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Report for ANACOM

Mobile BU-LRIC model update – Model documentation

12 June 2018

Confidentiality notice

- Confidentiality notice: This document and the information contained herein are strictly private and confidential, and are solely for the use of ANACOM
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Introduction

Overview of principles

Market model

Network dimensioning

Portuguese geotype model

Network design

Network costing

Model calibration

Model results

Annexes

Analysys Mason has developed a bottom-up model to support the setting of mobile termination rates

- ANACOM has commissioned Analysys Mason to update the long-run incremental cost (LRIC) model ('2017 model') for the purposes of establishing and regulating the cost of mobile voice termination in Portugal
  - the previous version of the model ('2014 model') was developed in 2014 and 2015
- This wholesale service falls under the designation of Market 2[1] (previously Market 7, according to the European Commission 2009 Recommendation on relevant markets (the EC 2009 Recommendation)[2])
- Analysys Mason and ANACOM have agreed a process to deliver the LRIC model, which will be used by ANACOM to inform its regulation for mobile termination
  - this process presents industry participants with the opportunity to contribute at various points during the project (data request, consultation)
  - the model and this document have been updated to take into account the data and comments presented by operators in the data request and in the public consultation
- This document is drafted to accompany the model submitted to ANACOM and has the objectives of:
  - introducing the mobile cost model
  - outlining the approach to demand, dimensioning, deployment, expenditures, depreciation and incremental costing applied in the calculation
- The remainder of this document describes the mobile LRIC model and is structured as follows:
  - overview of principles
  - market model
  - network dimensioning
  - Portuguese geotype model
  - network design
  - network costing
  - model calibration
  - model results

Notes:

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.*

The key model inputs were consistently modified for confidentiality reasons in the public version of the model

- The 2017 model is populated and calibrated partly based on information that was provided by ANACOM and the three MNOs (MEO, Vodafone, NOS) following a structured data request process
  - note that the inputs derived from those sources are confidential and will be treated accordingly
  - compared to the contents of the data request, Vodafone provided limited information and was therefore excluded from the calibration
  - the data request was submitted also to the MVNOs, which however have not provided any response
- To protect the confidential information, a public version of the model was drafted where all inputs from the public model were modified:
  - inputs were modified by a random percentage of between -15% and +15%
    - for instance, if a variable has a value of 1 in the confidential model, it could have any value between 0.85 and 1.15 in the public model
  - for units costs, we will apply a further coarse rounding
- This allows to slightly alter the final result of the model (pure LRIC and LRAIC+) and will still allow interested parties to understand the inner workings of the model
- Portuguese operators have commented on the update of the model and their views and data points have been analysed and taken into account.

The same inputs anonymisation methodology was followed for the public versions of the 2014 mobile LRIC model and for the LRIC model developed to calculate fixed termination costs (FTR) in Portugal

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We retained the modelling principles of the 2014 model [1/2]

- The hypothetical existing operator has been defined based on Analysys Mason experience, ANACOM input, and responses from industry players to a Concept Paper in the 2014–2015 process, which presented the main modelling options
- **Methodology**: In line with the EC 2009 Recommendation and as instructed by ANACOM, we have used a bottom-up architecture to construct a pure LRIC model:
  - this approach increases the transparency and explicitness of the underlying calculations
  - it also facilitates the specification of a hypothetical operator by providing a consistent model framework
- **Market share**: We have built a model capable of calculating costs for a hypothetical existing operator achieving a 20% market share in the short term, and growing to 33.3% by 2017:
  - the model reflects aspects such as a hypothetical (efficient) coverage and topology
- **Radio network**: 2G + 3G + 4G networks as well as outdoor and indoor coverage have been modelled:
  - outdoor population coverage through macro sites
  - deployment of indoor and micro sites
  - spectrum allocation (and spectrum fees) have been modelled based on existing operators' spectrum awards and assignments
  - scorched-node calibration has been applied to radio sites, BTSs, NodeBs and eNodeBs
- **Core network**: We have modelled one core network architecture (transmission and switching) based on an all-IP (NGN) mobile core:
  - MGW, MSC (MSS) and SGW layers
  - all-IP core transmission
  - IP distribution layer for radio sites
- **Voice and data services**: We have reflected all major services in the model:
  - 2G/3G/4G voice
  - SMS and MMS
  - GPRS, EDGE, R99, HSPA and LTE data bearers
  - economies of scope have been shared across voice and data in the LRAIC+ model

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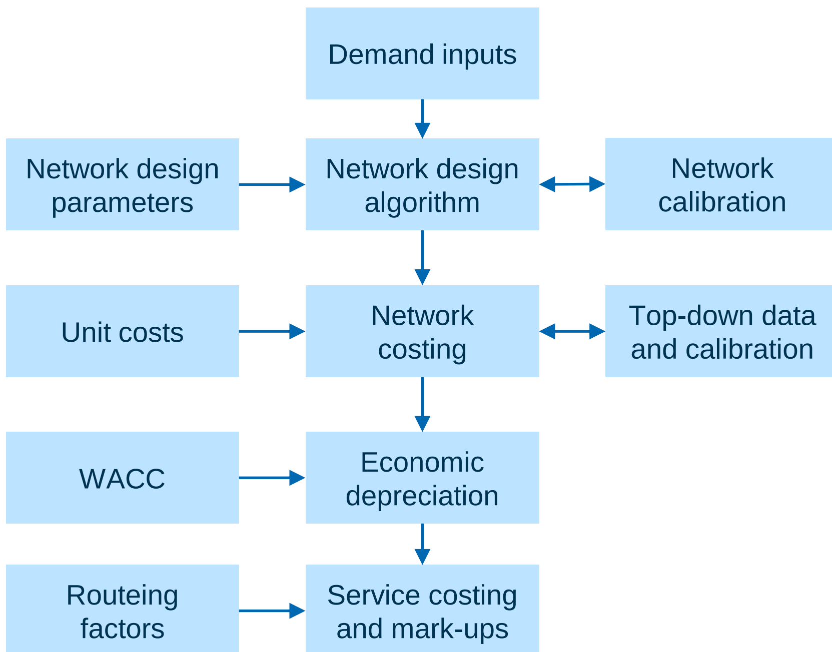
We retained the modelling principles of the 2014 model [2/2]

- **Wholesale network costs**: The model covers network activities plus common business overheads:
  - retail costs (handsets, subsidies, dealer payments, promotions, customer care, sales and marketing, etc.) have not been modelled
  - the LRAIC+ results include a share of business overheads
  - pure LRIC results exclude all common cost components
- **Increments**: We have considered two increments:
  - *LRAIC+*: the average incremental cost of all traffic plus a mark-up for common costs: network common costs represents the cost incurred to meet the minimum coverage requirements of mobile subscribers
  - *pure LRIC*: the avoidable long-run cost of the wholesale mobile termination volume, as the last service in the network, for which we have used the EC 2009 Recommendation
- **Depreciation**: We have modelled economic depreciation for a discounted full-time series over 45 years in real 2017 EUR
  - this is the same functional form of economic depreciation that Analysys Mason has applied in similar regulatory cost models in the Netherlands, Denmark, Norway, France, Sweden and Belgium, and was satisfactorily tested by Ofcom during its economic depreciation considerations
  - moreover, this was the methodology used in Portugal itself for the 2014 model
- **WACC**: Following ANACOM’s methodology, we have calculated a mobile WACC to reflect prevailing capital cost parameters, using the same methodology and benchmark companies as in the 2014 model
- **Years of calculation**: The model calculates costs over the lifetime of the business, including ongoing equipment replacements:
  - discounted over 45 years
  - terminal value beyond 45 years is assumed to be negligible

Outline form of the model

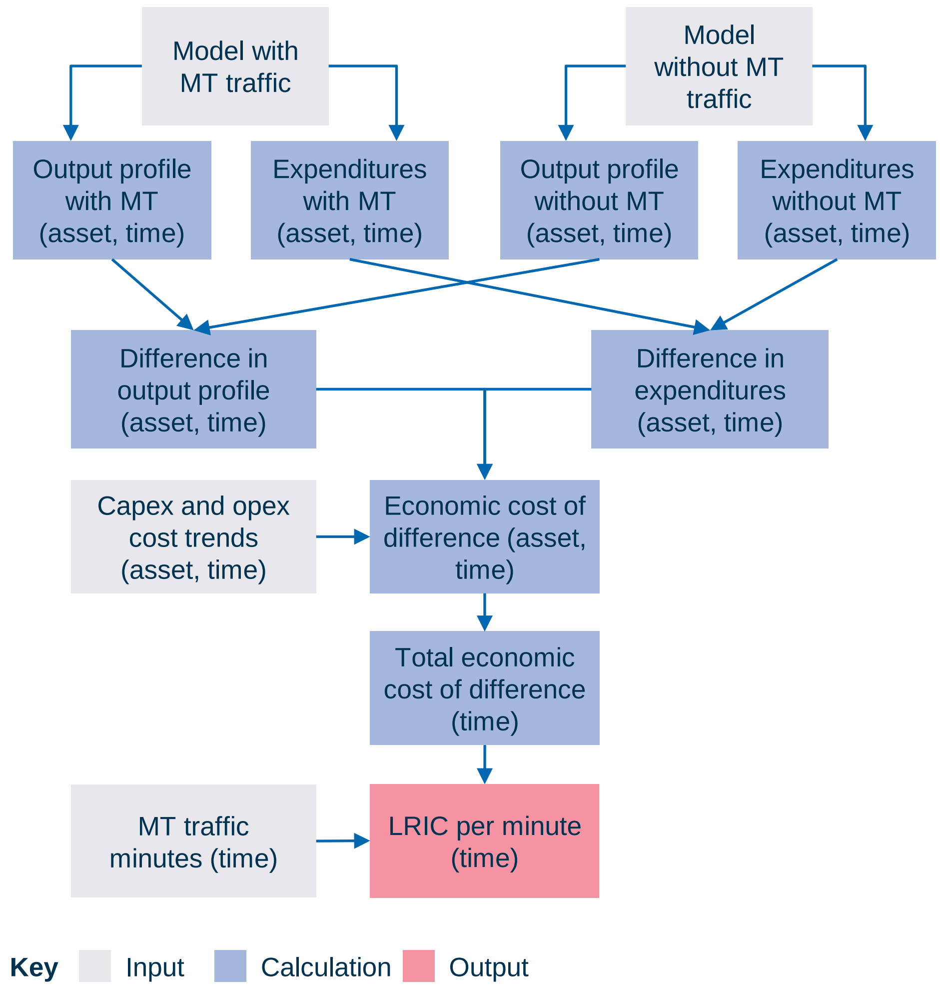
- **Demand inputs**: market subscribers and traffic for the operator
- **Network design parameters**: busy-hour factors, coverage parameters, switch capacities, network topology, etc.
- **Network design algorithm**: calculation of network element requirements over time
- **Network calibration**: check and/or application of scorched-node adjustments in the model depending on whether the modelled network is realistic when compared to actual operator deployments
- **Unit costs**: modern-equivalent asset input prices for network elements, indirect costs, business overheads and cost trends over time
- **Network costing**: calculation of capital and operational expenditures over time
- **Top-down data and reconciliation**: categorisation of operators' top-down data and activity of reconciliation with the modelled bottom-up expenditure
- **WACC**: discount rate
- **Economic depreciation**: annualisation of expenditures according to defined economic principles
- **Routeing factors**: average resource consumption inputs
- **Service costing and mark-ups**: calculation of per-unit long-run average incremental costs, plus common-cost mark-ups

Overall flow of the bottom-up model



The model calculates ‘pure’ LRIC results as the delta in expenditures and traffic: with and without termination

- The model uses a macro to run the network design:
  - *with* and *without* the volume of **wholesale mobile termination**
  - including a small number of related technical assumptions:
    - reduced number of special sites: we assume that the proportion of micro sites scales with termination traffic in a similar fashion to what happens for macro sites
    - ‘relaxation’ of 3G cell breathing, which is the shrinking of the coverage radius with increasing cell loading (see the network design section for more details)
- The delta in expenditures calculated by the model in these two states is annualised using the economic depreciation algorithm, which spreads (i.e. depreciates) the cost according to:
  - underlying equipment price trends
  - volume of wholesale termination traffic
  - discount factor (to calculate the cost of capital employed)



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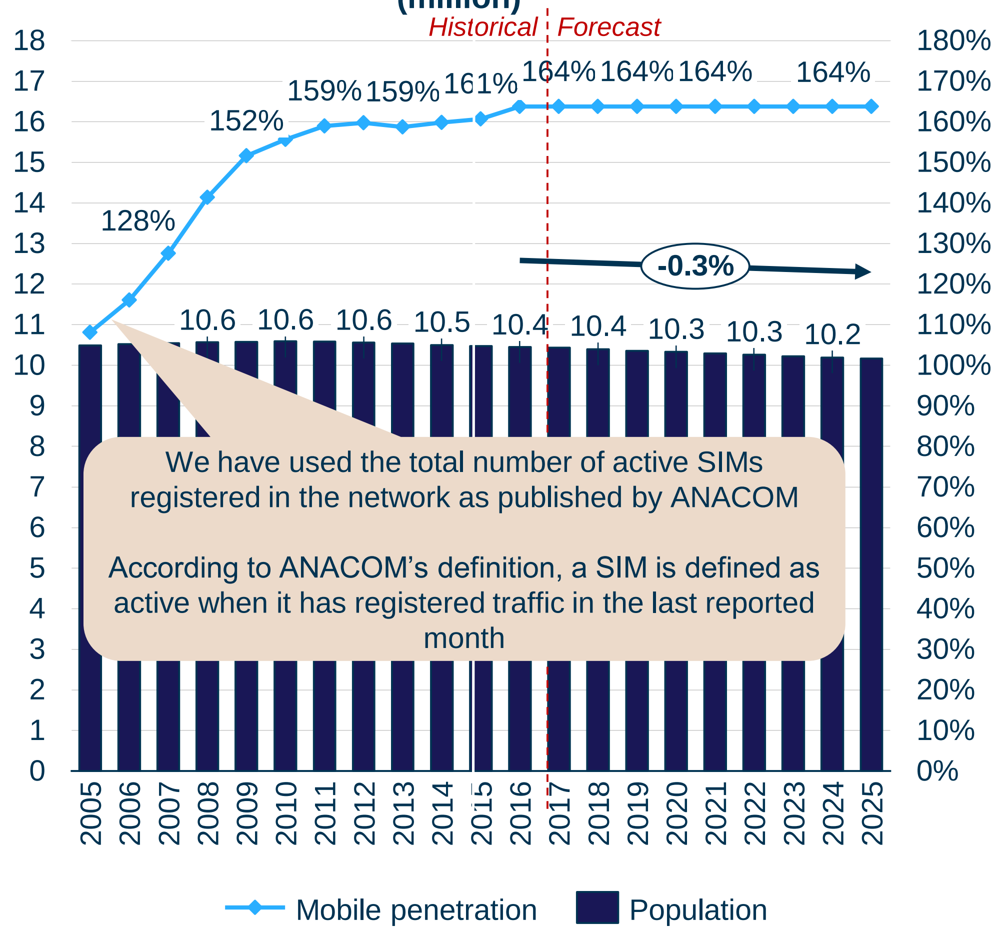
The market model forecasts subscribers, traffic and market share

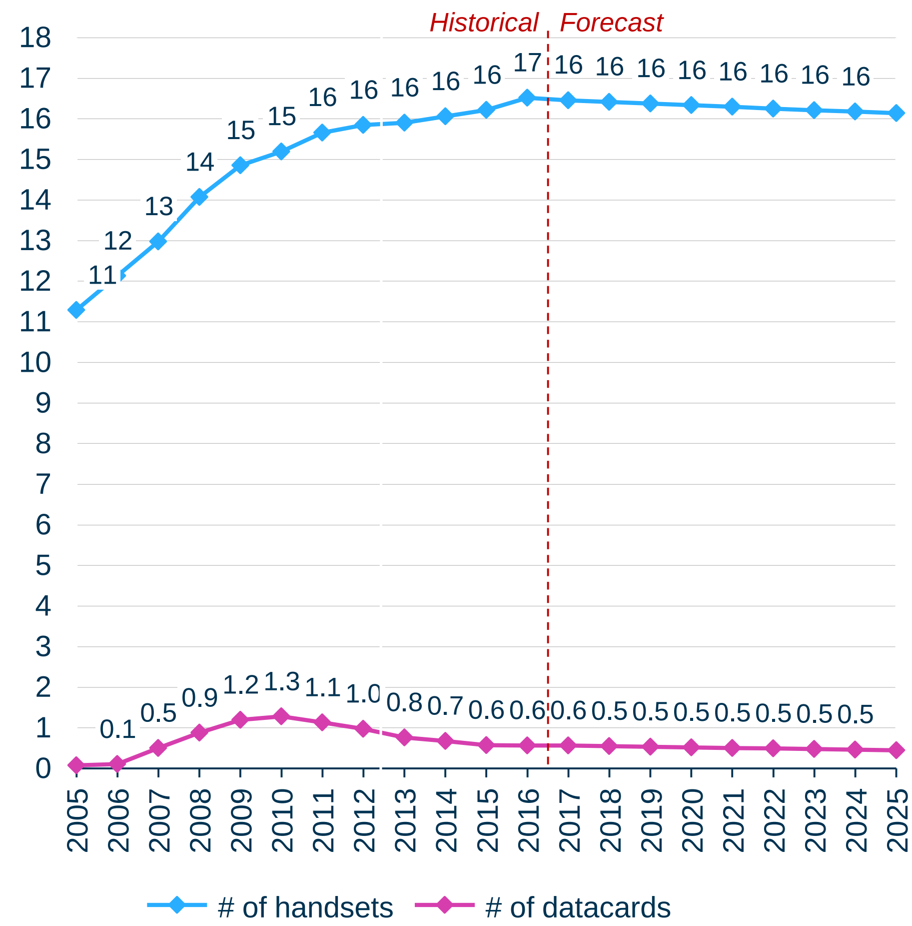
- Market demand is modelled based on historical data provided by ANACOM and on forecasts by Analysys Mason Research and other research companies
  - for future years, a forecast market average is defined, towards which all operators converge by 2025
  - we have modelled a static market after 2025
- The market share of the modelled operator is expected to reach 20% in 2011 and keep growing to 33.3% in 2017
  - the market share evolution follows Proposed Concept 3 of the Concept Paper that was published for the consultation process, and is in line with the EC 2009 Recommendation
- The number of active subscribers in the market is calculated using a projection of future population and penetration of digital mobile services
  - as part of the model finalisation, we have modelled no additional growth of SIM penetration after 2025
- The forecast voice and SMS traffic demand for the market is determined by a projection of traffic per subscriber, multiplied by the projected subscriber numbers
  - historical traffic is based on ANACOM's statistics
  - total traffic is distributed among the different types of traffic based on traffic proportions from 2017
  - the total traffic for the modelled operator is based on the market share of the operator
    - the termination (i.e. incoming excluding on-net) traffic for the modelled operator is calculated as a proportion of the outgoing one for the modelled operator itself
- We have forecast the take-up of 3G and 4G among the market subscribers, obtaining the evolution of the technological mix
  - the model takes into account that a 4G (or 3G) subscriber is expected to generate a proportion of non-4G (or non-3G) traffic as well, depending on the cell it is connecting to
- We have then calculated the number of data users split on a device (handset/MBB) and technology (2G/3G/4G) basis, leveraging on the data published by ANACOM

We have forecast mobile penetration as well as the split between handsets and mobile broadband (MBB) SIMs in Portugal

Population and year-end mobile penetration of active SIMs (million)



