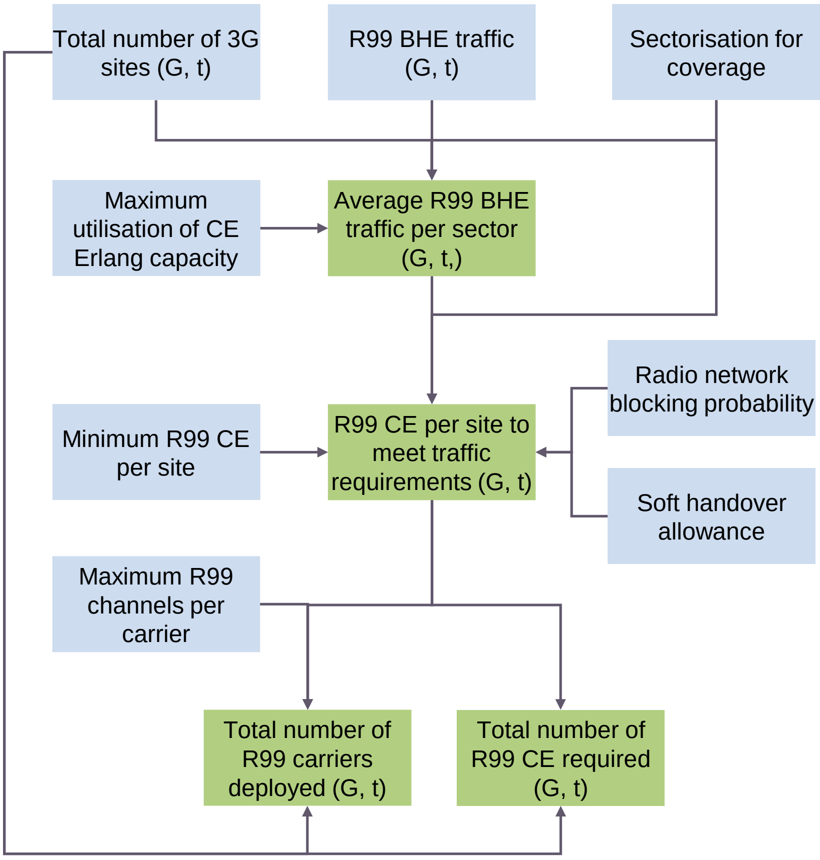
The dimensioning of the 3G channel kits is done in a similar manner to the calculation of 2G TRXs, with the exception that an allowance is made for soft handover for voice, video and PS R99 data traffic.

Additional channel elements (CEs) for high-speed data services are dimensioned based on:

- configuration profiles for the various high-speed data service technologies (e.g. the number of CEs per NodeB for HSDPA, etc.)
- activation profiles by year and geotype.

The total number of CEs required is obtained by multiplying the number of sites by the number of CEs per site. This process is repeated for each carrier and for each type of CE (R99, HSDPA, HSUPA), as shown in Figure B.14 on the next page.

Figure B.14: 3G channel kit and carrier dimensioning [Source: Analysys Mason, 2017]



G = by geotype, t = by time

4G capacity requirements

We have calculated the number of LTE capacity-driven sites through a two-step internationally validated approach which firstly calculates the number of eNodeBs and eventually the number of carriers needed to carry the assumed volume of 4G traffic. Both steps are described below.

eNodeB requirements

We have assumed six LTE upgrades (as shown in Figure B.15). Each incremental step allows the operator to increase both the speed offered to customers and the throughput (capacity).

Figure B.15: LTE upgrades used in the model [Source: Analysys Mason, 2017]

Peak speed in Mbit/s	Modulation	MHz paired spectrum	MIMO configuration
37.0	64 QAM	2×5MHz	2×2
75.6	64 QAM	2×10MHz	2×2
152.7	64 QAM	2×20MHz	2×2
229.8	64 QAM	2×30MHz	2×2
306.9	64 QAM	2×40MHz	2×2
604.5	64 QAM	2×40MHz	4×4

Note: The peak speed achievable has been calculated assuming a 10% guard band, 7 OFDMA symbols in a timeslot and a 15kHz subcarrier size.

We have assumed that the modelled operator is deploying the following carrier configurations across all geotypes:

- 2×10MHz carrier in the primary spectrum band (800MHz)
- 2×20MHz carrier in the secondary spectrum band
- 2×20MHz carrier in the tertiary spectrum band; this carrier is assumed to be deployed only if needed to fulfil excess traffic demand
  - of course, the availability of 2×20MHz spectrum in the 1800MHz is subject to its re-farming from GSM.

The other main inputs to the eNodeB capacity calculation used in the model are summarised in Figure B.16 below.

Figure B.16: Description of major user inputs used in the eNodeB calculation [Source: Analysys Mason, 2017]

Name	Value assumed	Description
Effective Mbit/s as a proportion of peak Mbit/s (average throughput)	25%	For example, the peak rate might be c. 12Mbit/s, but the effective rate over the cell area is c. 3Mbit/s
Coverage frequency	800MHz – primary spectrum	Frequency assumed to be used to deploy coverage eNodeBs in all geotype
Capacity frequency	2600MHz – secondary spectrum; 1800MHz – tertiary spectrum	Remaining frequencies available for 4G services. The tertiary spectrum band is only deployed if the demand exceeds the capacity available in primary and secondary spectrum bands

In terms of methodology, we firstly calculated the BH Mbit/s per coverage site by accounting for the carriers' maximum utilisation factor and average throughput. We then calculated the maximum bitrate across all carriers, multiplying the total number of carriers (coverage and capacity) available by the capacity per carrier (capacity per sector multiplied by the average number of sectors). This capacity depends on the evolutionary step adopted by the modelled operator (see Figure B.15) in both the coverage and capacity layers. As a consequence, the capacity per available carrier increases over time as the modelled operator upgrades its LTE technology.

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

$$eNodeB\ macrocells = eNodeBs\ required\ for\ coverage \times \left[\left(\frac{BH\frac{Mbit}{s}\ per\ coverage\ eNodeB}{Maximum\ bitrate} - 1\right)\right]$$

By definition, the total number of eNodeBs required is the sum of those previously calculated for coverage plus the demand capacity-driven ones calculated in this step, as shown in Figure B.17.