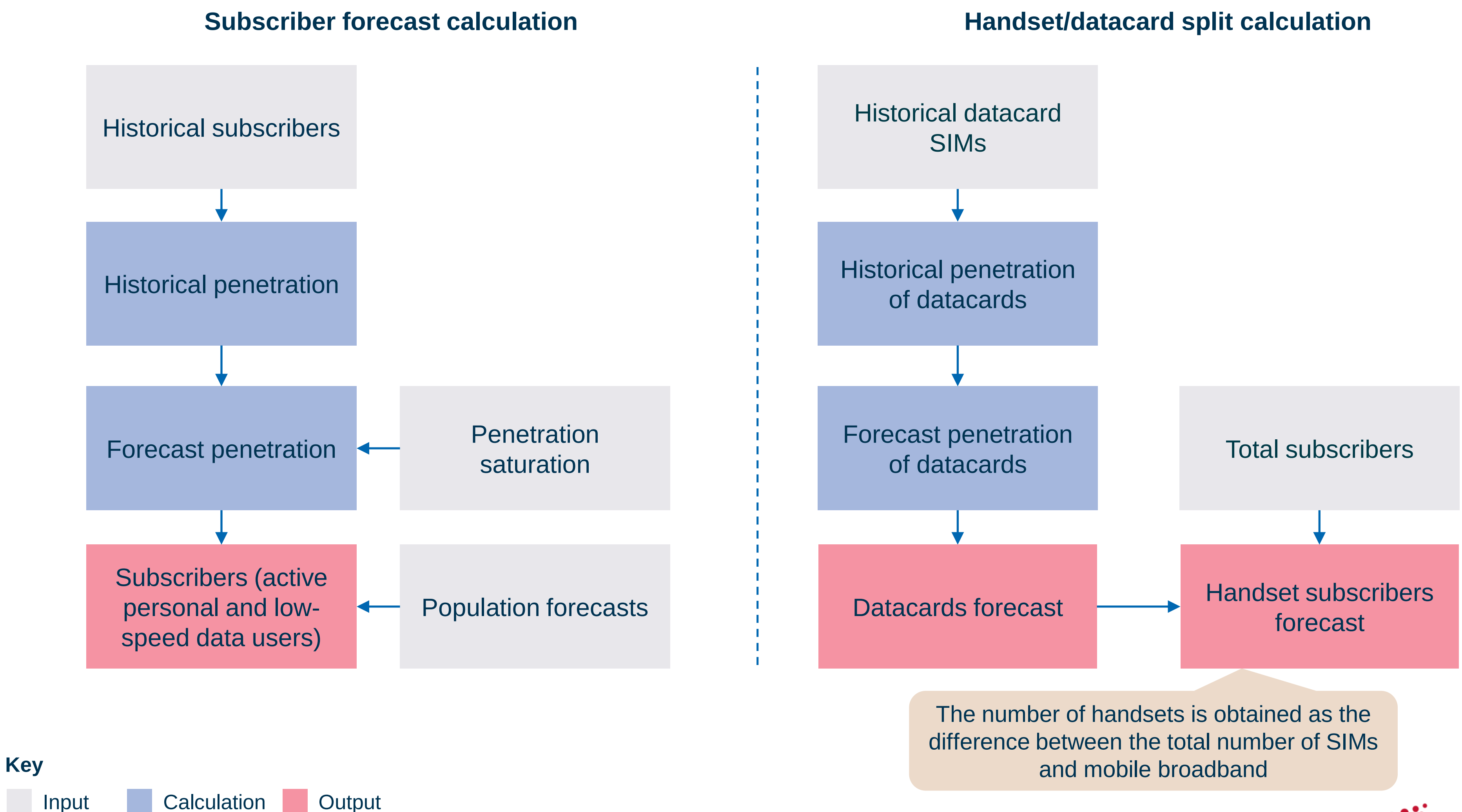
Split of subscribers by device (million)



Note: MBB is here defined as dongles and datacards

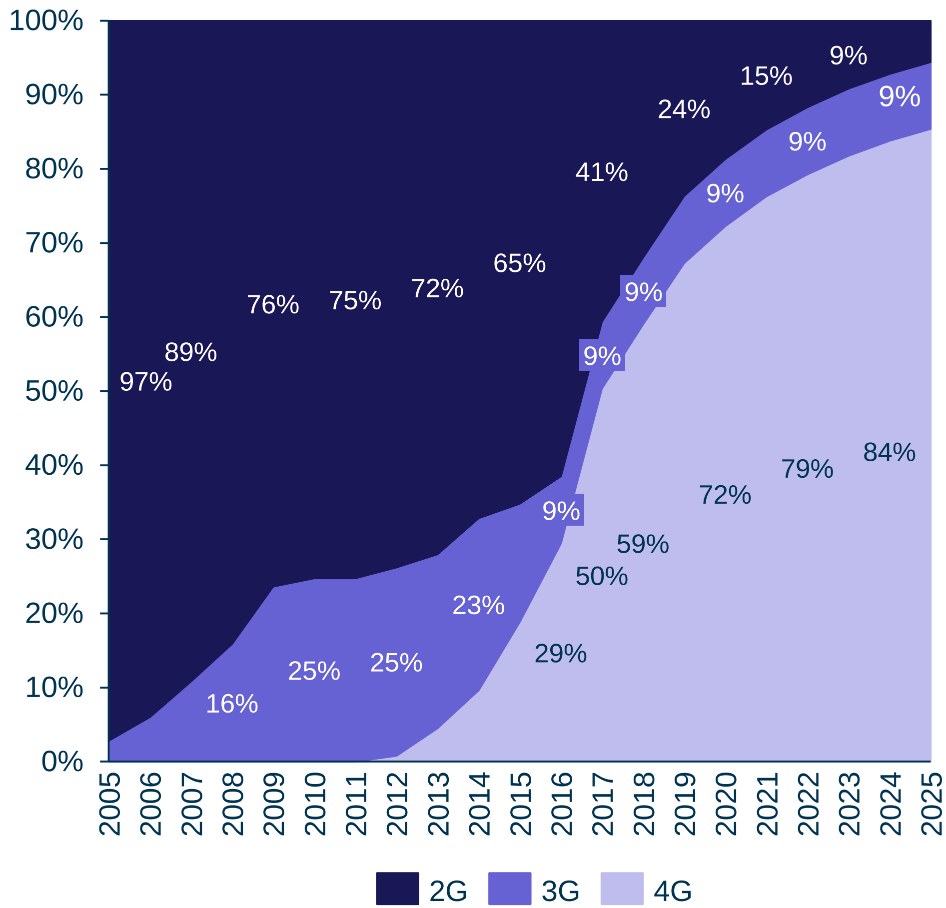
Source: Analysys Mason model, ANACOM, Euromonitor, ITU, EIU, Analysys Mason Research

Active mobile subscribers are forecast first, from which we have derived the split of MBB and handset SIMs

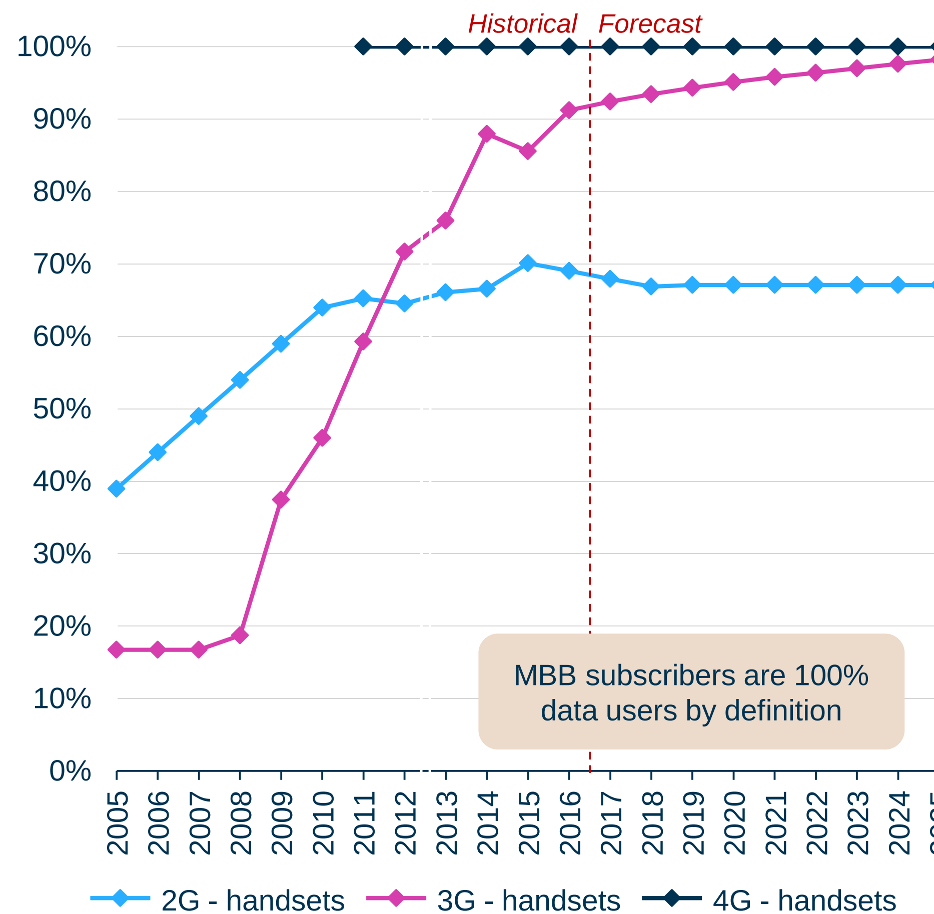


We have made an estimate of the take-up of data services both by device (handset/MBB) and by technology (2G/3G/4G)

Share of subscribers by technology



Share of subscribers taking data services by technology

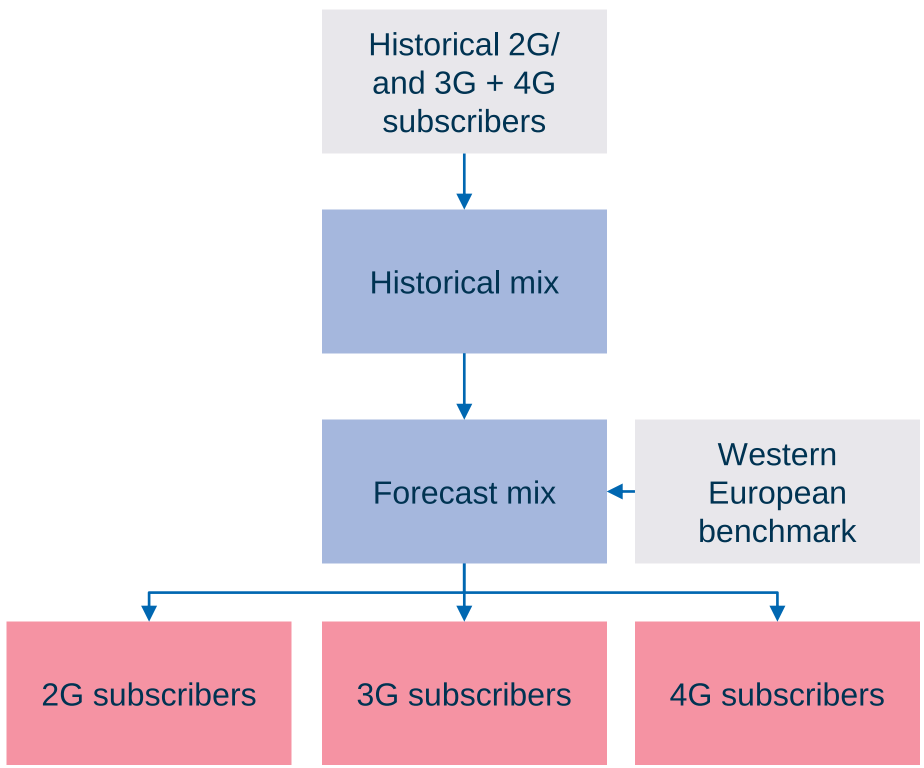


Note: A subscriber is, for instance, defined as 4G if it has a 4G-capable device along with a 4G subscription (these users are expected to generate non-4G traffic as well, depending on the cell they are connecting to)

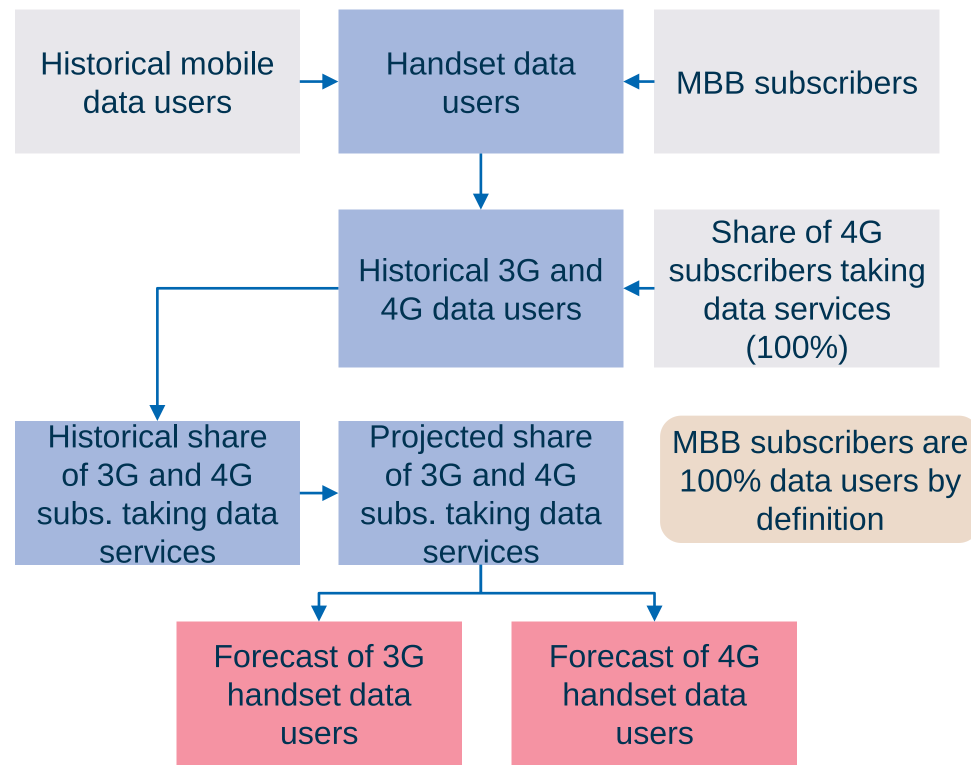
Source: Analysys Mason model, ANACOM

Starting from the data provided by ANACOM we have made estimates on the technological mix and the take-up of data services

Subscribers' technological mix forecast



High-speed data users forecast (handset only)



A similar methodology has been adopted to estimate and project low-speed 2G (GPRS and EDGE) and 3G (UMTS R99) subscribers

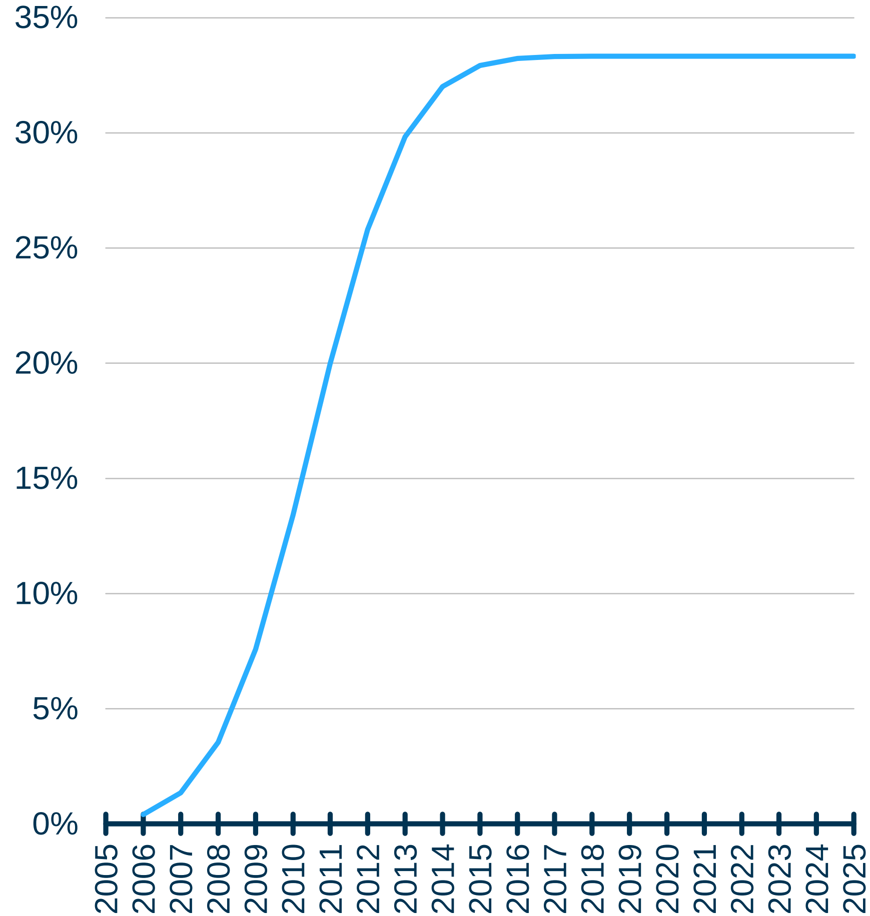
Key

Input Calculation Output

Market share is assumed to reach 20% in 2011 and then rise to 33.3% in 2017 when it will reach its plateau

- The model includes a hypothetical efficient-scale operator defined as starting its network deployment in 2005 and launching its commercial operations one year later (2006)
- The operator is assumed to reach a 20% market share 5 years after launch and a 33.3% share by 2017 (stabilising thereafter)
- The hypothetical operator's growth in traffic (i.e. voice, messaging and data) is proportional to its market share and the overall size of the Portuguese market

Subscribers' market share of the hypothetical existing operator



Source: Analysys Mason model, ANACOM

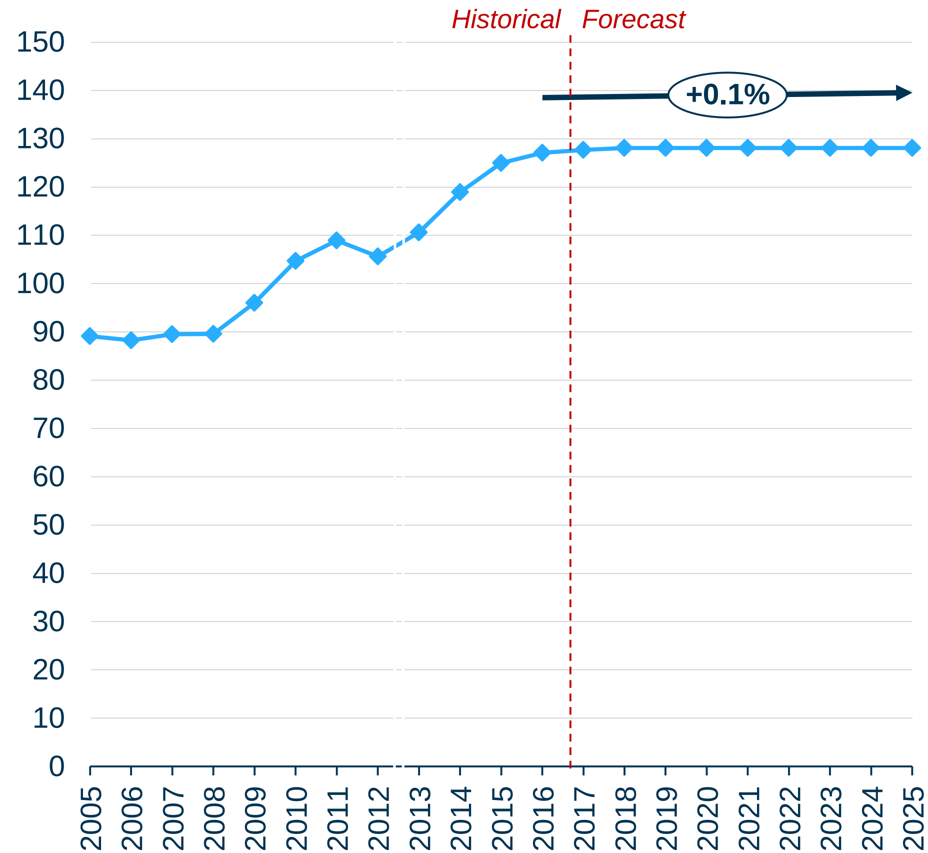
Voice usage per SIM is modelled using actual market data and forecasting its growth until 2017