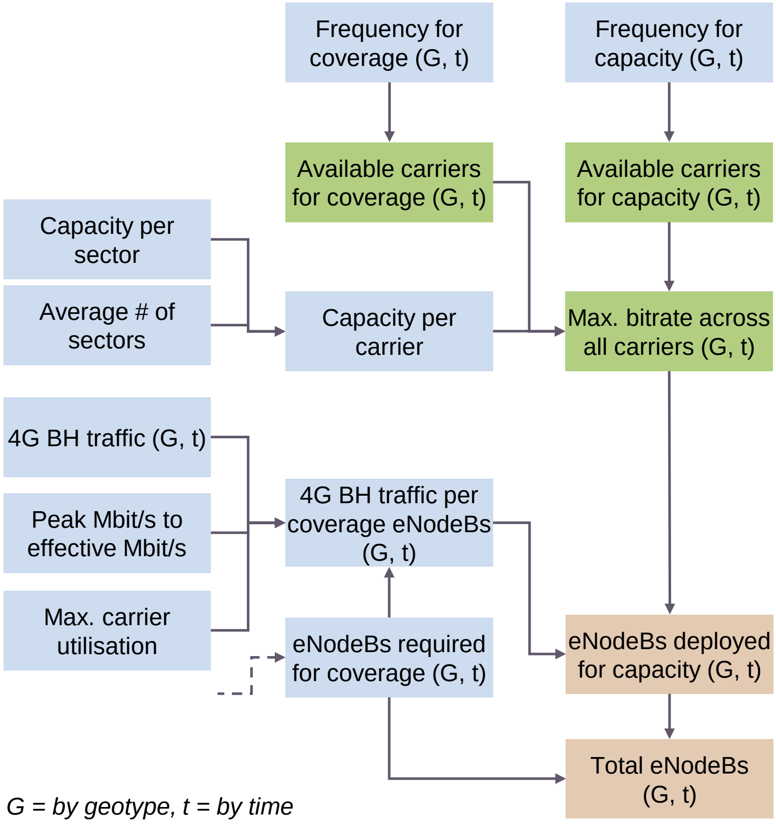


Figure B.17: Calculation of eNodeB requirements [Source: Analysys Mason, 2017]

► *Carrier requirements*

We first calculate the BH Mbit/s per eNodeB (including both coverage and capacity eNodeBs this time), again accounting for the carriers' maximum utilisation factor. 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 insufficient, we then sequentially check whether deploying an additional carrier per eNodeB would be sufficient. The functionality has been included in the model to repeat this process for up to a maximum of three carriers. The first two iterations are mandatory, since the model assumes that deployment of the first two carriers is driven by commercial considerations. The third and last carrier is, however, deployed only if the capacity provided by the previous ones is not sufficient to cope with the traffic demand.

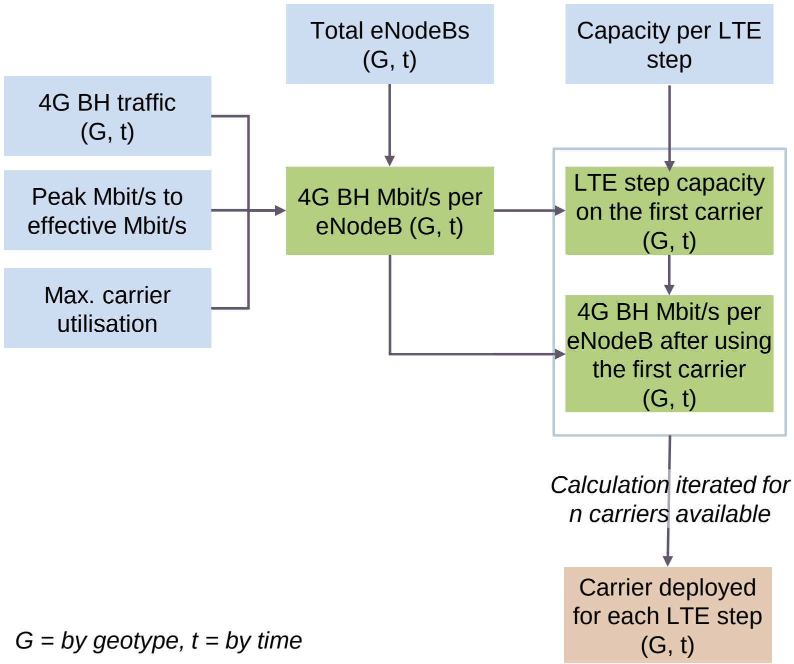


Figure B.18: Calculation of LTE carrier requirements [Source: Analysys Mason, 2017]

We then sum up the total number of carriers deployed across all LTE upgrades available. The planning period is then factored into the output, with the final results by cell type then aggregated into tables of macro-/micro-cell carriers by geotype over time.

B.2.3 Calculation of radio physical sites

We have calculated the number of radio physical sites and considered the co-location of the different mobile technology generations, on the basis of the following drivers:

- share of 2G sites capable of hosting 3G
- share of 2G sites capable of hosting 4G
- share of 2G sites without 3G capable of hosting 4G
- share of 3G sites without 2G capable of hosting 4G.

We assume that, as far as possible, mobile operators will roll out the incremental technology on top of existing physical sites, in order to optimise their capital expenditure. Radio sites in the model can have one of the following technological configurations:

- 2G only
- 3G only
- 4G only
- 2G + 3G
- 2G + 4G
- 2G + 3G + 4G
- 3G + 4G.

The total number of physical locations required by the radio access network is the sum of all configurations above.