- We assume traffic per SIM to stabilise after 2017 and a non-changing distribution of the traffic by destination:
  - a conservative approach in forecasts reduces the risk of introducing uncertainties in the model's calculations

Distribution of traffic by destination in 2017

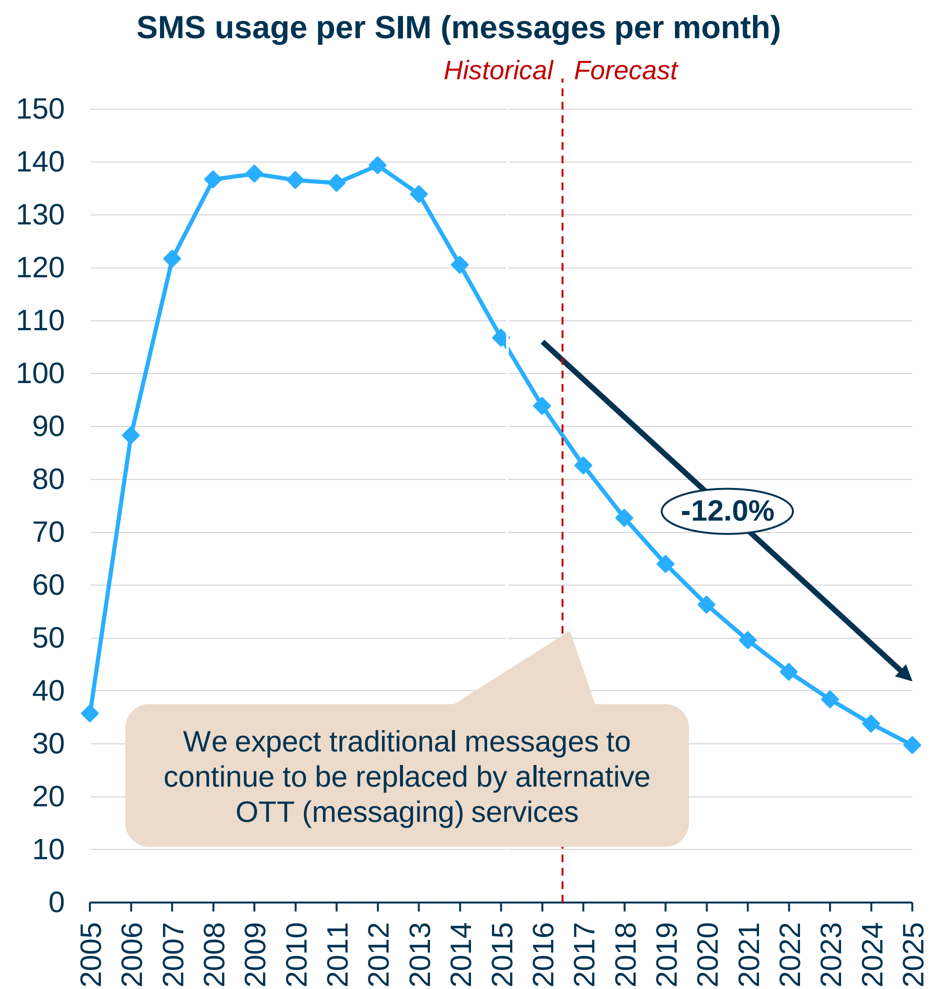
Traffic	% voice traffic
Outgoing	69.3%
Mobile on-net	47.2%
Mobile to fixed/non-geographical numbers	4.9%
Mobile to mobile (off-net)	15.2%
Mobile to international	2.0%
Incoming	27.6%
Fixed to mobile	1.5%
Mobile to mobile (off-net)	23.8%
International to mobile	2.3%
Roaming	3.1%
Roaming in	1.6%
Roaming out	1.5%

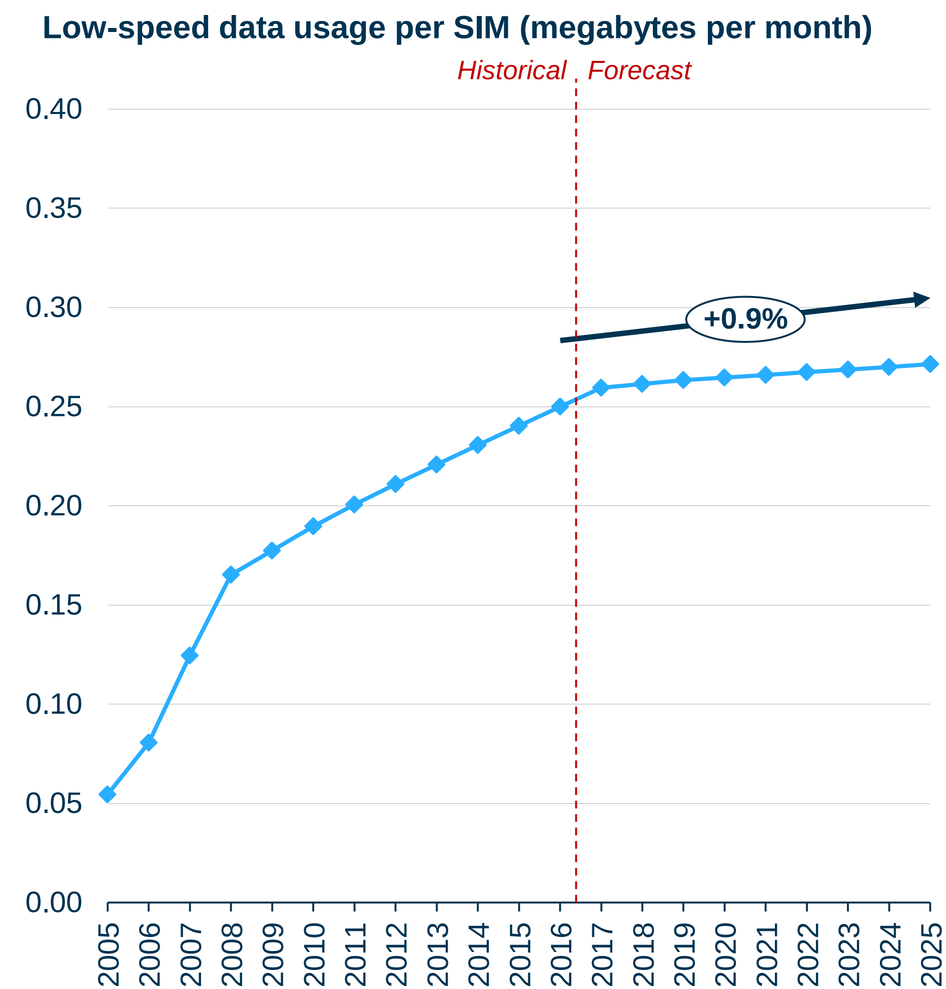
Voice usage per voice SIM (minutes per month)



Source: Analysys Mason model, ANACOM

We project that messaging usage will quickly be replaced by alternative OTT services, while low-speed data usage is forecast to grow moderately

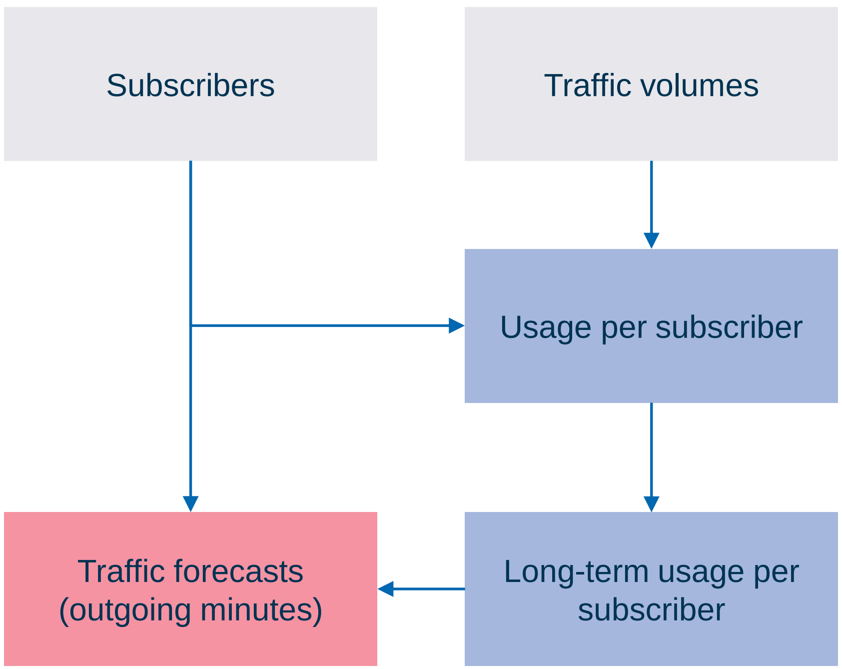




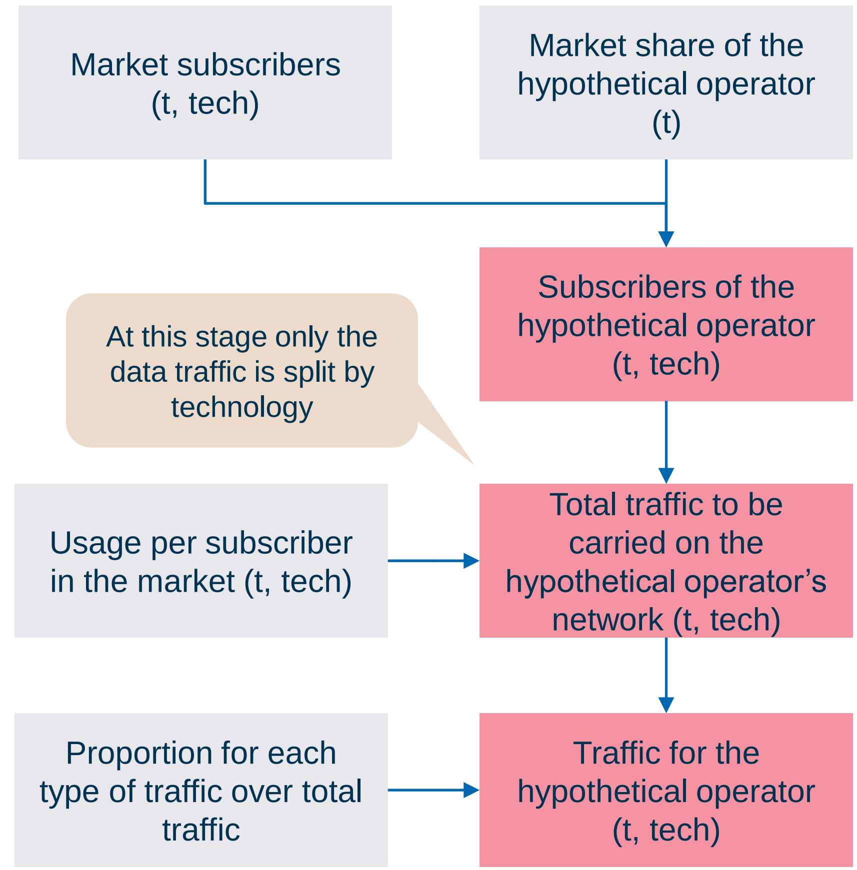
Note: Low-speed data usage per SIM has been based on estimates from Analysys Mason
Source: Analysys Mason model, ANACOM

We have estimated outgoing and incoming traffic for the hypothetical operator from the total traffic for the market

Algorithm used to forecast traffic usage parameters



Algorithm used to calculate the traffic for the hypothetical operator



Key

Input Calculation Output

Note: t = varying with time, tech = varying with technology (i.e. 2G/3G/4G)

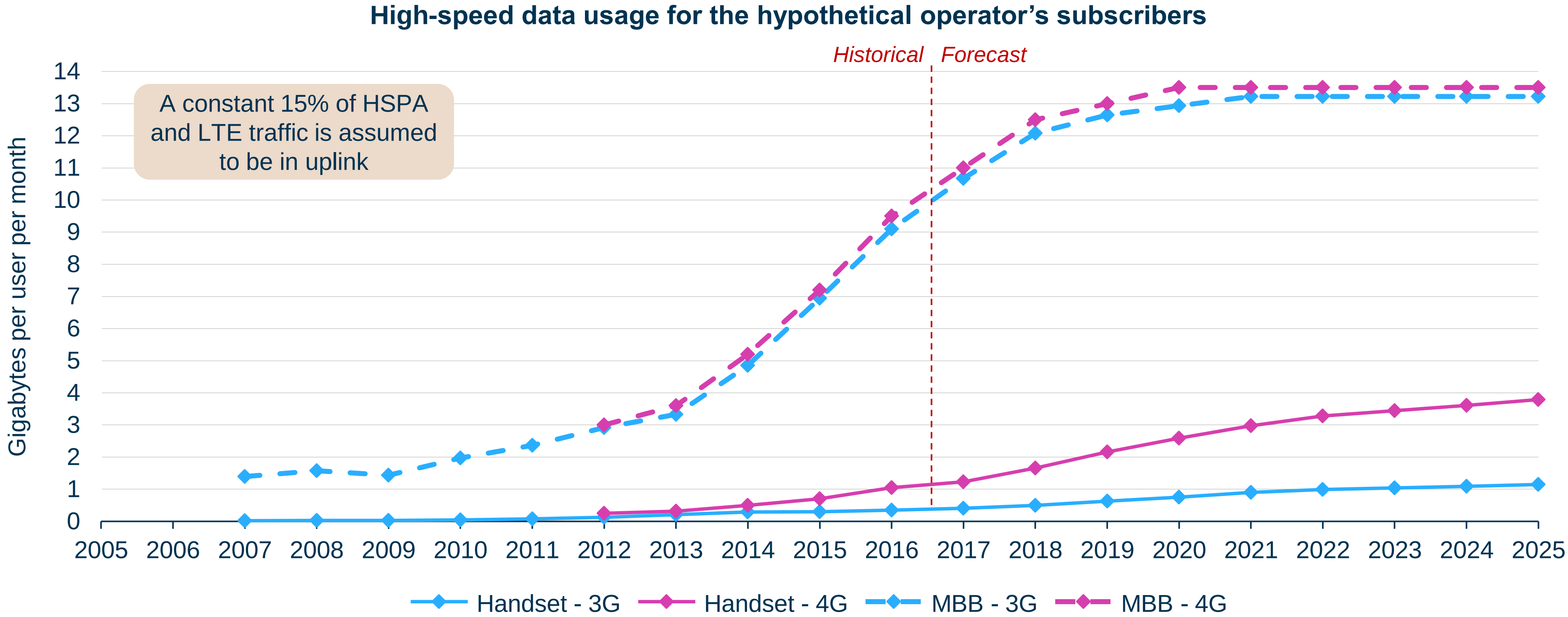
The proportion of the outgoing traffic to off-net evolves based on the market share of the hypothetical existing operator

- We have estimated the incoming traffic from off-net through a two-step approach, estimating (i) the share of outgoing traffic to mobile off-net and (ii) the incoming traffic from off-net as a percentage of the outgoing traffic
  - the first step is needed because the outgoing traffic to on-net is by definition equal to the incoming traffic from on-net
- The share of outgoing traffic to mobile off-net is usually not constant among operators with different market shares because of the different customer behaviours and operators' strategies
  - in Portugal, the differences among operators are relatively small
- The proportion of outgoing traffic to mobile off-net is based on a slope that defines the share of outgoing traffic to mobile off-net based on the market share of the modelled operator
  - the slope has been calibrated based on the market data for 2016 received by both the MNOs and ANACOM
- The incoming traffic from off-net as a percentage of outgoing traffic is calculated based on the actual market data and is maintained stable over time at approx. 24.3%
  - the incoming traffic from on-net, equal to the outgoing to on-net calculated in the previous step, is added on top of the incoming traffic from off-net to get to the total incoming traffic

Relationship between market share and proportion of outgoing traffic to mobile off-net in the model

Source: Analysys Mason, ANACOM, data request to MNOs

The model estimates the evolution of data usage separately for handset/MBB and HSPA/LTE users



- We have calculated the total traffic per user on the basis of data published by ANACOM
  - the average usage per handset subscriber sits at the bottom of our Western European country benchmark
- We assumed a growth in data usage consistent with what is expected in other peer countries
  - we forecast a higher growth than what was assumed in the 2014 model based on recent trends

Source: Analysys Mason model, ANACOM

We have made some assumptions on the traffic fall-back to other networks

- The model calculates the total traffic generated by 2G, 3G and 4G subscribers separately
- However, the traffic generated by a 4G subscriber is not necessarily carried over the 4G network: indeed, it can fall back to 3G or 2G on the basis of operators' technical and commercial considerations

Examples of reasons why traffic falls back to other networks

Coverage gaps	Availability of capable devices	User experience/capex efficiency
▪ There are differences in terms of coverage among the networks – GSM coverage provides an almost ubiquitous coverage layer, to ensure the provision of basic voice services ▪ Whenever the signal reception is weak or absent the subscriber will automatically connect to the strongest available signal, regardless of the technology of the SIM card installed and of the handset	▪ Mobile users might not have a handset capable of supporting a certain technology despite having an enabled SIM ▪ For instance: – there still is a large share of 2G handsets in the market that are not able to connect to 3G – most of the handsets currently sold are not able to support VoLTE services	▪ Mobile operators are interested in maximising the user experience offered to their customers ▪ On the basis of 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 allows operators to limit the capex required to increase capacity on the constrained network, by better utilising the capacity already installed for other technologies

The model handles the fall-back by assuming (separately for voice and data) that a certain percentage of traffic is carried over a lower-generation technology than that of the subscriber's SIM

A certain percentage of 4G data traffic will continue to be carried over legacy networks; VoLTE is expected to be launched in 2020

Share of traffic carried by network for each type of SIM

Network tech. / *Subscriber tech.*

Voice			
Technology	2G	3G	4G
2G	100%	-	-
3G	10%	90%	-
4G	*See VoLTE chart on the right*		