B.2.4 Transmission network

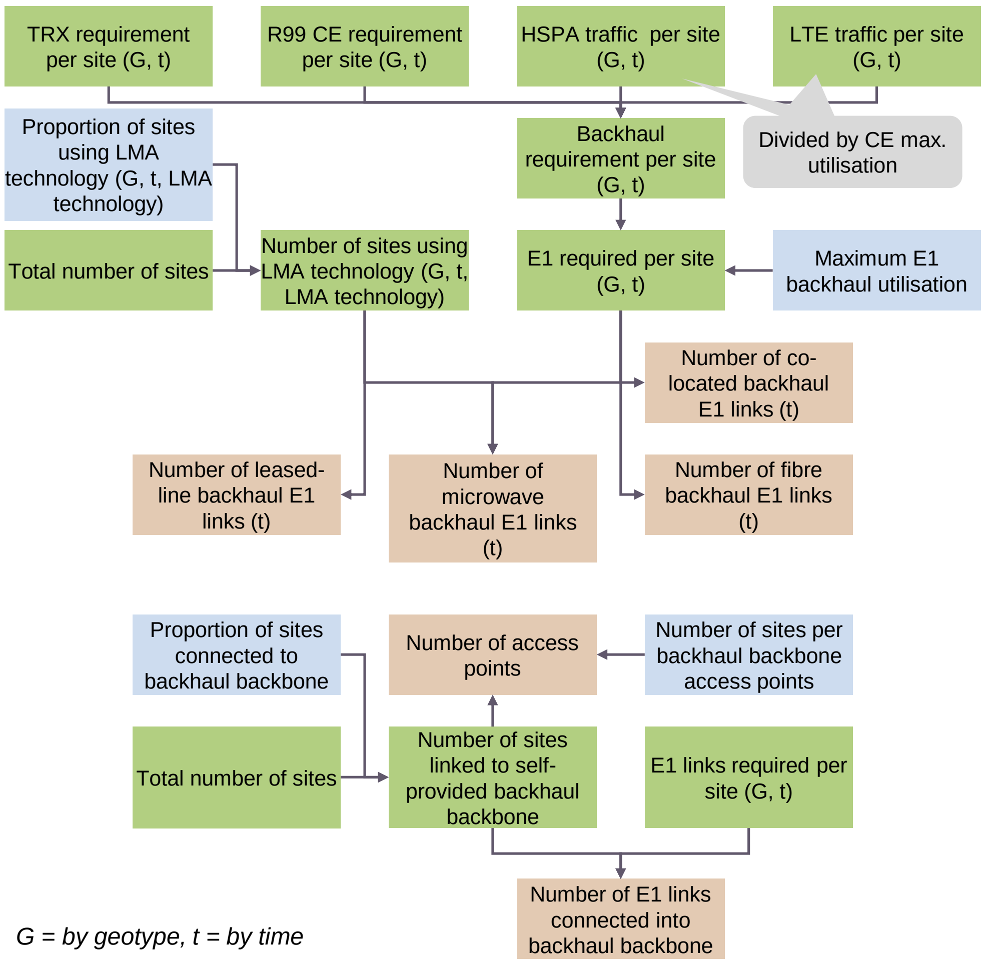
We have split the transmission network into three parts:

- National backbone based on leased dark fibre, which connects the major cities of Portugal and is used to carry inter-switch voice traffic, voice mail system (VMS) traffic and data traffic to the Internet
- Regional backbones based on leased dark fibre, which connect the major cities on the national ring with the regions of the country. They are used to carry backhaul transit, i.e. traffic between sites, BSC/RNC and transmission access points. They are also used to carry BSC–MSC and packet control unit (PCU)-serving GPRS support node (SGSN) traffic for remote BSCs.
- Last-mile access (LMA) network based on leased lines, microwave or fibre. These network links are used to carry traffic from BTS/NodeBs to the nearest BSC/RNC or transmission access point.

B.2.5 2G, 3G and 4G backhaul transmission

The calculation of the number of backhaul links and the corresponding number of ports required is set out in Figure B.19 below.

Figure B.19: Backhaul calculation [Source: Analysys Mason, 2017]



Step 1: Capacity requirements

The number of links required per macro-site to fulfil backhaul capacity requirements is calculated. There are eight channels per TRX, which translates into eight circuits in the backhaul since the backhaul is dimensioned to support all TRX channels.[30] Taking into consideration the co-location of primary and secondary BTSs on the same site, the number of channels per site is calculated on the basis of the number of channels per TRX multiplied by the number of 900MHz and 1800MHz TRXs. The effective capacity per link is calculated based on the maximum capacity of a link and the link utilisation. The number of links required per site is then obtained by simply dividing the circuits per site by the actual capacity per link.

In a similar way, R99 CEs drive the number of 3G voice channels requiring backhaul.

For HSDPA, HSUPA and LTE the backhaul need is derived from the average traffic generated per site, taking into account the backhaul maximum utilisation factor.

Step 2: Backhaul network design algorithms

There are three types of backhaul to be considered in the network: microwave (*x*Mbit/s links), leased lines and fibre. The distribution of LMA technologies is an input to the model.

The number of E1s required per site (on average) is different in each geotype but does not vary with the LMA technology used.

A specified proportion of sites is also linked to the BSC (for 2G), to the RNC (for 3G) and to the LTE-AP (for 4G) via the fibre ring network. The capacity of these links is dimensioned according to the average number of links per site (by geotype).

Micro-sites and special sites are assumed to use only leased-line backhaul and hence are added to the leased-line requirement of the macro layer at the rate of *n* E1per site.

Other rules applied are the following:

- Microwave links are not typically used in urban areas due to line-of-sight difficulties
- Fibre links are not used in rural areas due to distance/availability between sites and the points of presence (PoPs).

In order to dimension the backhaul links, microwave E1s are converted into microwave links (e.g. 32Mbit/s equivalents). Leased-line E1s are identified separately by geotype as their price is often distance-dependent. In addition, a defined proportion of sites are assumed to require backhaul transit on the regional backbones.

30 The backhaul requirements are not affected by the use of half-rate coding, as the backhaul demand is a function of the number of TRXs. It is the number of channels per TRX that is impacted by half-rate coding.

B.2.6 2G BSC deployment

The structure of the BSC deployment algorithm is set out in Figure B.20 below.

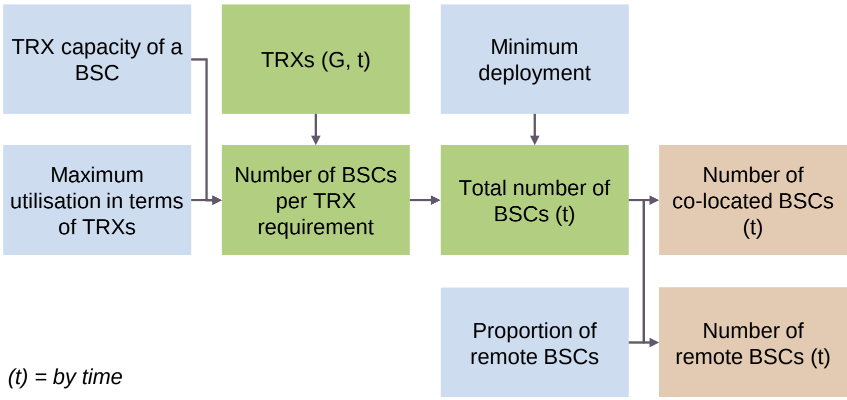


Figure B.20: BSC deployment [Source: Analysys Mason, 2017]

BSC deployment is driven by two requirements:

- the maximum number of TRXs controlled, assuming a maximum utilisation
- the minimum number of BSCs deployed in the network (for redundancy).

Each of those two requirements leads to a different number of BSC units: the total number of BSCs corresponds to the higher of the two values.