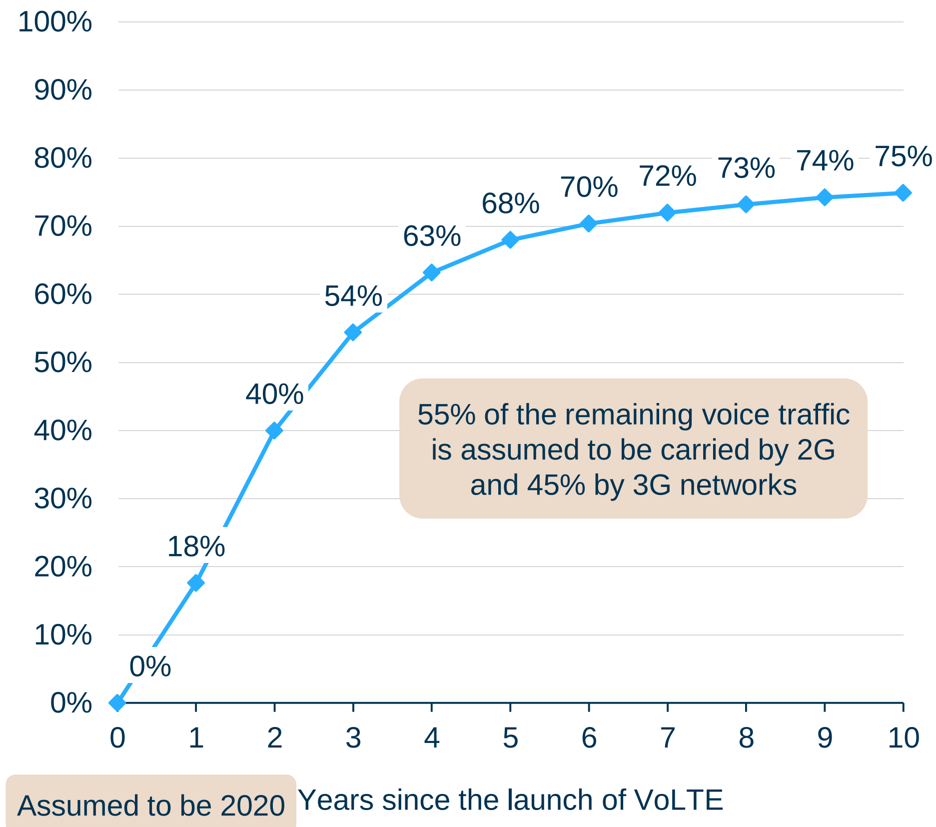
Network tech. / *Subscriber tech.*

Messaging			
Technology	2G	3G	4G
2G	100%	-	-
3G	10%	90%	-
4G	*See VoLTE chart on the right*		

Network tech. / *Subscriber tech.*

Data			
Technology	2G	3G	4G
2G	100%	-	-
3G	5%	95%	-
4G	*-*	*5%*	*95%**

Share of voice and messaging traffic generated by 4G subscribers that is routed via VoLTE

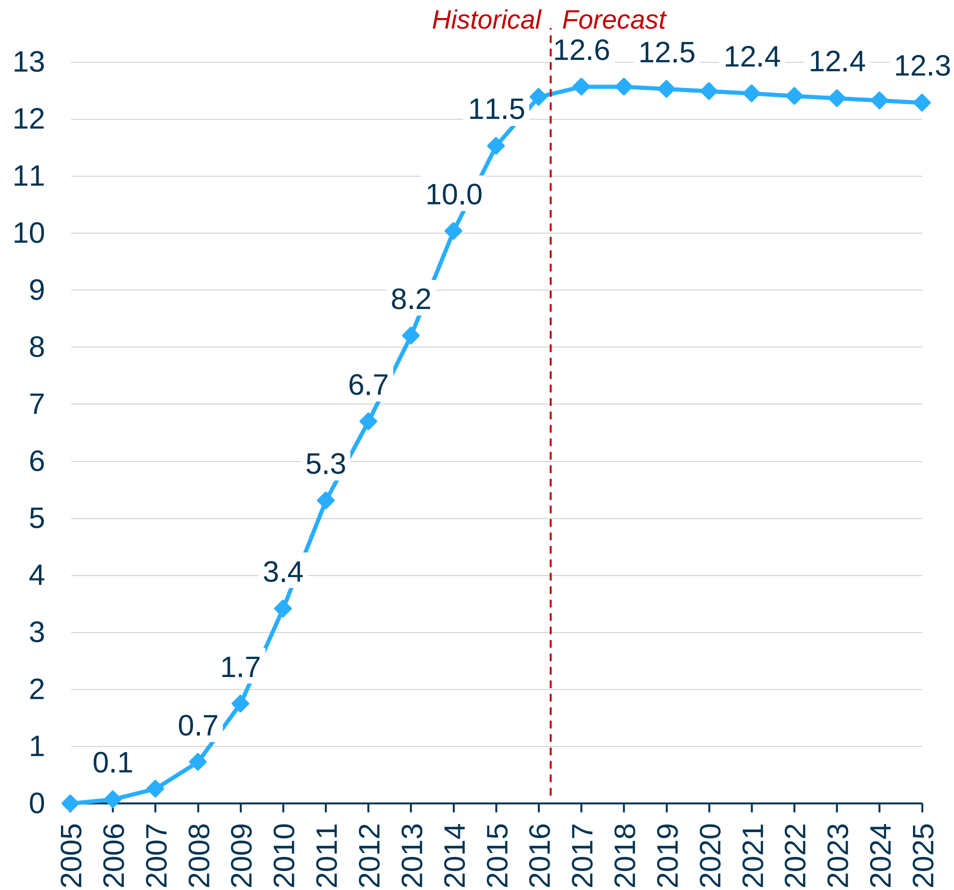


** A higher percentage of data traffic is expected to be carried over 3G in the short term due to coverage gaps and limited availability of LTE-capable handsets*

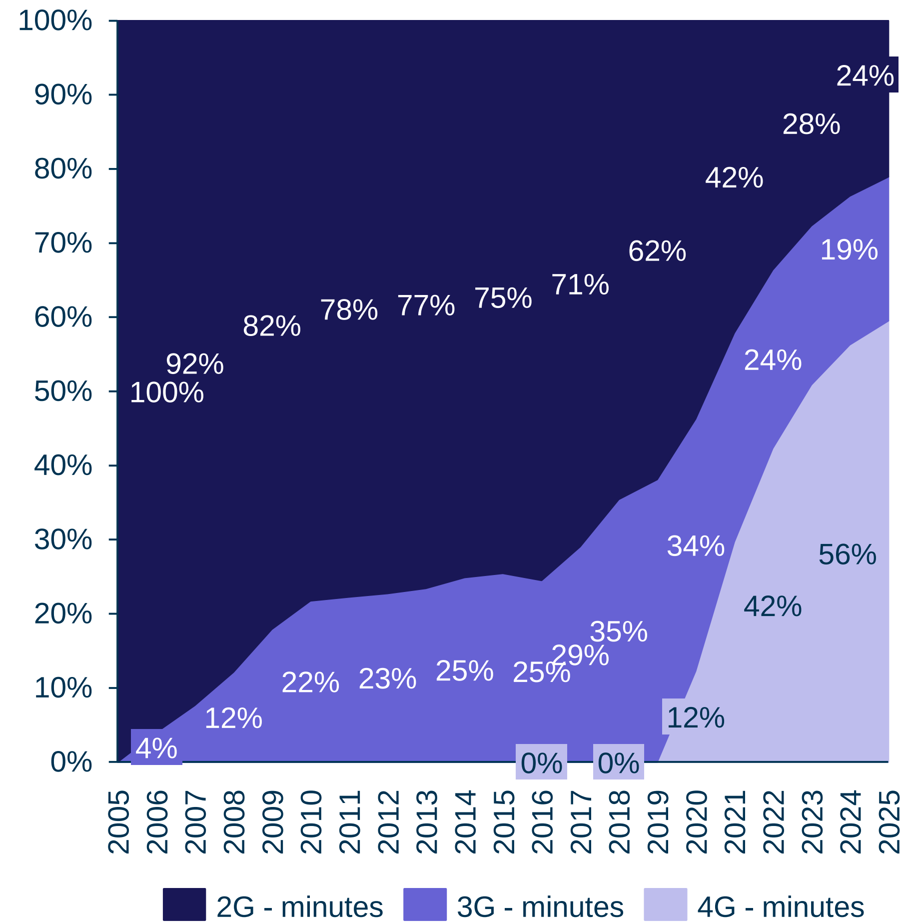
Source: Analysys Mason model

The voice traffic is projected to decrease marginally from its 2017 peak of circa 13 billion minutes

Forecast of the hypothetical operator total voice traffic (billion minutes per year)

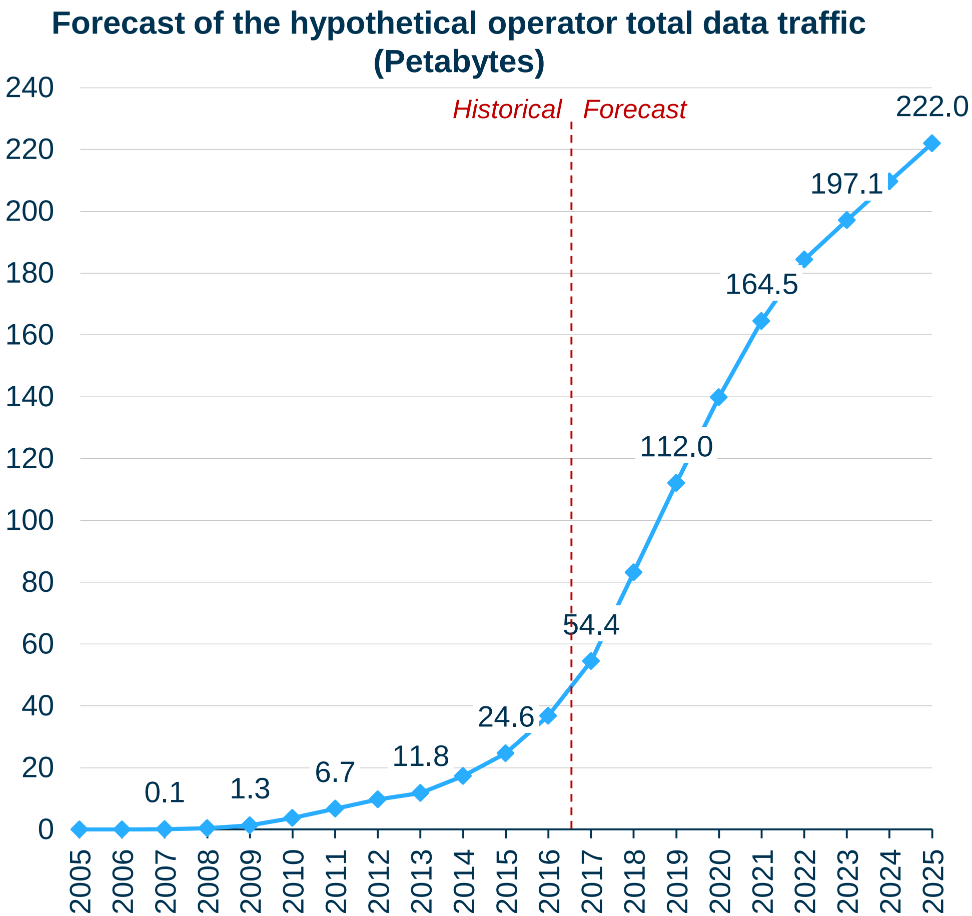


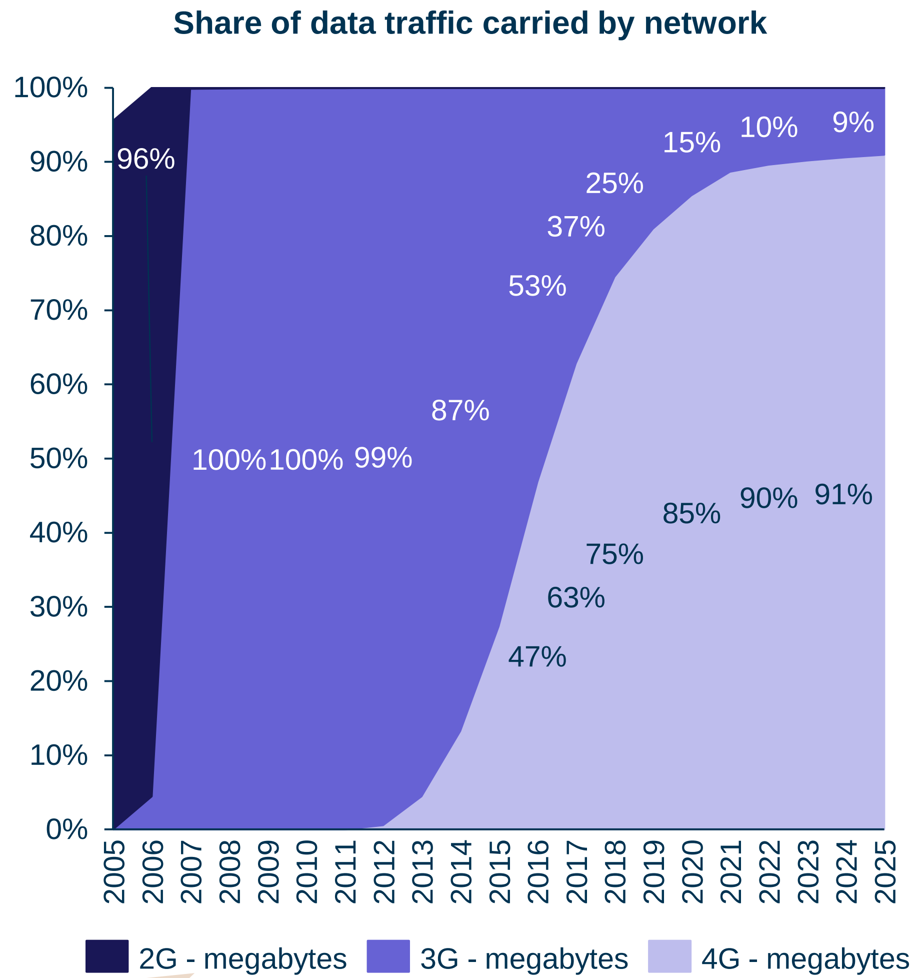
Share of voice traffic carried by network



Source: Analysys Mason model, ANACOM

The data traffic is expected to increase dramatically driven by the take-up of high-speed data services on next-generation mobile networks





Data traffic on 2G is negligible

Source: Analysys Mason model, ANACOM

The model uses a set of inputs from ANACOM, Analysys Mason and other sources in order to calculate the number of subscribers …

Input	Source of historical data	Source of forecast data
Population	Euromonitor, ITU, EIU, Analysys Mason	Euromonitor, ITU, EIU, Analysys Mason
Mobile penetration	ANACOM, ITU	Analysys Mason
Subscribers	ANACOM, ITU	Analysys Mason
Datacards	ANACOM, Analysys Mason	Analysys Mason based on benchmark
Handsets	ANACOM, Analysys Mason	Analysys Mason based on benchmark
Technological mix (2G/3G/4G)	ANACOM, Analysys Mason	Analysys Mason based on benchmark
Data users	ANACOM, Analysys Mason	Analysys Mason

Source: Analysys Mason model

… as well as the total traffic generated by the users of voice, messaging and data services

Input	Source of historical data	Source of forecast data
Mobile outgoing on-net traffic	ANACOM	Analysys Mason
Outgoing traffic mobile to fixed	ANACOM	ANACOM proportions
Outgoing traffic mobile to non-geographic	ANACOM	ANACOM proportions
Outgoing traffic mobile to off-net	ANACOM	ANACOM proportions
Outgoing traffic mobile to international	ANACOM	ANACOM proportions
Incoming traffic fixed to mobile	ANACOM	ANACOM proportions
Incoming traffic off-net to mobile	ANACOM	ANACOM proportions
Incoming traffic international to mobile	ANACOM	ANACOM proportions
Roaming in origination	ANACOM	ANACOM proportions
Roaming in termination	ANACOM	ANACOM proportions
SMS	ANACOM	Analysys Mason on ICP.ANACOM data
MMS	ANACOM	Analysys Mason on ICP.ANACOM data
Low-speed data volumes	ANACOM, Analysys Mason	Analysys Mason
HSPA/HSUPA data volumes	ANACOM, Analysys Mason	Analysys Mason based on benchmarks
LTE data volumes	Analysys Mason	Analysys Mason based on benchmarks

Source: Analysys Mason model

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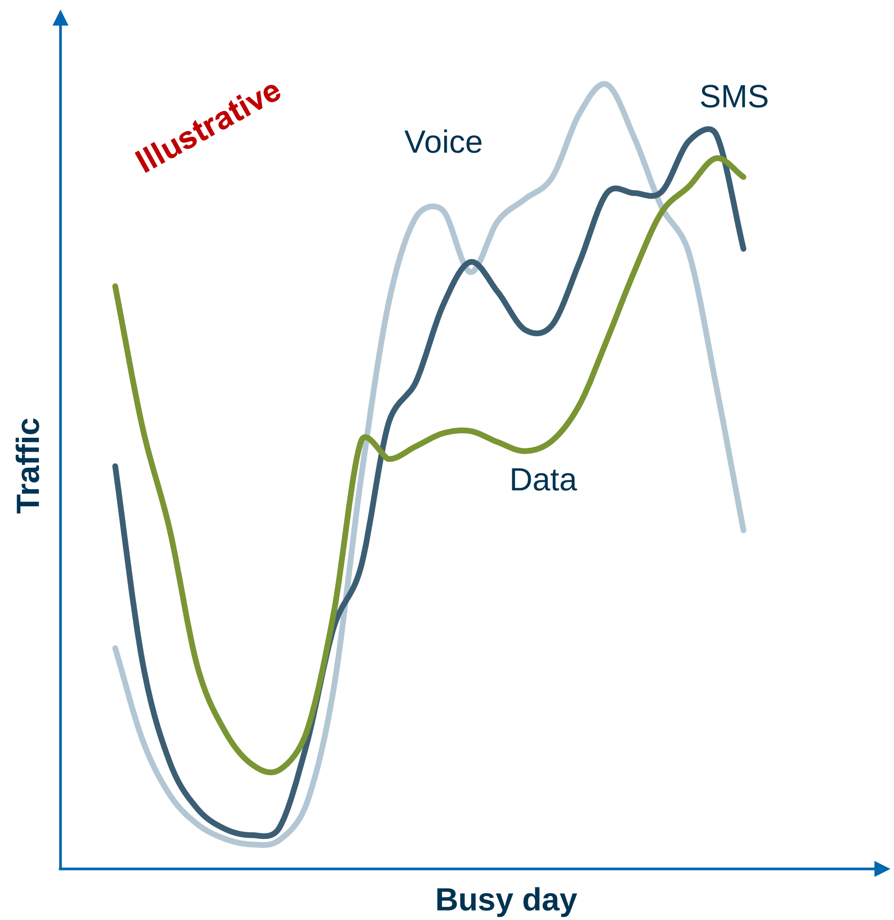
Voice, SMS and data traffic is converted into a busy-hour load using three inputs

- **Busy days per year**: 250
- **Weekday proportion of traffic**: based on Analysys Mason estimates
- **Busy-day traffic profile**: based on data provided by operators
- For the dimensioning of the network we use voice, SMS and data proportions in the voice busy hour based on data provided by operators and Analysys Mason estimates
- Peak-hour proportions are based on data provided by operators

Traffic in the busy-hour calculation parameters

	Voice	SMS	Data
% traffic in the weekday	DATA REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION		
% traffic in the peak hour			

Traffic profile for voice, SMS and mobile data



Source: Analysys Mason model

We apply further loading factors to calculate voice Erlangs and call attempts

Network loading parameters

Voice services	Ring time per call	Average call duration	Call attempts per successful call	Erlang per minute
On-net calls	Circa 12 seconds	DATA REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION		2
Outgoing calls to other national fixed networks	Circa 12 seconds			1
Outgoing calls to other national mobile networks	Circa 12 seconds			1
Outgoing calls to international	Circa 12 seconds			1
Incoming calls from other national fixed networks	Circa 12 seconds			1
Incoming calls from other national mobile networks	Circa 12 seconds			1
Incoming calls from international	Circa 12 seconds			1
Roaming in origination	Circa 12 seconds			1
Roaming in termination	Circa 12 seconds			1
Source used	Analysys Mason estimate	Operator data	Operator data	By definition

Source: Analysys Mason model

The model uses industry-standard codecs for the conversion of voice and SMS traffic to Mbit/s traffic

AMR-WB codec (4G)	AMR codec (3G)
6.60kbit/s	4.75kbit/s
8.85kbit/s	5.15kbit/s
12.65kbit/s	5.90kbit/s
14.25kbit/s	6.70kbit/s
15.85kbit/s	7.40kbit/s
18.25kbit/s	7.95kbit/s
19.85kbit/s	10.20kbit/s
23.05kbit/s	12.20kbit/s
23.85kbit/s	

Selected

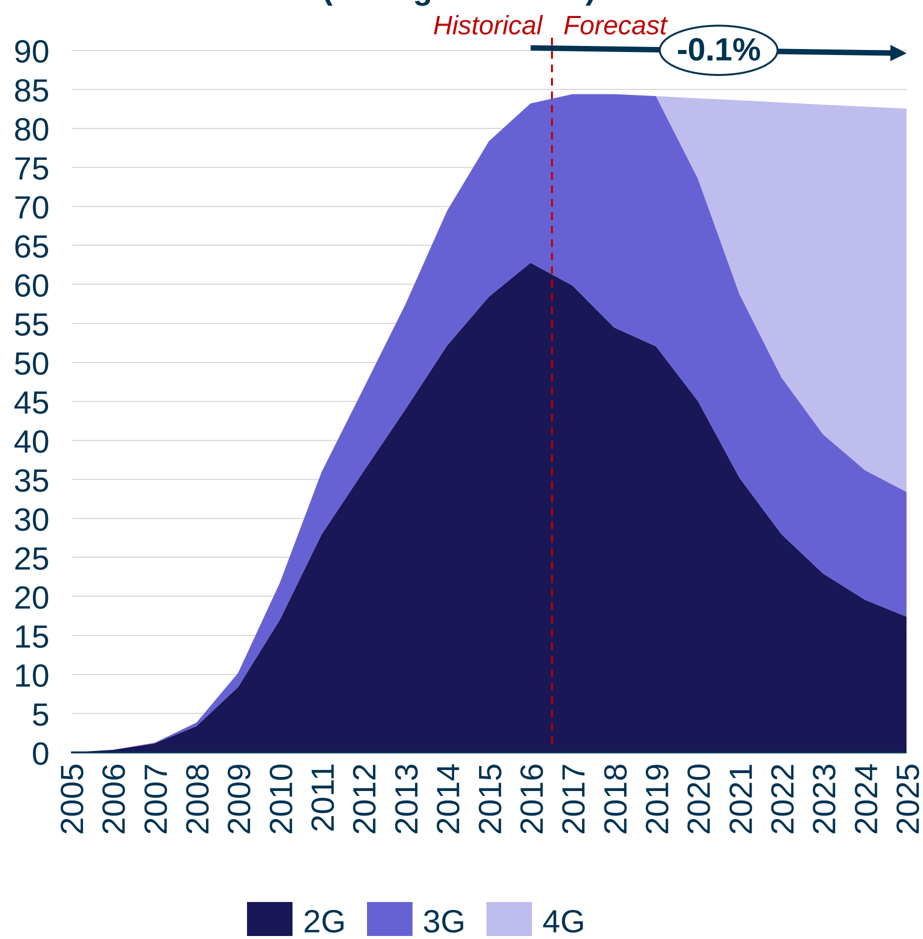
Industry standard

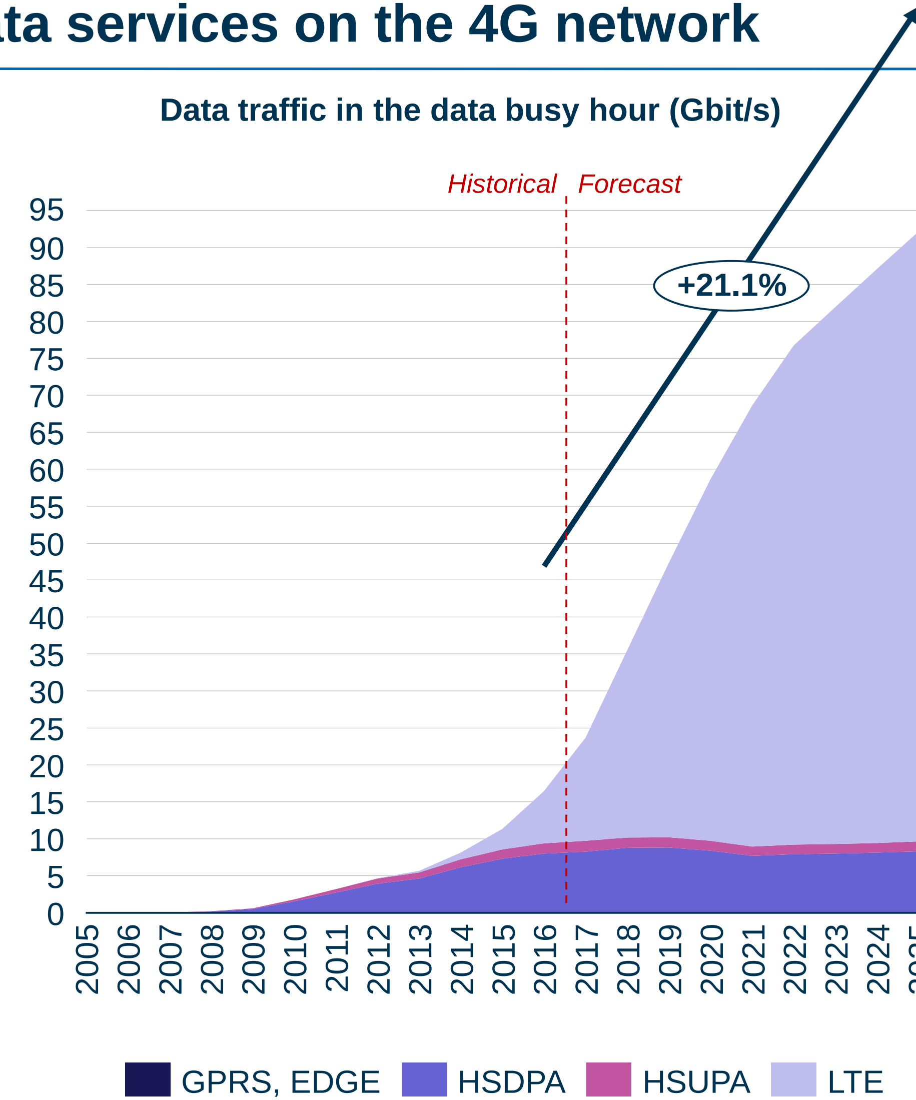
Industry standard

- For SMS traffic we assumed a 40-byte size per message
  - the voice channel rate is assumed to be 6136bit/s for SMS on 2G and 16 000bit/s on 3G and 4G

Source: Analysys Mason model

Data traffic is expected to grow at a significantly faster pace than voice, driven by the take-up of high-speed data services on the 4G network

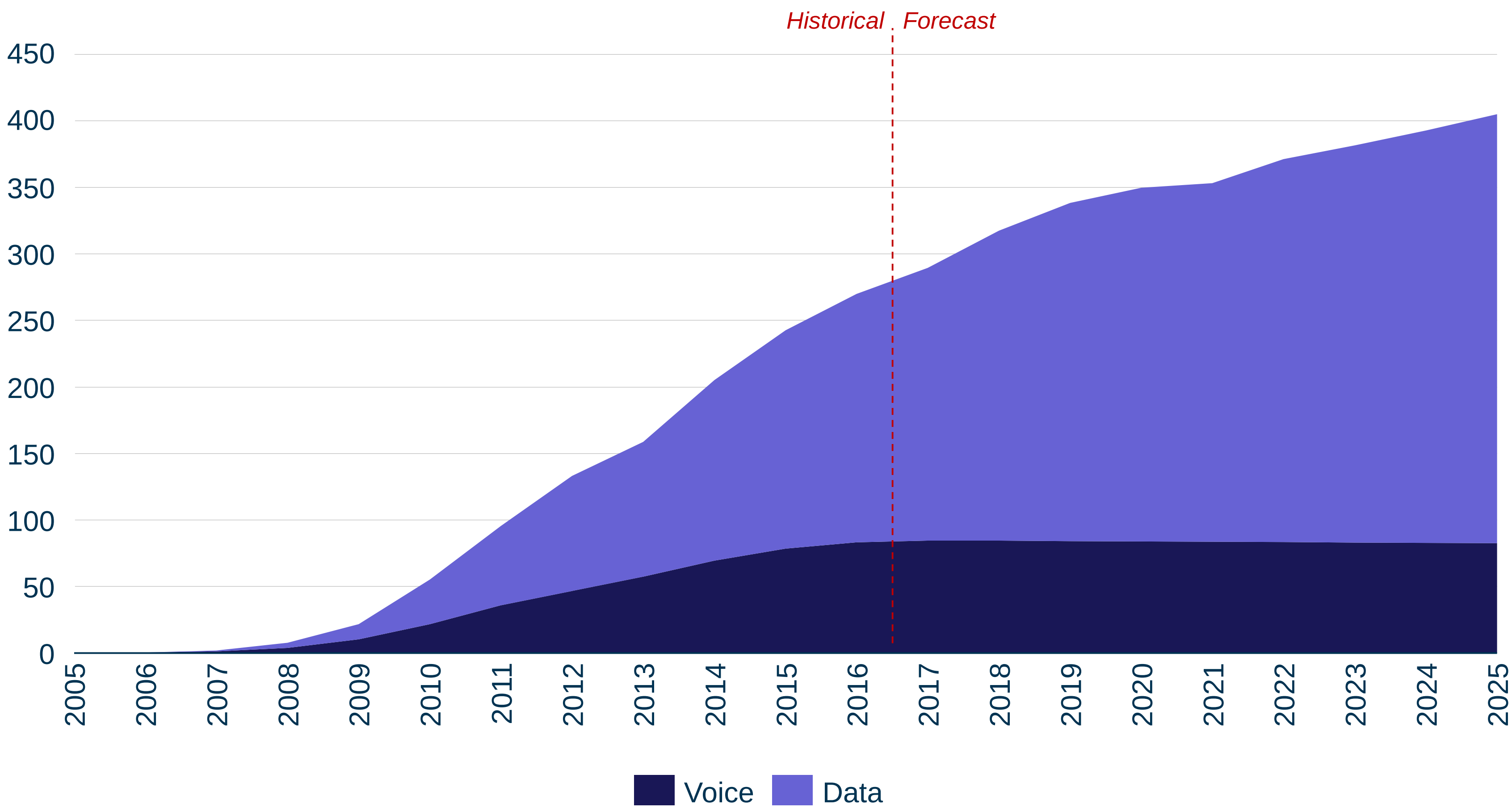




Source: Analysys Mason model

Data is expected to account for the majority of the total traffic carried by the network

Split of the total traffic carried by the network between voice and data (Erlang thousand in the voice busy hour)



Source: Analysys Mason model

Introduction

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Portuguese geotype model

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We obtained population and area statistics for the 4255 Portuguese *freguesias*

- We have divided the Portuguese geography at the *freguesia* (parish) level in order to enhance the level of granularity of the data and the model
- We are aware that the number of *freguesias* has been reduced recently; however, the model retains the previous administrative division in order to be consistent with the data available from the 2011 census, which has been used as the source for population inputs
  - we do not expect this assumption to have a material impact on the results of the model
- We have classified the *freguesias* into four geotypes based on their population density, as per the table below

Geotype	Population density (pop/km^2)
Dense urban	d > 14 000
Urban	1100 < d < 14 000
Suburban	100 < d < 1100
Rural	d < 100

- We have defined our model geotype definition based on the specificities of the Portuguese geography and population density, ensuring they are consistent with geotype definitions used in other regulatory models built by NRAs
  - roads and railways are implicitly included in the above four geotypes
- Theoretical coverage radii were updated according to the definition of geotypes and cross-checked against available benchmarks

The model includes the latest census figures from 2011 and the 'individuals' present in a *freguesia* have been used as metric, since this better reflects the number of users generating traffic in the area

Source: Analysys Mason model

Traffic distribution among geotypes is calculated based on the definition of the geotype thresholds

- The definition of geotype results in a distribution of area and population as shown in the table below
  - the ‘dense urban’ geotype is characterised by having a high proportion of population in a small area
  - on the opposite side, the ‘rural’ geotype is characterised by a small percentage of total population in a large area
- Traffic is distributed unevenly among geotypes
  - dense urban and urban areas are likely to have a *higher* proportion of traffic than their population proportion
  - conversely, suburban and rural areas are likely have a *lower* proportion of traffic than their population proportion
- Different reasons explain why higher-density areas carry more traffic in relative terms
  - urban areas are characterised by higher data/voice consumption propensity and access to technology
  - a higher number of medium and big companies, which have a high consumption of communication products, is usually concentrated in urban areas
  - the fastest networks – e.g. HSPA and LTE – are usually deployed first in more dense areas

Comparison of area, population (individuals) and mobile traffic by geotype in Portugal

Geotype	Area	Population (2011 census)	Voice traffic	Data traffic
Dense urban	0.01%	1.7%	4.3%	3.4%
Urban	1.6%	39.5%	54.4%	49.8%
Suburban	16.8%	40.9%	31.0%	36.0%
Rural	81.6%	17.9%	10.3%	10.9%
Total	**100%**	**100%**	**100%**	**100%**

Data traffic distribution is expected to be less skewed towards dense areas because of the higher MBB traffic

Source: Analysys Mason model, Census 2011

We have divided the country into eight regions, each with its own regional transmission hub/network links

- There is a major network point of presence in six main cities and two archipelagos, covering the whole country
- These points of presence host four switching sites and eight core transmission sites
- Each of the regions has its own core transmission site
  - typically, a national transmission network connects these cities in a ring or mesh topology
- The urban, suburban and rural population in each region is used to determine the amount of regional traffic by region
  - dense urban areas are assumed to be directly connected to the switching site
- Madeira and the Azores are connected to the continent through a submarine STM-4 connection

Regional networks for Portugal

Region code	Region
N	North
P	Porto
C	Centre
L	Lisbon
A	Azores
M	Madeira
S	Setúbal
F	Faro

Source: Analysys Mason model

Regional transmission is provided by a regional fibre ring

- We have defined a regional fibre link for each region:
  - the length of regional ring includes only the fibre situated in a given region
  - traffic is distributed among the regional networks based on their relative population

Regional rings and population distribution among them

Region	Length of regional ring (km)	Distribution of population per ring
Region N	305	13.93%
Region P	162	24.03%
Region C	489	21.78%
Region L	133	20.42%
Region S	465	10.89%
Region F	220	4.19%
Region A	1100	2.41%
Region M	168	2.36%

Source: Analysys Mason model

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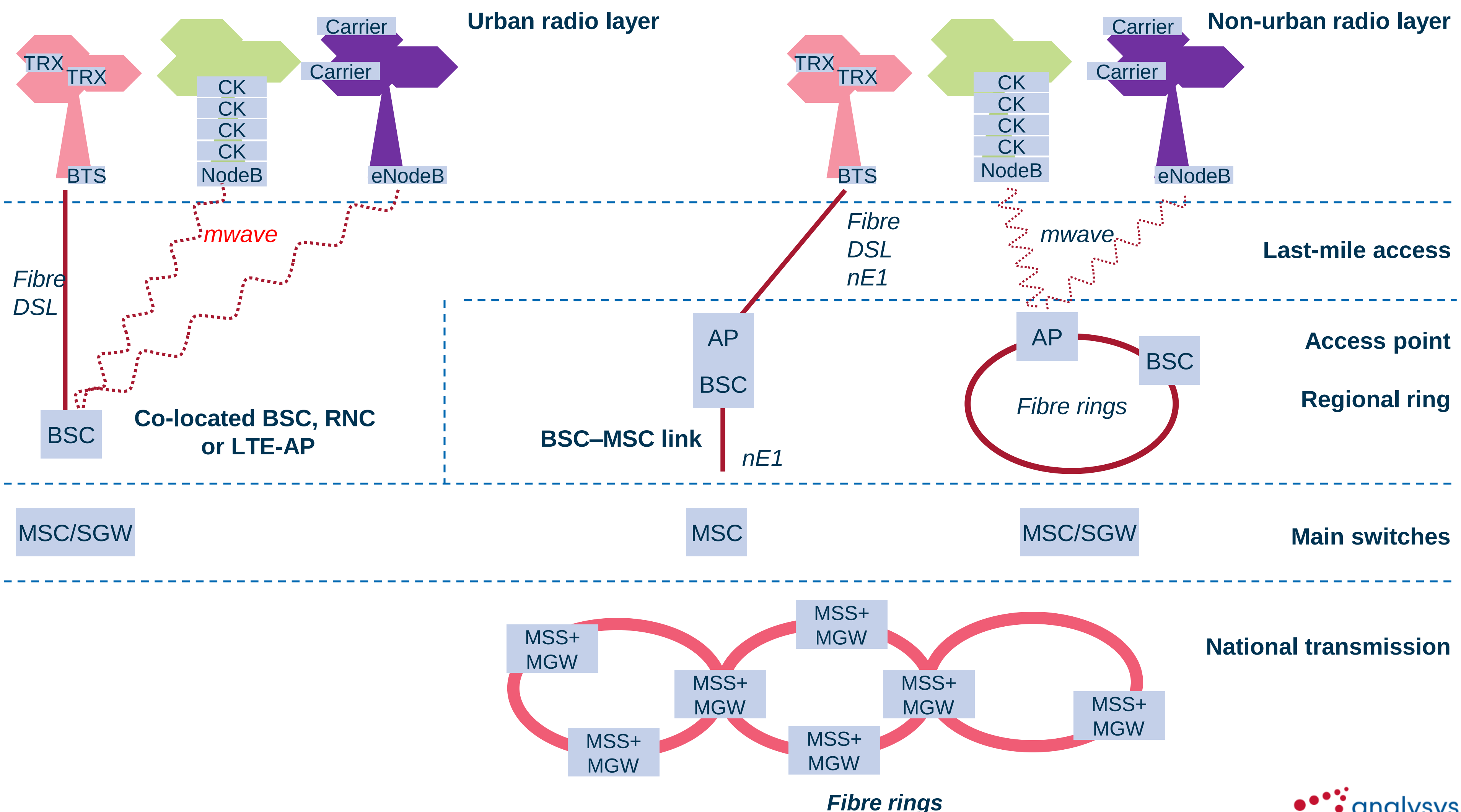
Overview of network architecture