A proportion of BSCs are designated as ‘remote’ (i.e. not co-located with an MSC). In addition, the new BSCs have AMR capabilities. As explained earlier when we discussed TRXs (see page B–9), this feature allows for decreased radio resource consumption.

The traffic transiting through co-located BSCs and MSCs is backhauled to the MSC using tie cables or other cables laid out within the switching site.

The model has the flexibility to reflect the potential deployment of remote BSCs. In this situation, the total traffic handled by each remote BSC can be calculated using the total BHE transceiver traffic. The average BHE traffic handled by each remote BSC is converted into a channel requirement using the Erlang table. The number of links is then calculated by dividing this channel requirement by the capacity of a link, adjusted for maximum utilisation. It should be noted that the capacity of the BSC–MSC transmission depends on where the transcoder equipment is located. For remote BSCs, the transcoder is assumed to be located in the MSC.

The number of BSC–MSC ports is determined on the basis of the number of BSC–MSC links.

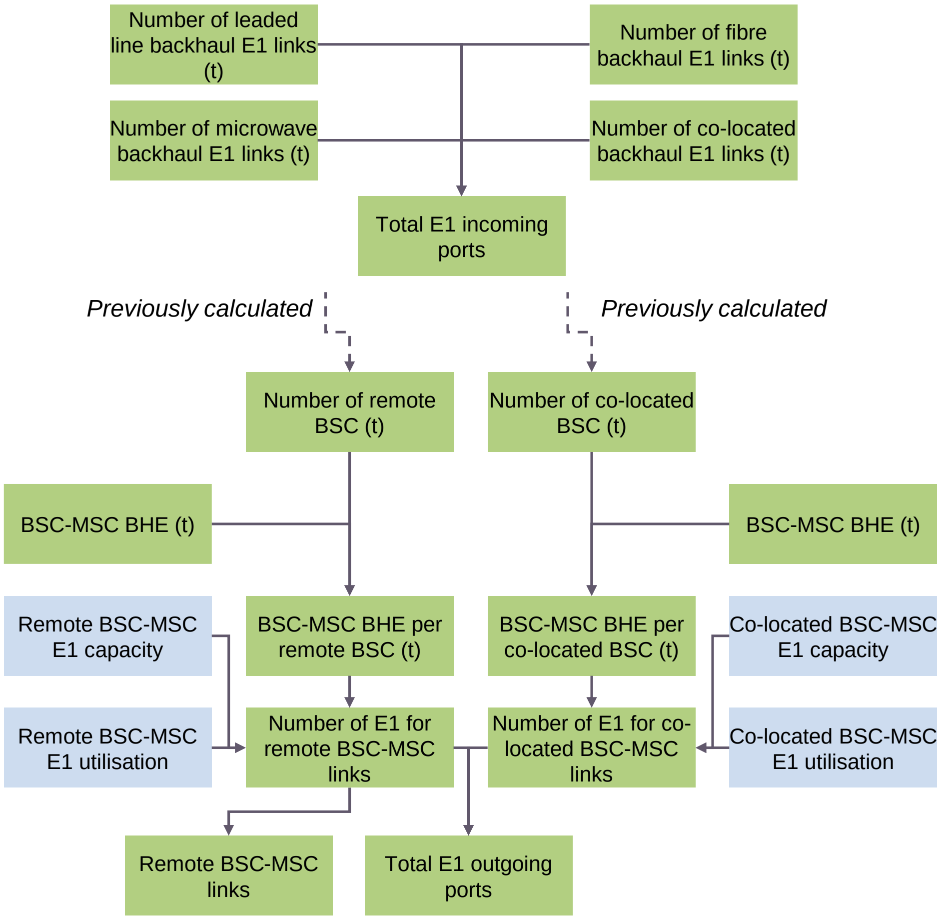
Total outgoing ports for co-located BSCs

Given the total number of co-located BSCs and BHE transceiver traffic, the total number of outgoing ports for co-located BSCs is calculated. The flow of calculation for co-located BSC ports is similar to that shown in Figure B.21. The transcoder is assumed to be in the BSC and the co-located links are not modelled (because this is part of the in-building cat-5 or similar wiring).

Incoming and outgoing ports

The incoming ports to the BSC face the BTS, while the outgoing ports face the MSC. Figure B.21 below shows the calculation of the BSC incoming and outgoing ports and transmission requirements.

Figure B.21: Calculation of BSC incoming and outgoing ports and transmission requirements [Source: Analysys Mason, 2017]



The total number of incoming ports into a BSC is the sum of the microwave, leased-line and fibre backhaul links, while the total number of outgoing ports is the sum of the total number of links for both remote and co-located BSCs.

B.2.7 3G RNC deployment

The deployment of RNC units is driven by three requirements:

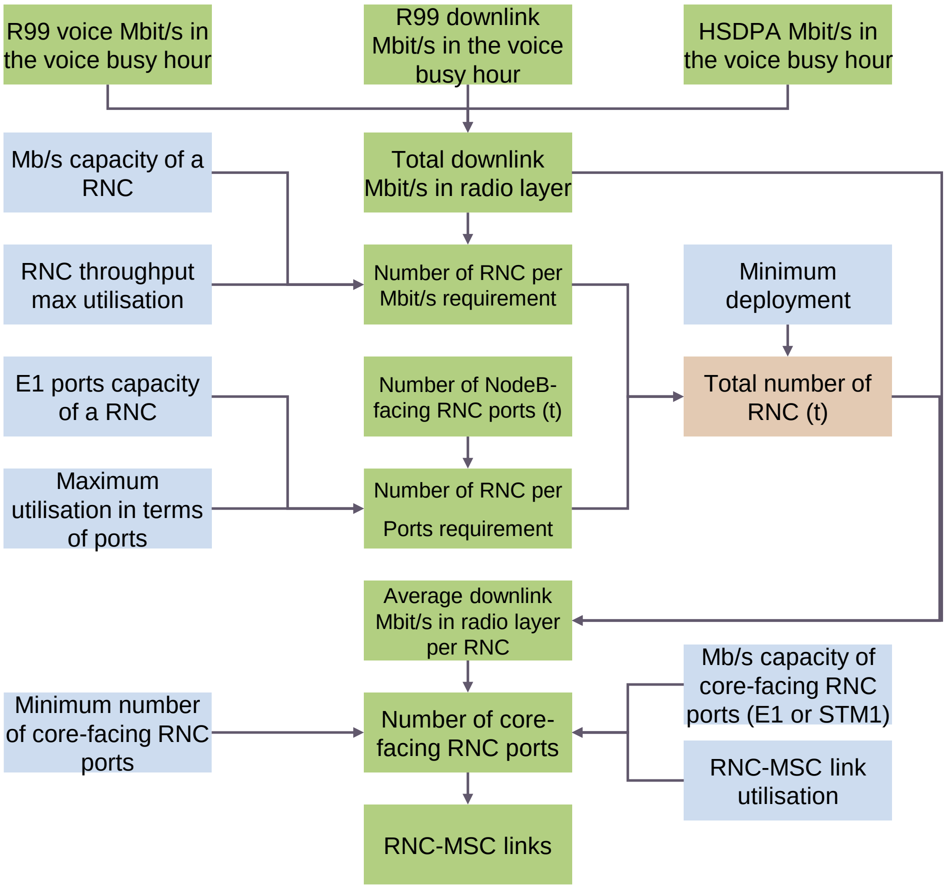
- the maximum throughput in Mbit/s (assessed in the downlink direction), assuming a maximum utilisation
- the maximum number of E1 ports connected, assuming a maximum utilisation
- the minimum number of RNCs deployed in the network for redundancy.