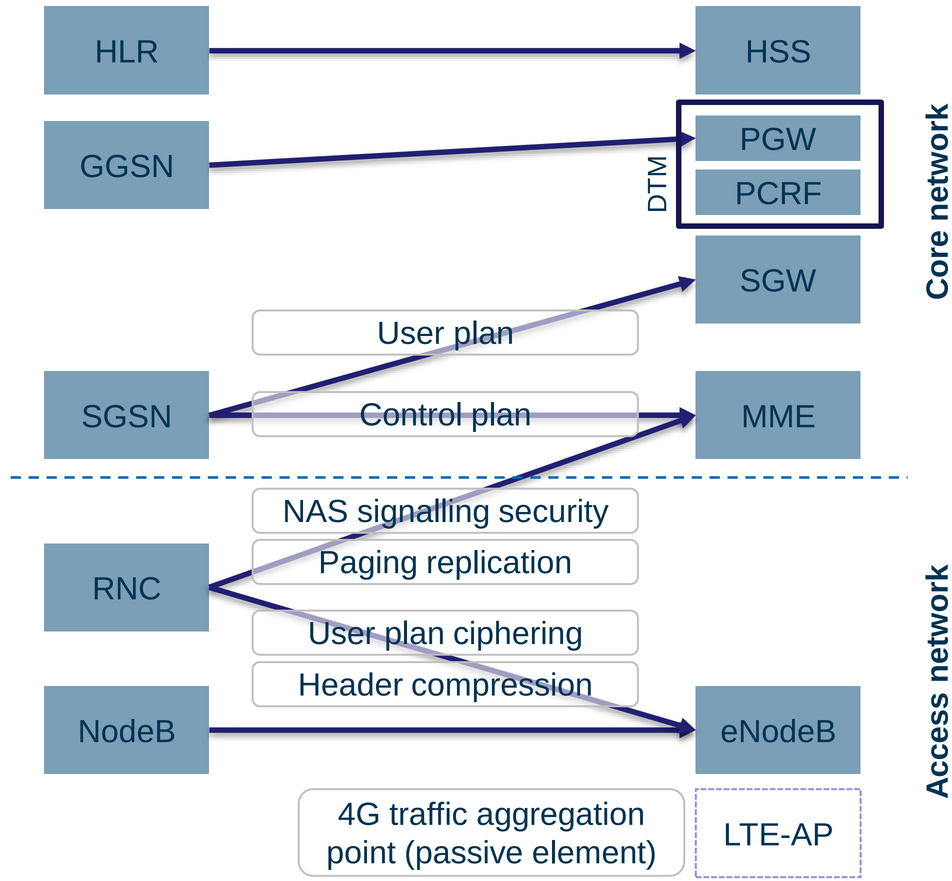


Source: Analysys Mason

We have modelled an all-IP LTE network, which is an evolution of the pre-existing GPRS data network

- The inclusion of a 4G radio network requires the modelling of a 4G core network, which is assumed to be an enhanced packet core (EPC) network
  - this is an industry-standard architecture used to carry the data traffic from 4G eNodeBs
- LTE network does not require the equivalent of the RNC, whose functionalities are performed by other components
  - we have modelled an LTE aggregation point (LTE-AP) that aggregates LTE traffic from the eNodeBs and multiplexes it
- The four main component assets of a 4G core network are
  - *Serving gateway (SGW)* – Its primary function is the management of the user-plane mobility; furthermore, it acts as a demarcation point between the RAN and the core network
  - *Data traffic manager (DTM)* – This equipment includes any other systems that handle data traffic, including the PDN gateway (PGW) and the policy and charging rules function (PCRF) for policy and rules functions
  - *Mobility management entity (MME)* – Manages signalling and control functions, the assignment of network resources, the management of the mobility states to support tracking, paging, roaming and handovers and the control plan functionalities
  - *Home subscriber server (HSS)* – This equipment is the 4G equivalent of the home location register (HLR)

Scheme of the evolution from GPRS to LTE

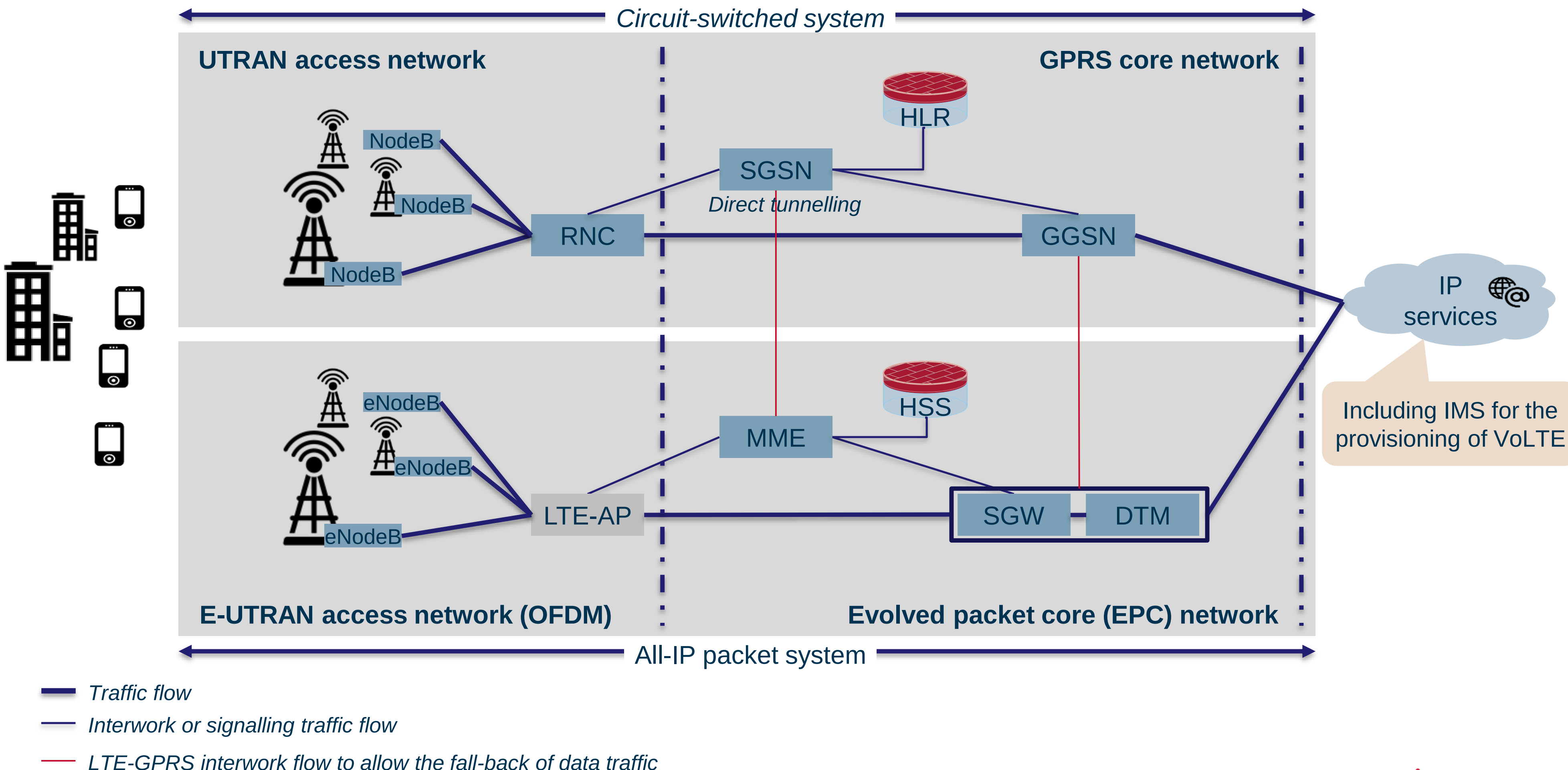


Vendors also offer the upgrade of the existing GPRS equipment to support LTE; however, we have modelled a dedicated network overlay in order to reduce the impact and the investments on the existing GSM/UMTS networks

Source: Analysys Mason, Alcatel Lucent, "Notiziario tecnico" (Telecom Italia)

It is possible to map the relationship between the legacy networks and the modelled LTE network to show the logical flow of traffic in the latter network

Illustration of the modelled LTE network and its relationship with the legacy GPRS infrastructure

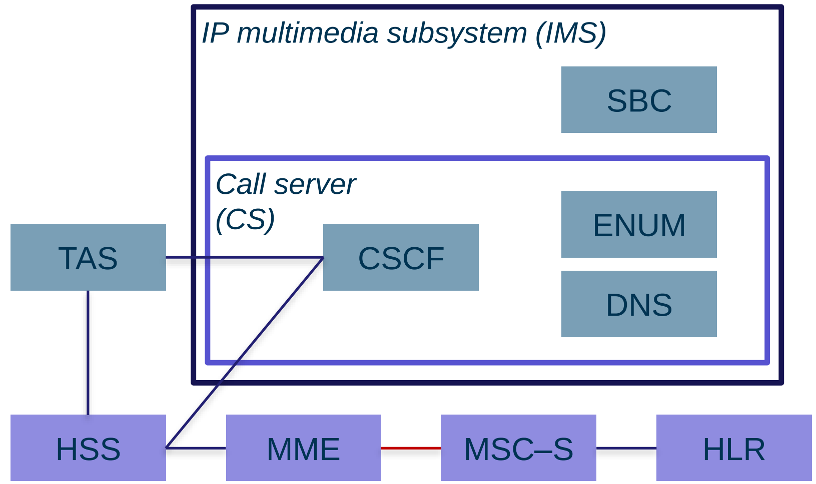


Source: Analysys Mason

We have included the deployment of the VoLTE platform to offer telephony services (voice and SMS) over the new 4G network

- With a VoLTE platform deployed in the core network, voice and data can both be provided over the 4G network under the control of the network operator
- VoLTE requires the deployment of an *IP multimedia subsystem (IMS)* in the core network; the heart of the IMS core is composed of
  - the *call server (CS)* asset, which contains the voice service functions CSCF, ENUM and DNS
  - *session border controllers (SBCs)*
  - *telephony application servers (TASs)*, which allow the provision of the supplementary telephony services (e.g. forwarding, call wait and call transfer)

Appearance of an IMS core



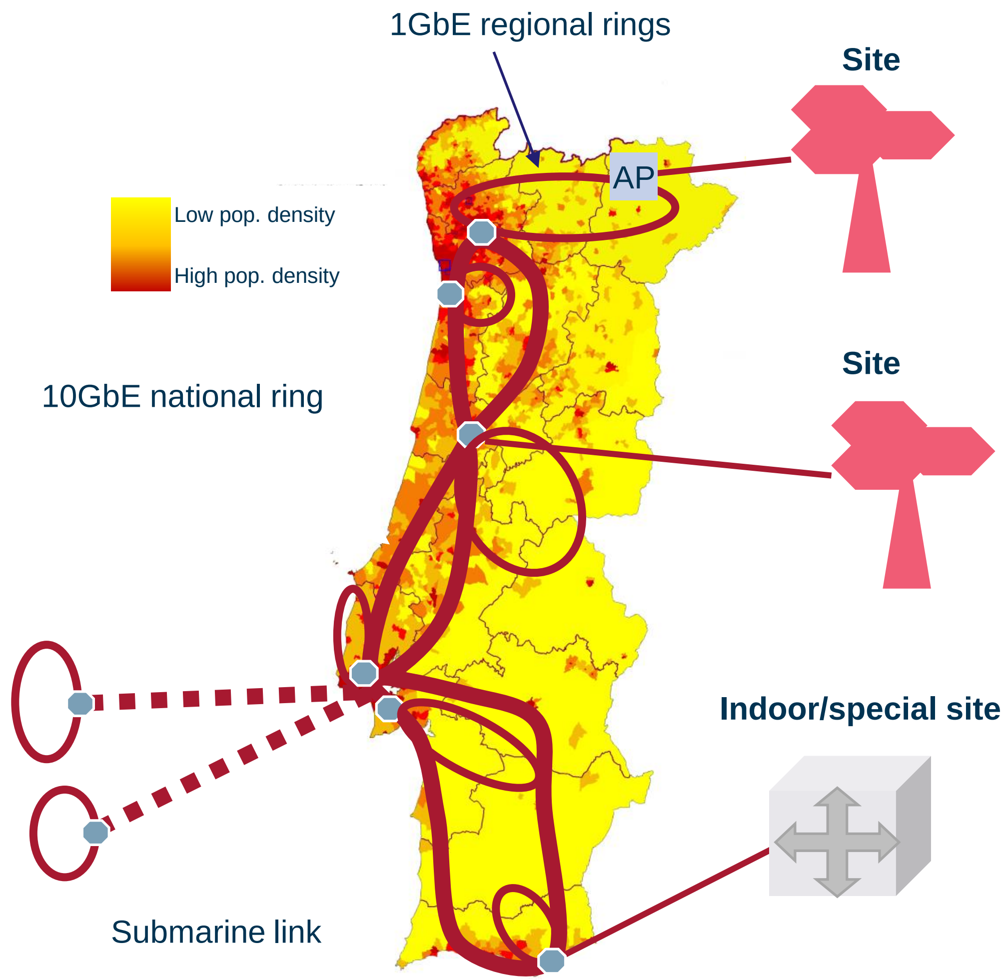
LTE–GPRS interwork flow to allow the fall-back of voice traffic

- The VoLTE platform must also communicate with the 4G data platform (via the MME/SGW), meaning that upgrades may be required for existing assets. In particular, the MSC–S could need some enhancements so that:
  - calls can connect to the IMS domain via the MSC–S, to continue to provide the voice service if a 4G user is within the coverage of the 2G/3G circuit-switched networks rather than the 4G network
  - calls can be handed over from the 4G network to the 2G/3G networks
- A separate converged HLR/HSS can also be deployed to manage data on the 4G subscriber base, keeping the legacy HLR unchanged
- Upgrades to the legacy network management system (NMS) may also be required

Source: Analysys Mason, Alcatel Lucent, Huawei, “Notiziario tecnico” (Telecom Italia)

The model deploys an NGN (all-IP) transmission architecture

- The operator deploys an NGN network from the start of operations
- Backhaul remains dependent on traditional technologies – fibre, DSL, microwave and leased lines
  - we assume that Ethernet technology is used over the backhaul fibre links

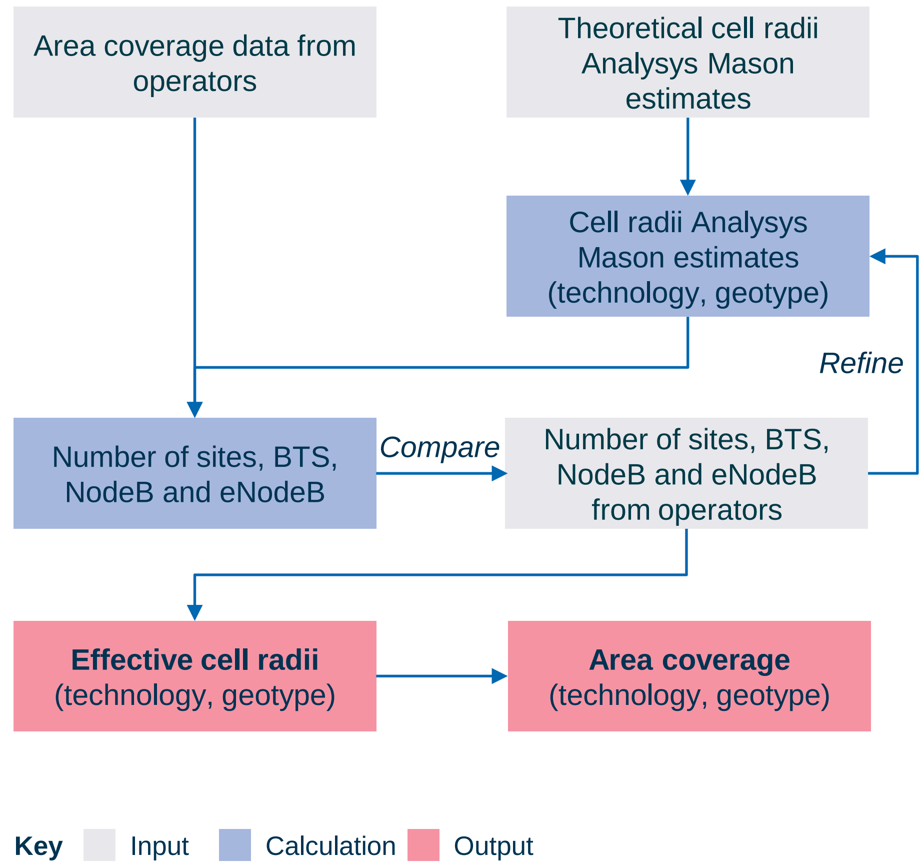


Source: Analysys Mason model

Radio network calculations: cell radii calibration has been part of a wider calibration process during the modelling work

- Two different types of cell radii are used within the model: *theoretical* cell radii and *effective* cell radii
- ***Theoretical cell radii*** apply to the hexagonal coverage area that a BTS or a (e)NodeB of a particular type, considered in isolation, would be estimated to have
  - theoretical cell radii values vary by geotype and technology, but not by operator – this is because theoretical cell radii differences are considered to be due to differences in radio frequency and geotype (clutter)
- ***Effective cell radii*** are the ones that apply in reality due to the sub-optimality of site locations
  - effective cell radii are calculated by applying a scorched-node coverage coefficient (SNOCC) to the theoretical cell radii
  - the value of this coefficient can vary by operator, technology and geotype, but is usually less than 100% for a complete coverage deployment

Process for calibrating the cell radii and deriving area coverage



Note: cell radii calibration took place during the ongoing development of the model and therefore only final (i.e. calibrated) outputs are presented in the draft model

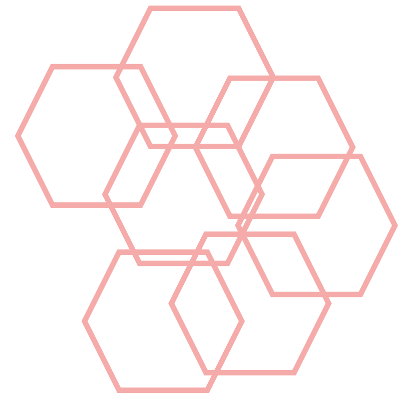
Source: Analysys Mason model

Radio network calculations: theoretical and effective cell radii [1/2]

- We apply 'coverage hexagons' by frequency, with an estimated theoretical cell radius to provide the population coverage for the modelled operator. This theoretical cell radius has been defined based on Portuguese specificities, and is consistent with that used in other regulatory models
- However, coverage cannot realistically be completed by a perfect hexagonal net
  - it is not possible to perfectly locate every radio mast so that coverage areas align optimally
  - the different shapes of buildings and their surroundings interfere with transmission of radio signals
- Therefore, we have estimated an SNOCC as presented on the following slide, which is applied to the theoretical cell radius resulting in an effective cell radii used to determine the effective coverage per site for all bands

Coverage models

Optimal locations of BTSs



Sub-optimal locations of BTSs occurring in reality

Source: Analysys Mason model

Radio network calculations: theoretical and effective cell radii [2/2]

Theoretical cell radius (km)

Geotype	800MHz	900MHz	1800MHz	2100MHz	2600MHz
Dense urban	0.55	0.45	0.40	0.40	0.38
Urban	1.96	1.61	1.43	1.43	1.39
Suburban	5.42	4.46	3.95	3.95	3.84
Rural	7.59	6.24	5.53	5.53	5.44

SNOCC

Geotype	800MHz	900MHz	1800MHz	2100MHz	2600MHz
Dense urban	0.475	0.573	0.579	0.519	0.585
Urban	0.518	0.625	0.631	0.566	0.638
Suburban	0.596	0.718	0.726	0.651	0.734
Rural	0.648	0.781	0.789	0.707	0.798

Effective cell radius (km)

Geotype	800MHz	900MHz	1800MHz	2100MHz	2600MHz
Dense urban	0.26	0.26	0.23	0.21	0.22
Urban	1.02	1.01	0.90	0.81	0.89
Suburban	3.23	3.21	2.87	2.57	2.82
Rural	4.91	4.88	4.36	3.91	4.34

The theoretical radii of 800MHz and 2600MHz cells are assumed to be 121% and 78% of the radius used for 900MHz

The 2100MHz effective cell radius also takes into account the cell-breathing effect illustrated on the following slides

- The SNOCC is lower for the 900MHz band compared to the 2100MHz band
  - the larger theoretical radius of the 900MHz sites makes it harder to find suitable site locations, especially in more dense areas where free space – e.g. rooftops – is a scarce resource contended by many operators

Source: Analysys Mason model

Radio network calculations: UMTS cell breathing

- In order to offer a HSDPA service, we assume that operators are deploying a typical ‘data’ quality network – to provide a 64kbit/s uplink path as a minimum, or sufficient signal strength for HSUPA (if activated)
- We assume that UMTS cell radii are planned to accommodate between 50% and 60% of the radio access loading depending on the geotype …
  - … so that cell breathing does not reduce coverage at the edge of cells in the peak hour