Each of those three requirements leads to a different number of RNC units. The total number of RNCs is the highest of these three values.

The number of RNC incoming ports (ports facing NodeBs) is derived directly from the number of backhaul E1 links, including all technologies.

The RNC–MSC links and core-facing E1 or STM-1 ports are dimensioned based on the average RNC downlink throughput, taking into account an utilisation factor that reflects, among other things, the need for redundant ports and links.

Figure B.22: RNC dimensioning [Source: Analysys Mason, 2017]



B.2.8 LTE-AP deployment

LTE does not require the equivalent of the RNC (for 3G) or BSC (for 2G). The functionalities of this equipment are distributed between the eNodeB (in the access network) and the MME (in the core network), effectively removing one network layer. Nonetheless, we have assumed the existence of an aggregation hub (LTE-AP) where the 4G backhaul links converge to aggregate the traffic into more capable links connecting to the regional and national backbone. We assume that the LTE-AP has additional functionalities and features, including multiplexing, and an optical distribution frame (ODF).

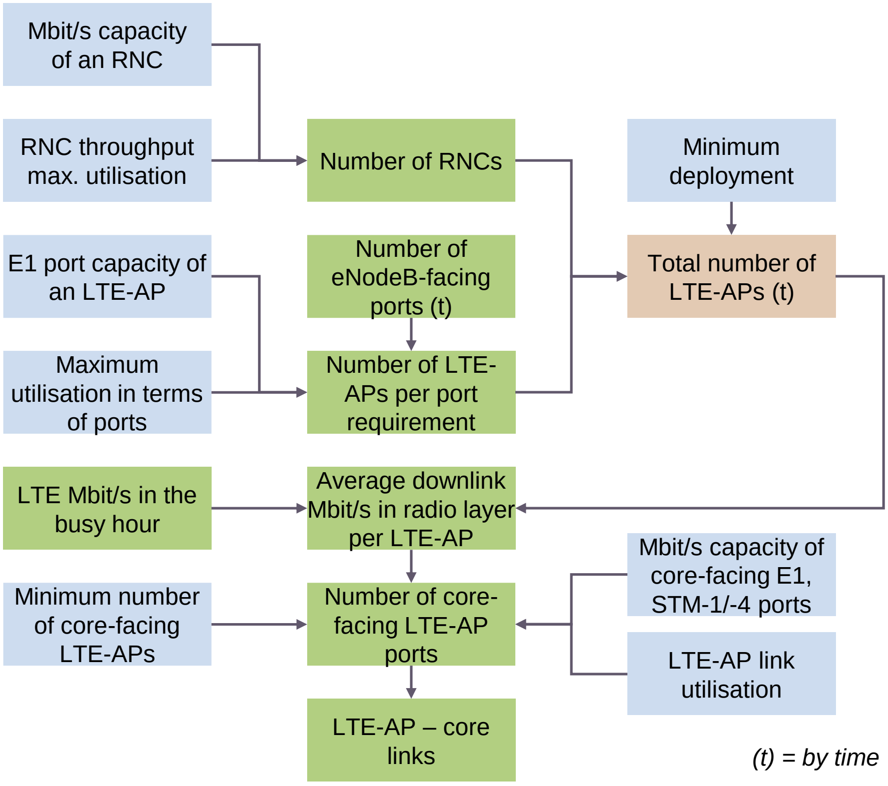
The LTE-APs are assumed to be co-located with RNCs and BSCs.

The deployment of LTE-APs is illustrated in Figure B.23 and is driven by:

- the maximum number of E1 ports connected, assuming a maximum utilisation
- the minimum number of LTE-APs deployed in the network for resilience
- the number of RNC locations.

The total number of LTE-APs is the highest of these three values.

Figure B.23: LTE-AP dimensioning [Source: Analysys Mason, 2017]



Similarly to what happens with the RNCs and BSCs, the number of incoming ports (ports facing eNodeBs) is derived directly from the number of backhaul E1 links, including all technologies.

The LTE-AP links facing the core are E1 or STM-1/-4 and are dimensioned based on the average LTE downlink throughput, taking into account a utilisation factor that reflects, among other things, the need for redundant ports and links.

B.2.9 MSC (MSC-server and MGW) deployment

In an all-IP network the MSC is modelled as two separate components, the MSS and the MGW:

- MSSs are driven by the voice processing capacity driver (busy-hour call attempts (BHCA))
- MGWs are driven by the voice traffic load and the BSC/RNC port requirements, as well as a typical deployment rule of one MGW pair per MSS.

Calculation of the number of MSC (MSS) units

In order to support processing demand, the number of MSC (MSS) units required is calculated from the central processing unit (CPU) capacity, processor utilisation and the demand for MSC processor time. Figure B.24 below shows the calculation sequence.

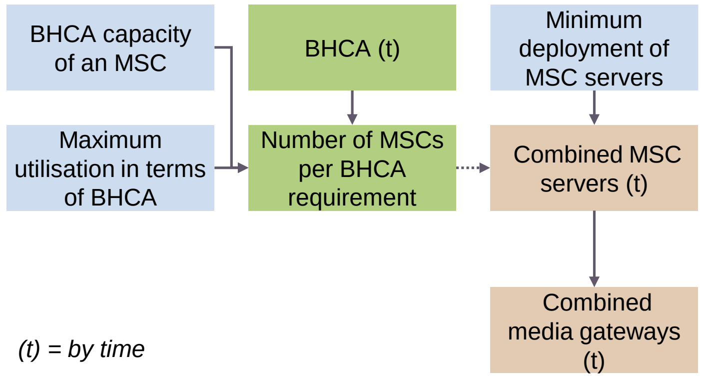


Figure B.24: Calculation of MSC (MSS) units [Source: Analysys Mason, 2017]

Taking into account the MSC (MSS) processor utilisation, the total number of processors required to meet the demand can be calculated as the total number of BHms divided by the effective capacity.