Geotype	Traffic load	Geotype	Traffic load
Dense urban	60%	Suburban	55%
Urban	55%	Rural	50%

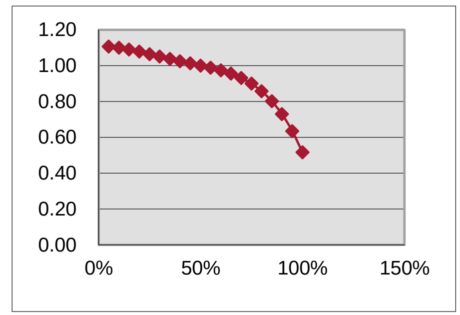
- We estimate the effect of cell breathing in a network without termination traffic as a reduction of 10% in the traffic load of the network with all traffic considered
  - this corresponds roughly to the proportion of termination traffic vs. (on-net traffic + termination traffic + R99 data in BHE + allowance for HSPA data in the shared carrier)

Geotype	Traffic load	Geotype	Traffic load
Dense urban	56%	Suburban	51%
Urban	51%	Rural	46%

- We have estimated an approximate parameterisation of the non-linear effect of cell-breathing based on illustrative link budget calculations:

Cell loading radius effect (cell breathing)

5%	1.11
10%	1.10
15%	1.09
20%	1.08
25%	1.06
30%	1.05
35%	1.04
40%	1.02
45%	1.01
50%	1.00
55%	0.99
60%	0.97
65%	0.95
70%	0.93
75%	0.90
80%	0.86
85%	0.80
90%	0.73
95%	0.63
100%	0.52



- The model takes into account the difference between the cell loading factors of the network *with* and *without* the termination traffic
- The effect of cell breathing on the coverage radius is then calculated for the network without termination traffic, based on its traffic load and the estimated non-linear radius function

Source: Analysys Mason model

Radio network: site deployment characteristics

- The model also contains inputs for the following aspects of radio site deployment
  - sectorisation of GSM, UMTS and LTE sites – based on actual operator data
  - primary and secondary spectrum:
    - the modelled operator starts its network deployment with 900MHz frequencies for GSM services
    - the modelled operator starts its network deployment with 800MHz frequencies for LTE services

Average sectorisation per site

	Dense urban	Urban	Suburban	Rural	Micro/indoor
LTE 800MHz					
GSM 900MHz					
GSM 1800MHz					
LTE 1800MHz					
UMTS 2100MHz					
LTE 2600MHz					

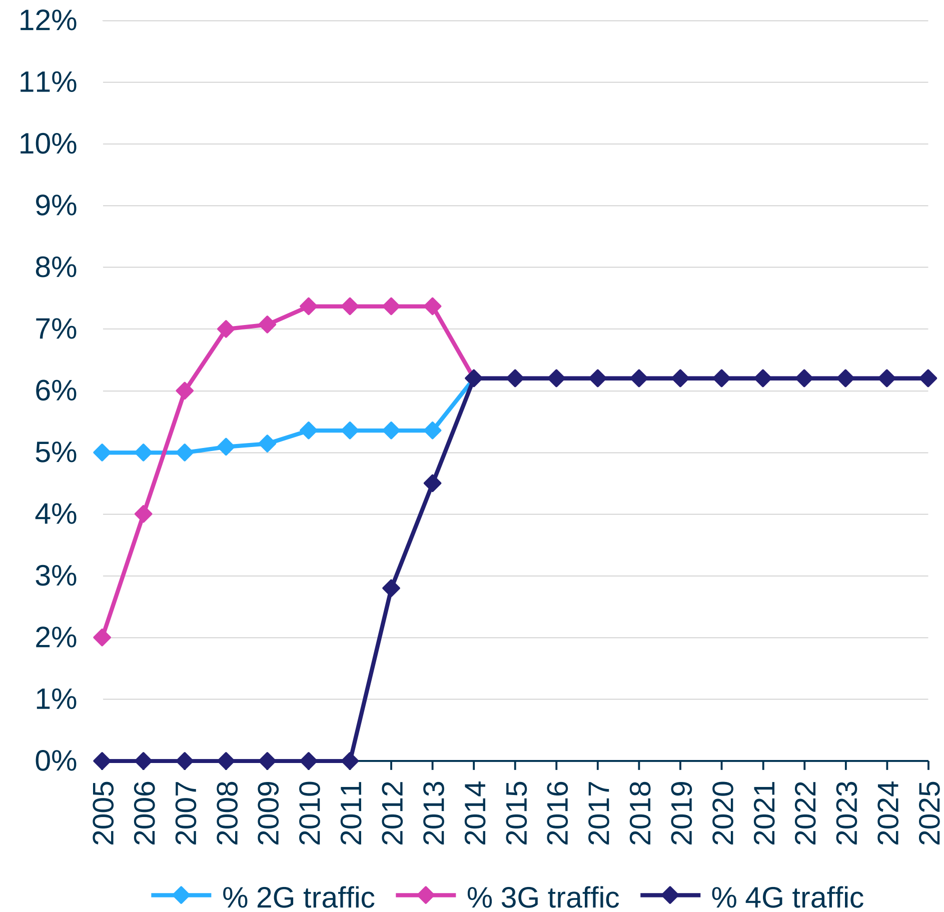
DATA REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION

Source: Analysys Mason model

Radio network: micro and special sites [1/2]

- In addition to outdoor sectorised macro sites, we have included in the model indoor special sites that serve two purposes:
  - **coverage extension** in hard-to-reach areas like tunnels, inside buildings, etc.
  - **capacity increase** in hotspot locations requiring dedicated capacity to avoid the saturation of macro cells (e.g. crowded stations, airports, crowded streets)
- Indoor special sites convey an assumed proportion of voice and data traffic, based on operator data

Share of traffic carried by indoor special sites



Source: Analysys Mason model

Radio network: micro and special sites [2/2]

- The number of indoor special sites has been estimated on the basis of the data provided by the operators
- The model is capable of setting the distribution of indoor special sites by geotype since they are likely to be skewed towards more densely populated areas
- The traffic carried by these sites is assumed to follow the same distribution as the one followed by macro sites

Distribution of indoor special sites by geotype

Geotype	2G	3G	4G
Dense urban	20%	20%	20%
Urban	80%	80%	80%
Suburban	-	-	-
Rural	-	-	-

Evolution of the number of micro and special site locations

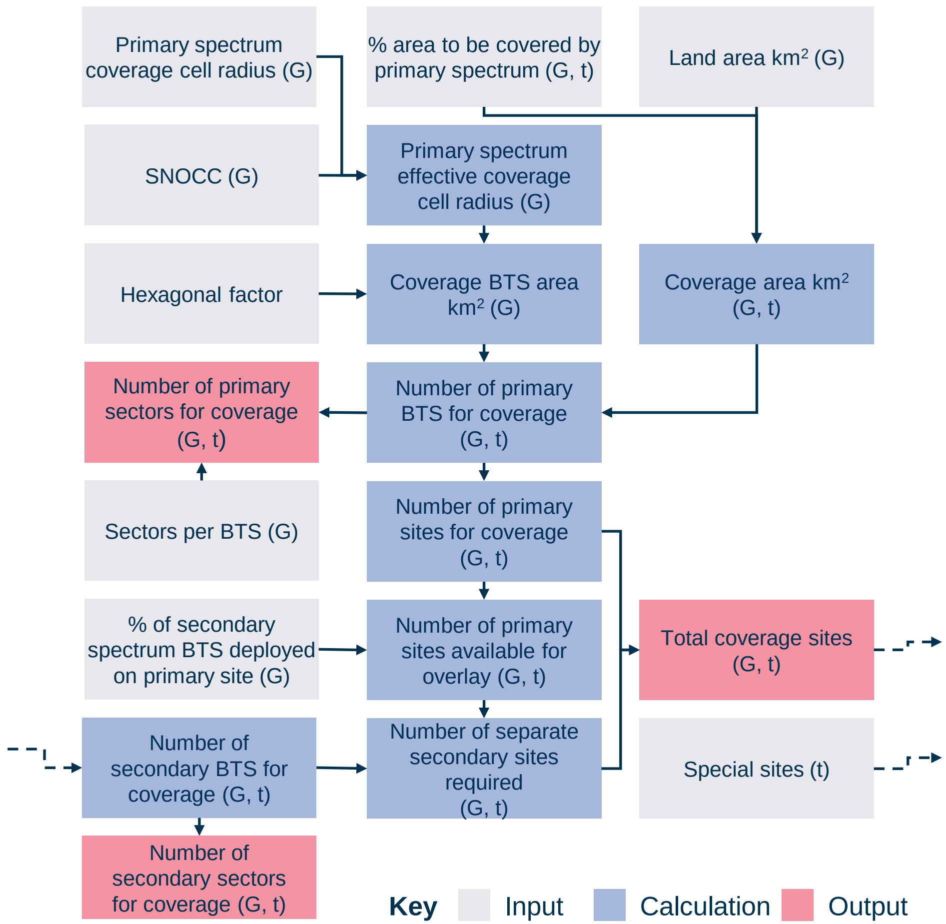
GRAPH REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION

Source: Analysys Mason model

Radio network: 2G coverage calculation

- The coverage networks for each frequency band (primary GSM, secondary GSM) are calculated separately within the model
- 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
  - total area covered in the geotype is divided by this BTS area to determine the number of primary coverage BTSs 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
- Special indoor sites are modelled as explicit inputs using operator data

2G coverage algorithm

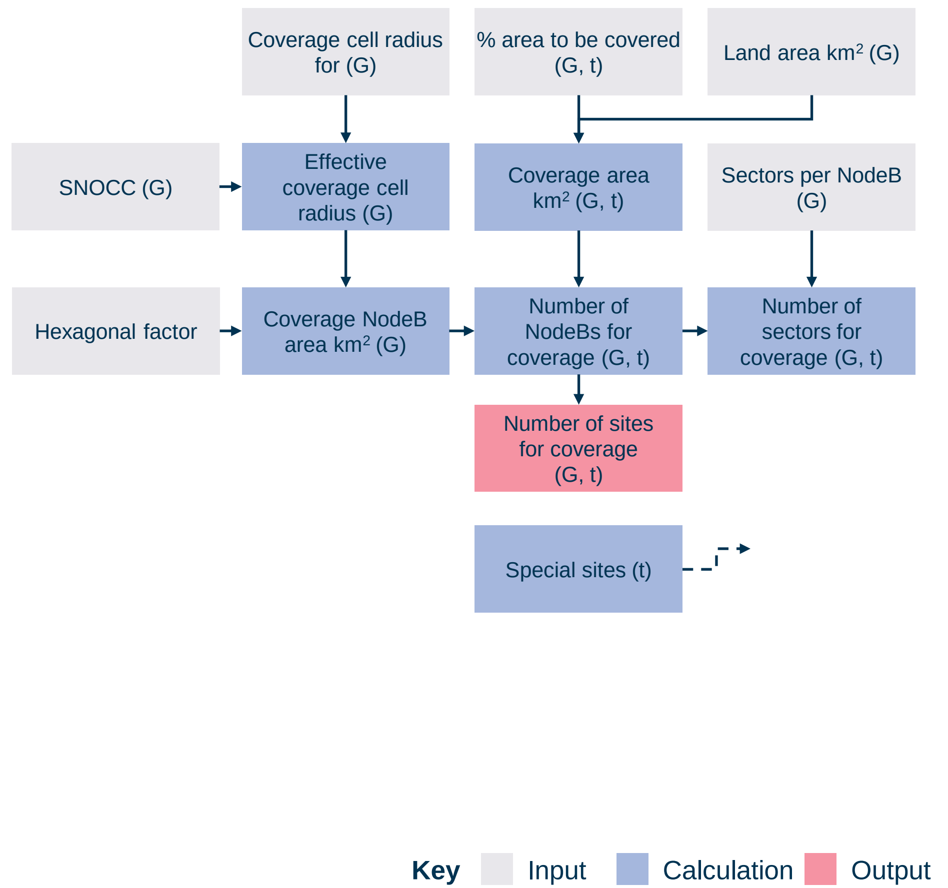


Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

Radio network: 3G coverage calculation

- The same methodology is used to derive the initial number of coverage NodeBs required for UMTS
- Special indoor sites are modelled as explicit inputs using operator data

3G coverage algorithm



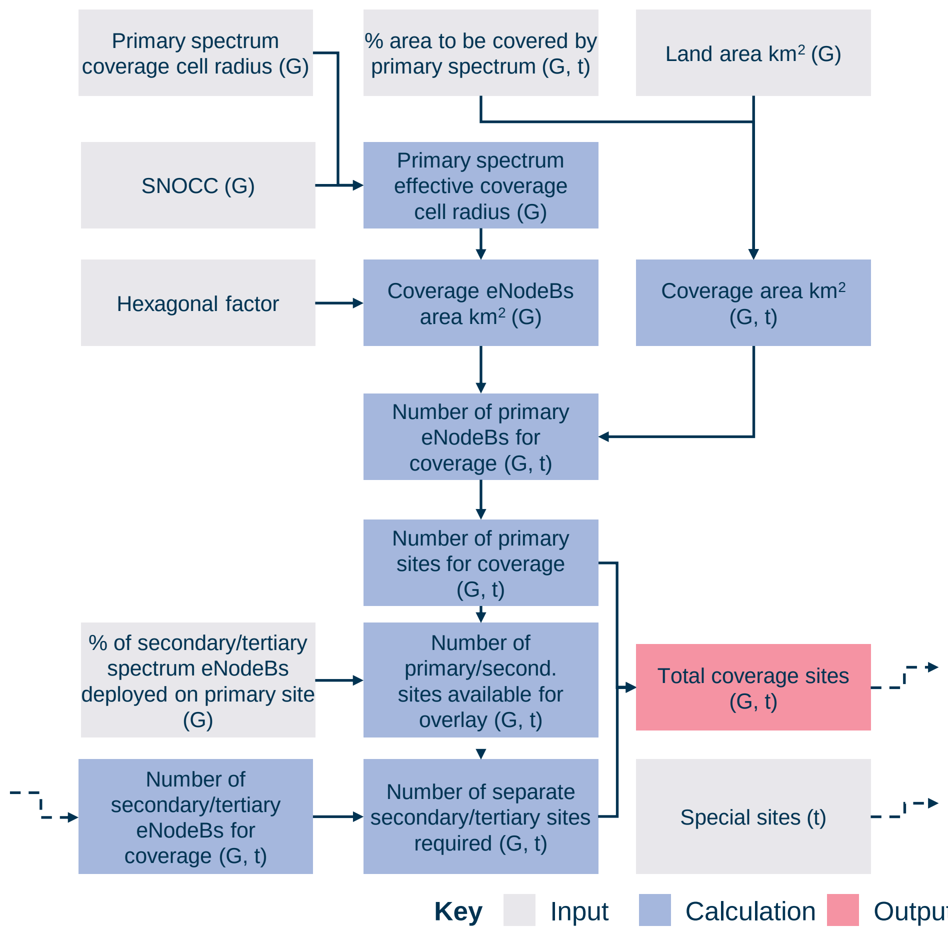
Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

analysys mason

Radio network: 4G coverage calculation

- The same methodology is used to derive the initial number of coverage eNodeBs required for LTE
- The model is also able to calculate the coverage sites on the secondary and tertiary spectrum layers if required and the degree of possible co-location of the sites
  - we have made an assumption on the percentage of primary coverage sites capable of hosting additional layers in order to infer the total number of coverage sites required
  - note that we are currently assuming that only the primary spectrum is being used for coverage, while secondary and tertiary spectrum bands are only used as capacity overlays
- Special indoor sites are modelled as explicit inputs using operator data

4G coverage algorithm



Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

Radio network: 2G capacity calculations

Main network parameters used for 2G network dimensioning

Parameter	Value	Source
Blocking probability	1%	Operator data
Amount of GSM-paired spectrum	8 + 5MHz (in the 900 and 1800MHz bands) until 2018 8MHz (900MHz only) from 2018	Operator data, Analysys Mason
Maximum re-use factor	12	Operator data
Minimum/maximum TRXs per sector	1/10 transceivers	Operator data
Number of channels per sector reserved for GPRS and EDGE	1.5 channels	Operator data
Number of channels per sector reserved for signalling	0.7	Operator data, Analysys Mason
GPRS/EDGE radio throughput rate	64kbit/s	Analysys Mason

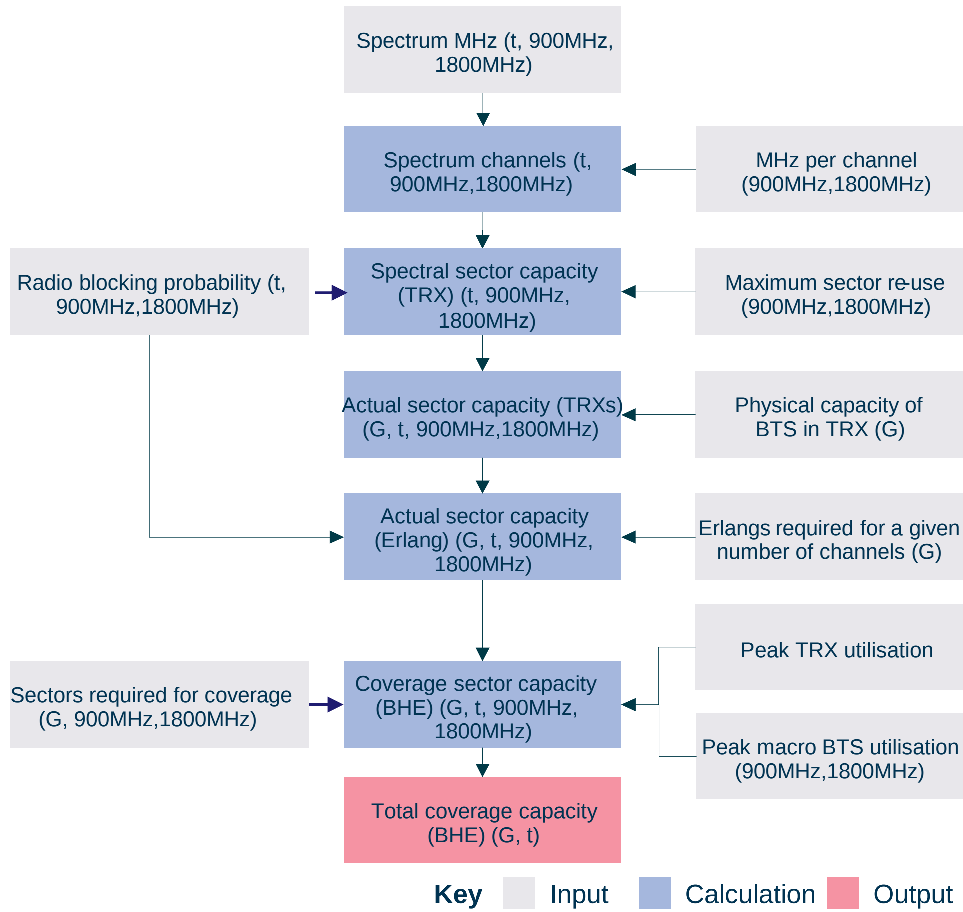
- Calculated TCH requirement in the model is driven by voice Erlang load
  - SMS assumed to be carried in the signalling channels
  - GPRS/EDGE in the busy hour assumed to be confined to the GPRS/EDGE reservation