B.2.10 Deployment of other network elements

Home location register (HLR)

HLR units are deployed based on the average number of 2G and 3G subscribers (see the 4G core network subsection of Section B.2.11 for more details on the treatment of 4G subscribers). Figure B.25 below shows the calculations used to obtain the number of HLR units required.

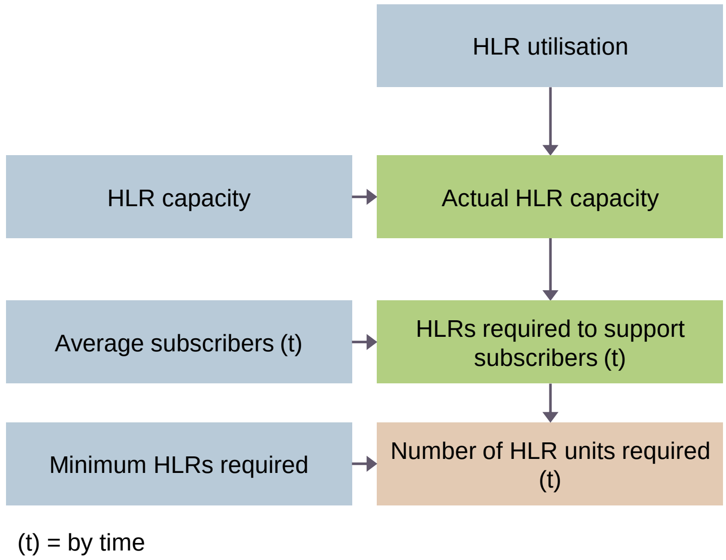


Figure B.25: HLR units calculation [Source: Analysys Mason, 2017]

A minimum of two HLR units is typically deployed from the start of operations, to cater for preprovisioned prepaid SIMs and redundancy. HLR units have an associated capacity and a maximum utilisation factor.

SMSC

The SMSC deployment is driven by SMS throughput demand. Figure B.26 below shows the calculation flow.

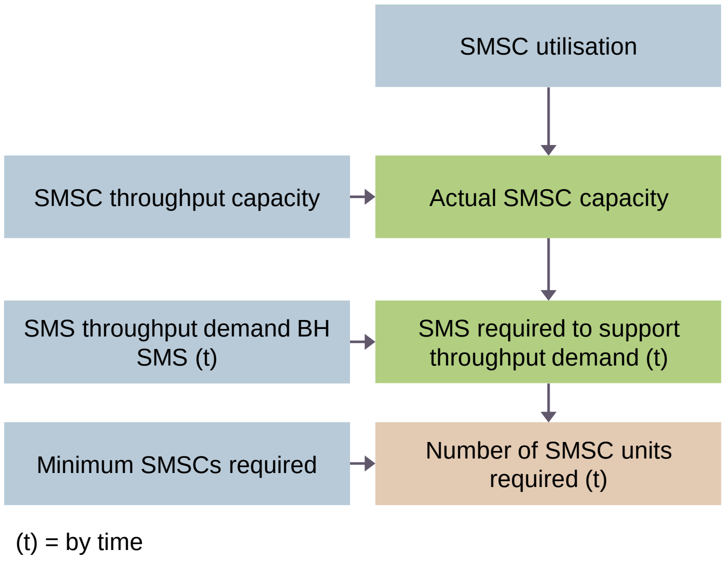


Figure B.26: Calculation of SMSC units [Source: Analysys Mason, 2017]

Dividing the SMS throughput demand by the actual SMSC capacity gives the number of SMSCs required to support this throughput demand. The number of SMSC units deployed is the higher of either the SMSCs required to support demand or the minimum SMSC units (one unit).

GPRS/EDGE/UMTS packet data infrastructure

There are three types of equipment specifically deployed for data services: PCU, SGSN and GGSN.

PCU units are added to the GSM BSCs to groom packet data to/from the radio transmission. A certain number of PCUs are deployed per BSC (if not incorporated within the modern BSC unit). It is assumed the UMTS RNC intrinsically contains PCU functionality. Figure B.27 below shows the calculation flow.

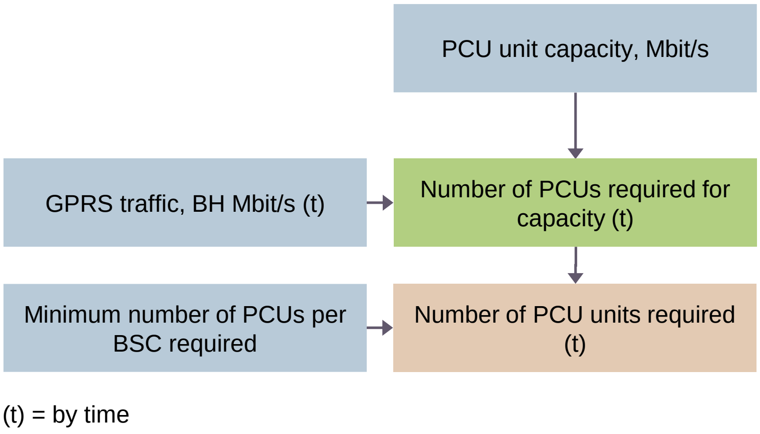


Figure B.27: Calculation of PCU units [Source: Analysys Mason, 2017]

The number of PCUs deployed is the maximum of the calculated number of PCUs required for capacity and the minimum number of PCUs per BSC required (which is one).

Figure B.28 below shows the calculations for SGSN and GGSN deployment, supporting connected and active packet data subscribers on both 2G and 3G networks. The same calculations are repeated for 2G, 3G and shared SGSN.

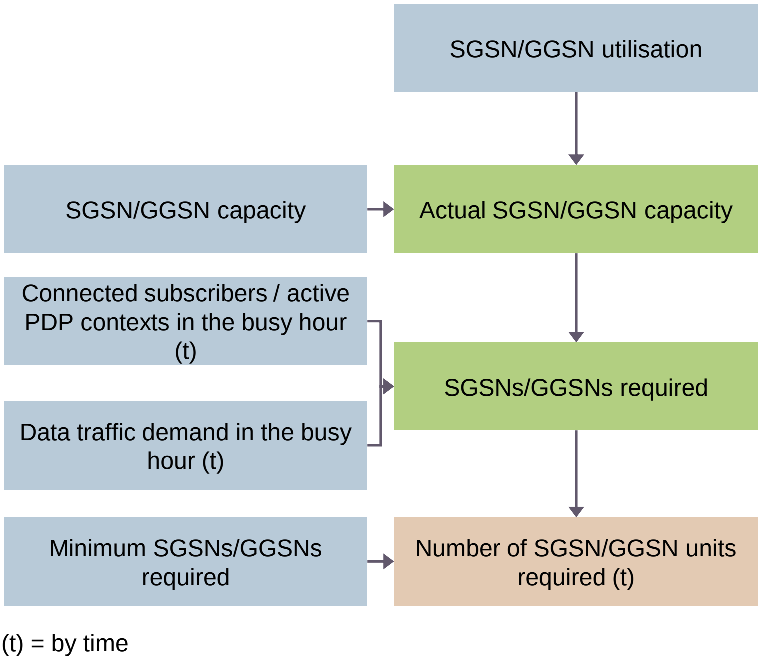


Figure B.28: Calculation of SGSN and GGSN units [Source: Analysys Mason, 2017]

The calculations for both SGSN and GGSN deployment are similar. SGSN deployment can be driven by the number of simultaneous active users (SAUs) in the busy hour, while GGSN deployment can be driven by the number of active packet data protocol (PDP) contexts in the busy hour. The minimum number of SGSNs and GGSNs deployed is two, for redundancy reasons.

The model assumes that the operator deploys new platforms, which are typically shared SGSNs and GGSNs, i.e. used for both GPRS/EDGE and UMTS.

Calculation of PCU–SGSN links (Gb interface)

This calculation involves four steps:

1 The Gb interface (PCU–SGSN links) is dimensioned to prevent it being the network bottleneck; that is, the capacity needed on the Gb interface is assumed to be equal to the capacity that would be needed if all GPRS channels reserved were simultaneously active on all sectors in the network
2 Remote Gb traffic is calculated based on the proportion of total PCU–SGSN traffic based on the proportion of remote PCUs, which is assumed to be equal to the proportion of remote BSCs
3 Remote Gb traffic is then converted into E1 equivalents, taking into account the utilisation of remote PCU–SGSN links
4 The Gb links are added to the BSC–MSC links for the purpose of calculating E1 or STM-1 equivalents, depending on the capacity needed.

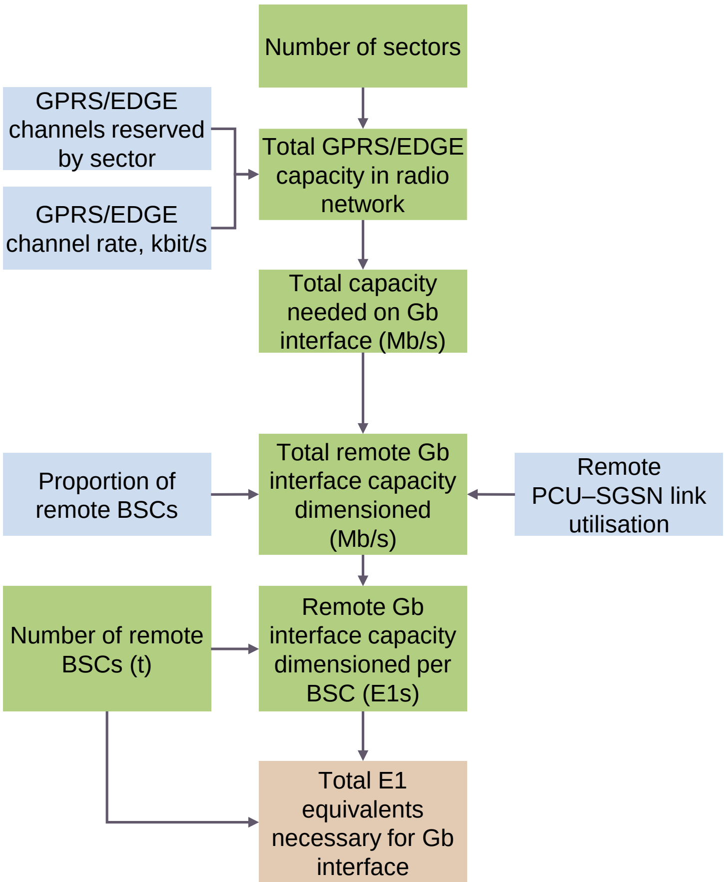


Figure B.29: Calculation of PCU–SGSN links (Gb interface) [Source: Analysys Mason, 2017]

VMS, intelligent network, billing system

These network elements are modelled as a single functional unit, deployed at the commencement of operations.

Network management system (NMS)

The network management system is deployed at the start of operations.

B.2.11 Deployment of 4G-specific core servers

4G core network

The inclusion of a 4G radio network requires the modelling of a 4G core network, which is assumed to be an evolved packet core (EPC)[31] one. This is an industry-standard architecture used to carry the data traffic from 4G eNodeBs, and is in line with the 4G network diagram provided by the operators. We have modelled four main assets:

- *Serving gateway (SGW)* – The primary function of this equipment is to manage the user-plane mobility and act as a demarcation point between the RAN and the core network. It serves as a local mobility anchor, meaning that packets are routed through this point for intra E-UTRAN mobility and for mobility through other generations (2G/3G)
- *Data traffic manager (DTM)* – This equipment includes any other systems that handle data traffic. Among others these include:
  - *packet data network gateway (PDN-G)* – This equipment, generally co-located with the SGW, serves as an anchor point towards the external packet data network. It supports policy enforcement features, packet filtering and charging support
  - *policy and charging rules function (PCRF)* – This equipment manages the policy and rule functions
- *Mobility management entity (MME)* – This equipment performs the signalling and control functions to manage the user equipment access to network connections, the assignment of network resources and the management of the mobility states to support tracking, paging, roaming and handovers. The MME also provides the control plan functionalities (similarly to the SGSN in a GPRS core network)
- *Home subscriber server (HSS)* – This is the 4G equivalent of the home location register (HLR).

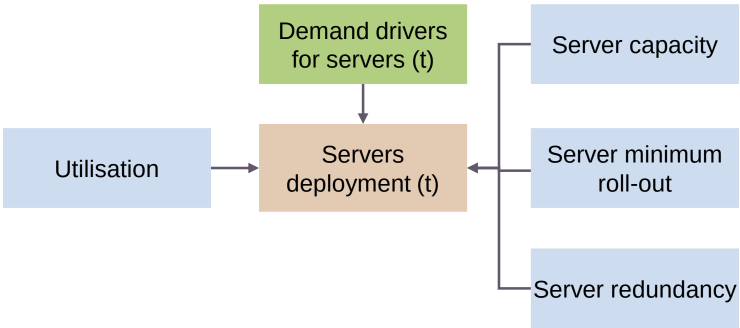
The main user inputs to the calculation are described in Figure B.30.

Figure B.30: Description of inputs used in the LTE core network calculations [Source: Analysys Mason, 2017]

Name	Description
Server capacity	The capacities of the core assets dimensioned in their respective units
Minimum roll-out	The minimum number of equipment units that must be deployed
Server redundancy	A value of 2 means that for each equipment deployed there is also a spare one
Server minimums	The minimum number of equipment units that must be deployed

31 Alcatel-Lucent, *Introduction to Evolved Packet Core*, available at http://resources.alcatel-lucent.com/?cid=133461.

Figure B.31: Calculation of 4G core network assets [Source: Analysys Mason, 2017]



The equipment deployed in the 4G core network is calculated according to the specific demand drivers, along with the assumed capacity and utilisation. We have made some assumptions regarding the capacity and maximum utilisation of the equipment, on the basis of our previous experience.

VoLTE network

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

VoLTE requires an IP multimedia subsystem (IMS) to be deployed in the core network. The IMS core is composed of:

- the call server (CS), which contains the voice service functions CSCF, ENUM and DNS[32,33]
- the session border controllers (SBCs)
- the telephony application servers (TASs), which must be deployed to manage voice services (in particular, the TASs manage capabilities such as call forwarding, call wait and call transfer).

The IMS core assets are summarised in Figure B.32 below.

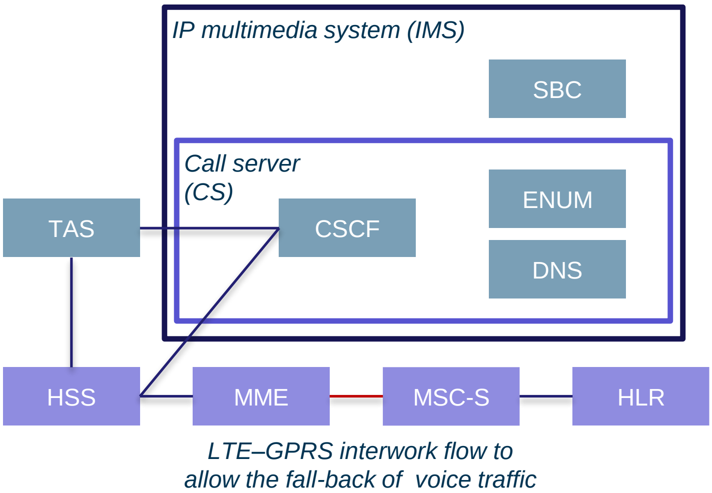


Figure B.32: Appearance of an IP multimedia system (IMS) [Source: Analysys Mason, 2017]

32 Call session control function, E.164 number mapping and domain name system, respectively.

33 The CSCF, ENUM and DNS are not explicitly modelled; they are contained within the call server (CS) and as such are treated as a single asset.

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 coverage of the 2G/3G circuit-switched networks but not 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, leaving the legacy HLR unchanged. Upgrades to the network management system (NMS) may also be required to support VoLTE.

The calculation structure for the VoLTE assets in the updated model is the same as that for the 4G core network, as shown in Figure B.31. The number of servers deployed in the VoLTE network is calculated according to their demand drivers, along with their specifications and utilisation. The planning period is then factored into the output.

Annex C Glossary

2G	Second-generation mobile telephony
3G	Third-generation mobile telephony
4G	Fourth-generation mobile telephony
AMR	Adaptive multi-rate
AMR-HR	Adaptive multi-rate half rate
AMR-WB	Adaptive multi-rate wideband
AP	Aggregation point
BH	Busy hour
BHCA	Busy-hour call attempts
BHE	Busy-hour Erlangs
BSC	Base-station controller
BTS	Base transceiver station
BU	Bottom-up
CCA	Current cost accounting
CDR	Call data record
CDMA	Code-division multiple access
CE	Channel element
CPU	Central processing unit
CS	Circuit-switched
CSCF	Call session control function
DNS	Domain name system
DSL	Digital subscriber line
DTM	Data traffic manager
E1	2Mbit/s unit of capacity
EC	European Commission
EPC	Enhanced packet core
EU	European Union
FAC	Fully allocated cost
FDD	Frequency division duplex
GGSN	Service GPRS support node
GPRS	General packet radio system
GSM	Global system for mobile communications
GSN	GPRS serving node
HCA	Historical cost accounting
HLR	Home location register
HSDPA	High-speed downlink packet access
HSPA	High-speed packet access
HSS	Home subscriber server
HSUPA	High-speed uplink packet access
IMS	IP multimedia subsystem
IP	Internet protocol
IRU	Indefeasible right of use
LMA	Last-mile access
LRAIC	Long-run average incremental cost
LRIC	Long-run incremental cost
LTE	Long-term evolution
LTE-AP	LTE aggregation point
MEA	Modern equivalent asset
MGW	Media gateway
MIMO	Multiple input, multiple output
MME	Mobility management entity
MMS	Multimedia messaging service
MNO	Mobile network operator
MSC	Mobile switching centre
MSS	Mobile switching centre server
MTR	Mobile termination rate
NGN	Next-generation network
NMS	Network management system
NPV	Net present value
NRA	National regulatory authority
ODF	Optical distribution frame
OFDM	Orthogonal frequency division multiplexing
PCRF	Policy and charging rules function
PCU	Packet control unit
PDN-G	Packet data network gateway
PDP	Packet data protocol
PGW	PDN Gateway
PoI	Point of interconnect
PoP	Point of presence
PS	Packet switched
PV	Present value
QAM	Quadrature amplitude modulation
RAN	Radio access network
RNC	Radio network controller
SAU	Simultaneous active users
SBC	Session border controller
SGSN	Serving GPRS support node
SGW	Serving gateway
SIM	Subscriber identity module
SMS	Short message service
SMSC	Short message service center
SNOCC	Scorched-node coverage coefficient
STM	Synchronous transfer mode
SWG	Server gateway
TAS	Telephony application servers
TDD	Time division duplex
UMTS	Universal mobile telecoms system
VMS	Voice mail system
VoLTE	Voice over LTE
WACC	Weighted average cost of capital