Source: Analysys Mason model

Radio network: capacity provided by 2G coverage sites

- Calculating the capacity provided by the coverage sites is the first step:
  - capacity for each frequency band is calculated separately
- The spectral limit per sector is calculated as the number of transceivers that can be deployed on a given sector, based on a spectrum re-use factor
  - the applied capacity for a sector is the lesser of its physical capacity and its spectral capacity
- The sector capacity in Erlangs is obtained using the Erlang-B conversion table and then multiplied by the total number of sectors in the coverage network to arrive at the total capacity of the coverage network:
  - in calculating the effective capacity of each sector in the coverage network, allowance is made for the fact that BTSs and TRXs are *on average* **less than 100%** loaded for the network busy hour
  - we also exclude signalling and reserved GPRS channels from the Erlang capacity

Calculation of the BHE capacity provided by the coverage network

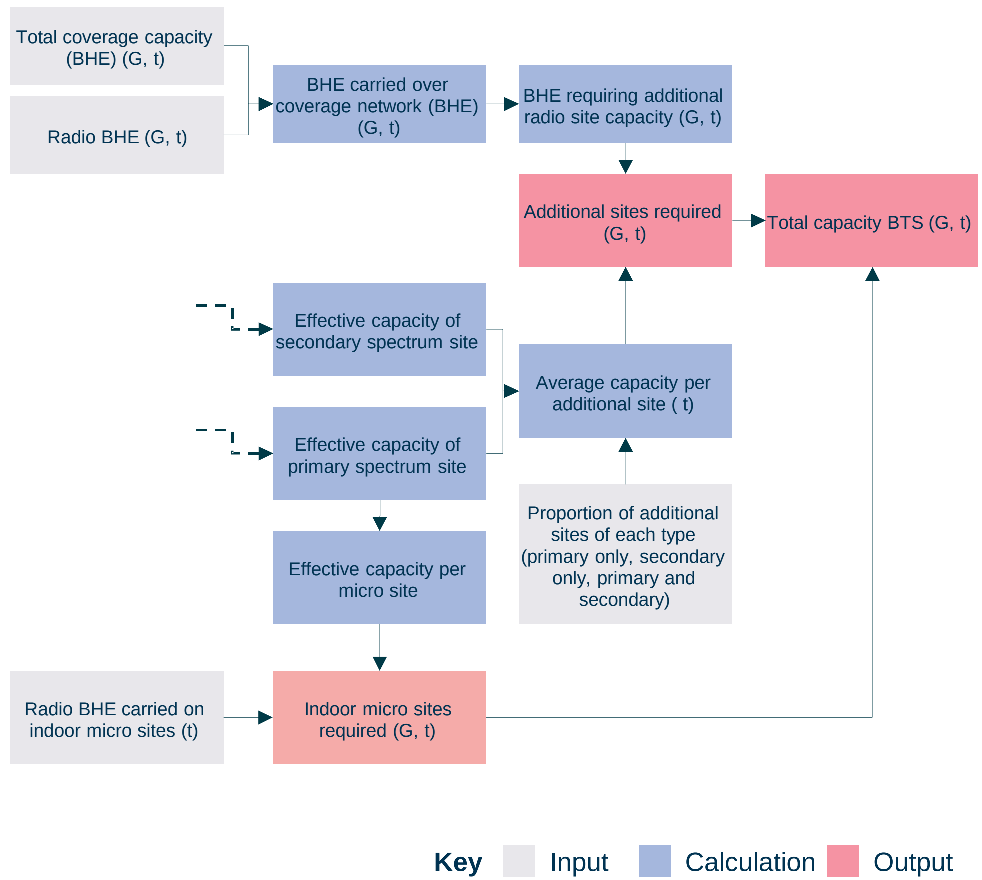


Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

Radio network: additional 2G sites deployed for capacity

- Additional sites required are calculated to fulfil capacity requirements after the calculation of the capacity of the coverage networks
- Three types of GSM sites are dimensioned according to the spectrum employed: primary-only sites, secondary-only sites and dual sites:
  - we currently assume that all additional sites are dual-spectrum (900MHz plus 1800MHz overlaid)
  - 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, to calculate the number of additional sites required to accommodate this remaining BHE
- Micro indoor sites are modelled as an additional layer of omni-sector primary spectrum capacity sites

Calculation of the additional 2G sites required to fulfil capacity requirements

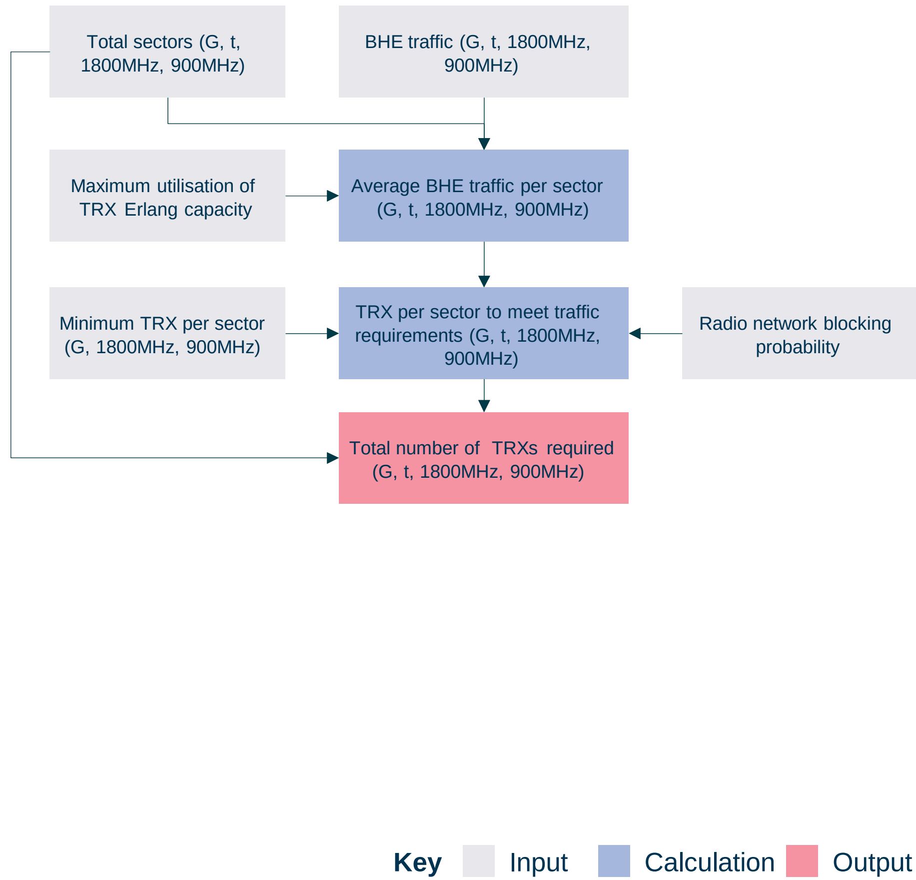


Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

Radio network: TRX requirements

- 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 conversion table and the assumed blocking probability
  - excluding signalling and GPRS channel reservations
  - assuming a minimum number of TRX per sector
    - 1 for the 900MHz
    - 2 for the 1800MHz
- The total number of TRXs required is obtained by multiplying the number of sectors and the number of TRXs per sector

Transceiver deployment



Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

Radio network: 3G capacity calculations

Main network parameters used for 3G network dimensioning

Parameter	Value	Source
Spectrum available	2×20MHz (2100MHz)	Operator data
Number of carriers (size: 2×5MHz)	4	Operator data
Blocking probability	1%	Operator data
Additional soft handover	20%	Analysys Mason
Minimum/maximum R99 channels per NodeB	*	Operator data
Number of carriers for voice, SMS and data (up to HSDPA 7.2Mbit/s)	1 carrier	Analysys Mason
Channel kit size	16kbit/s	Analysys Mason

- Additional channel elements are deployed for higher-speed data traffic

** Values have been removed to protect confidential operator information*

Source: Analysys Mason model

Radio network: 3G upgrades

Characteristics of the HSPA upgrades included in the model

HSPA release	Code	Modulation	MIMO	Minimum number of channels	Source
1.8Mbit/s	5	16 QAM	1×1	DATA REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION	Operator data
3.6Mbit/s	5	16 QAM	1×1		Operator data
7.2Mbit/s	10	16 QAM	1×1		Operator data
10.1Mbit/s	12	16 QAM	1×1		Analysys Mason
14.4Mbit/s	15	16 QAM	1×1		Analysys Mason
21.1Mbit/s	15	64 QAM	1×1		Operator data
42.2Mbit/s	15	64 QAM	1×1		Operator data
84.4Mbit/s	15	64 QAM	2×2		Analysys Mason
HSUPA	N/A	N/A	N/A		Operator data

Source: Analysys Mason model

Radio network: the model deploys a hierarchy of HSPA upgrades for HSDPA and HSUPA demand

Year of deployment of HSPA upgrades

HSPA release	Dense urban	Urban	Suburban	Rural	Micro/indoor
1.8Mbit/s	N/A	N/A	N/A	N/A	N/A
3.6Mbit/s	2006	2006	2007	2008	2007
7.2Mbit/s	2007	2010	2012	2015	2012
10.1Mbit/s	N/A	N/A	N/A	N/A	N/A
14.4Mbit/s	N/A	N/A	N/A	N/A	N/A
21.1Mbit/s	2010	2011	2012	N/A	2012
42.2Mbit/s	2012	2013	2015	N/A	2012
84.4Mbit/s	N/A	N/A	N/A	N/A	N/A
HSUPA	2007	2010	2012	2015	2012

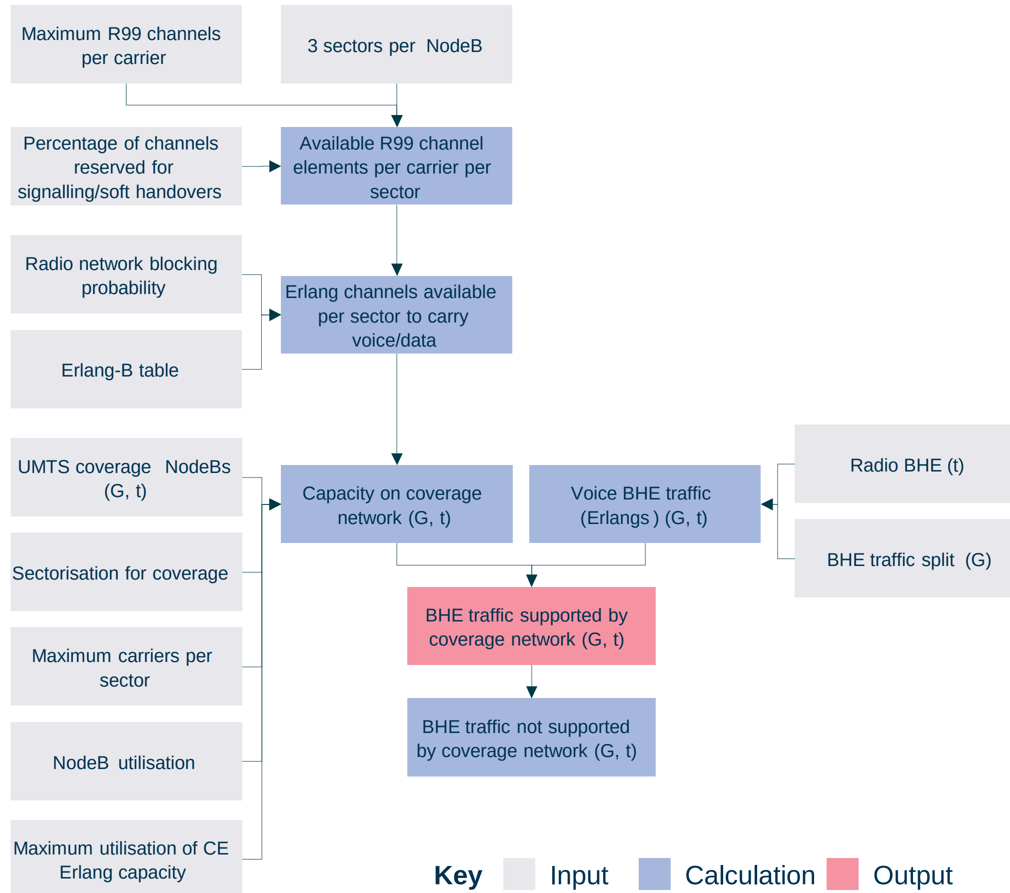
Note: N/A means that the release is not launched for a given geotype

Source: Analysys Mason model

Radio network: capacity provided by 3G coverage sites

- Calculating the capacity provided by the 3G coverage sites is the first step in the calculation of the capacity requirements
- The model assumes a maximum number of R99 channel elements (R99 CEs) per NodeB
  - the available channel elements per carrier are *pooled* between the three sectors of the NodeB after taking into account the soft-handover reservation
  - the sector capacity in Erlangs is obtained using the Erlang-B conversion table and the number of channel elements per sector
- The sector capacity in Erlangs is multiplied by the total number of UMTS sectors in the coverage network to arrive at the total capacity of the network
  - the average number of sectors per site is subject to the average utilisation factor
  - in calculating the effective capacity of each sector in the coverage network, allowance is made for the fact that NodeBs and channel elements are in fact less than 100% utilised on average during the network busy hour
- Micro sites are assumed to provide additional capacity as if they were an omni-sector site

Calculation of the BHE capacity provided by the UMTS coverage network

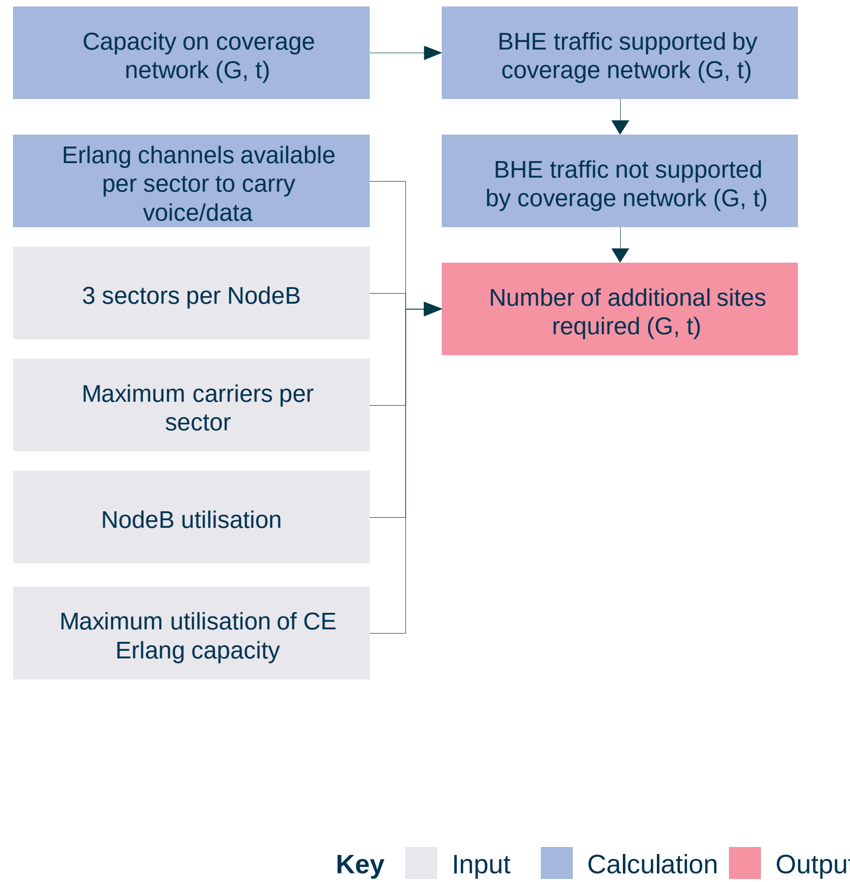


Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

Radio network: additional 3G sites deployed for capacity

- Additional sites required are calculated to fulfil capacity requirements after calculating the capacity of the coverage network:
  - BHE that cannot be accommodated by the coverage network by geotype are calculated
  - the calculation of the capacity of the additional sites assumes that the deployment of carriers per sector is subject to the average utilisation factor
- Micro sites are modelled as an additional layer of mono-sector capacity sites
- It should be noted that the 3G coverage network has significant capacity (having been implicitly designed to cope with a load up to 50–60% for cell-breathing purposes)
  - therefore, additional sites for capacity are only calculated in extremely high-traffic situations

Calculation of the additional 3G sites required to fulfil capacity requirements

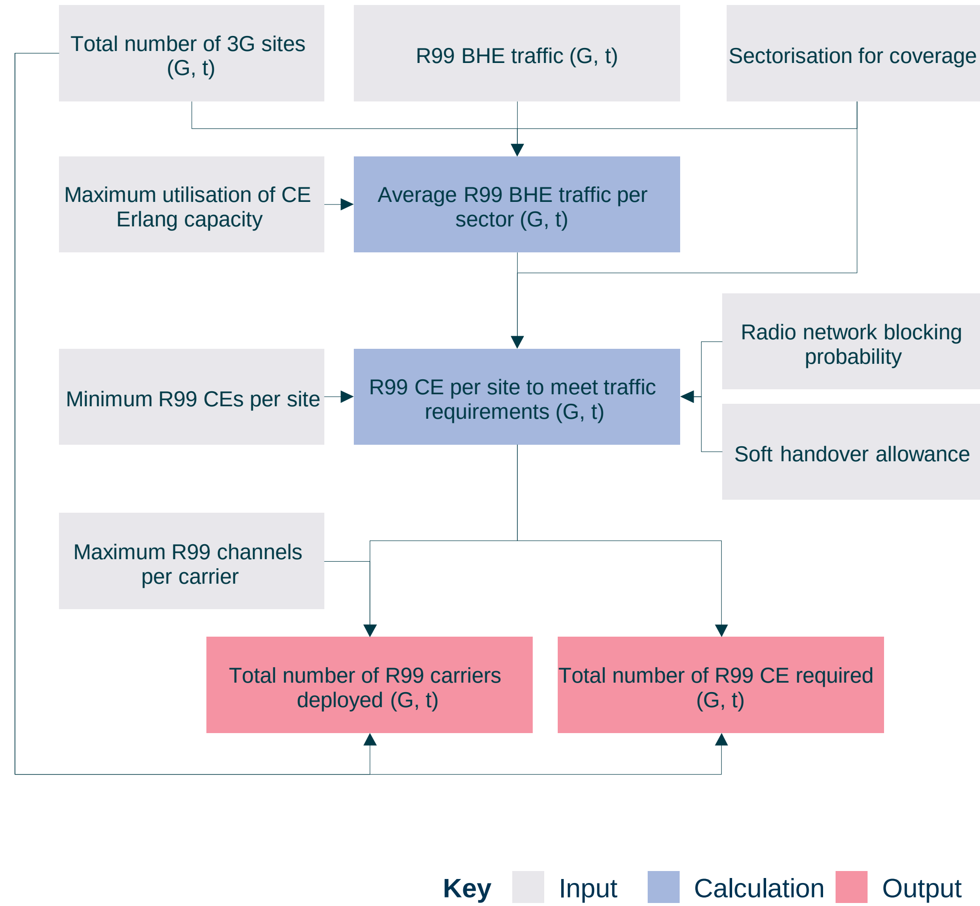


Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

Radio network: channel element and carrier requirements

- The dimensioning of R99 CEs is done in a similar manner to the calculation of 2G TRXs, with the exception that an allowance is made for soft handover:
  - the number of R99 carriers for each site is then calculated, based on the maximum number of R99 CEs per carrier
- Additional CEs for high-speed data services are dimensioned based on:
  - configuration profiles for the various high-speed data services technologies (i.e. number of CEs per NodeB for HSDPA 1.8Mbit/s)
  - activation profiles by year and geotype
- The total number of CEs required is obtained by multiplying the number of sites and the number of CEs per site:
  - this is repeated for carriers and for each type of CE (R99, HSDPA, HSUPA)

R99 channel kit and carrier dimensioning



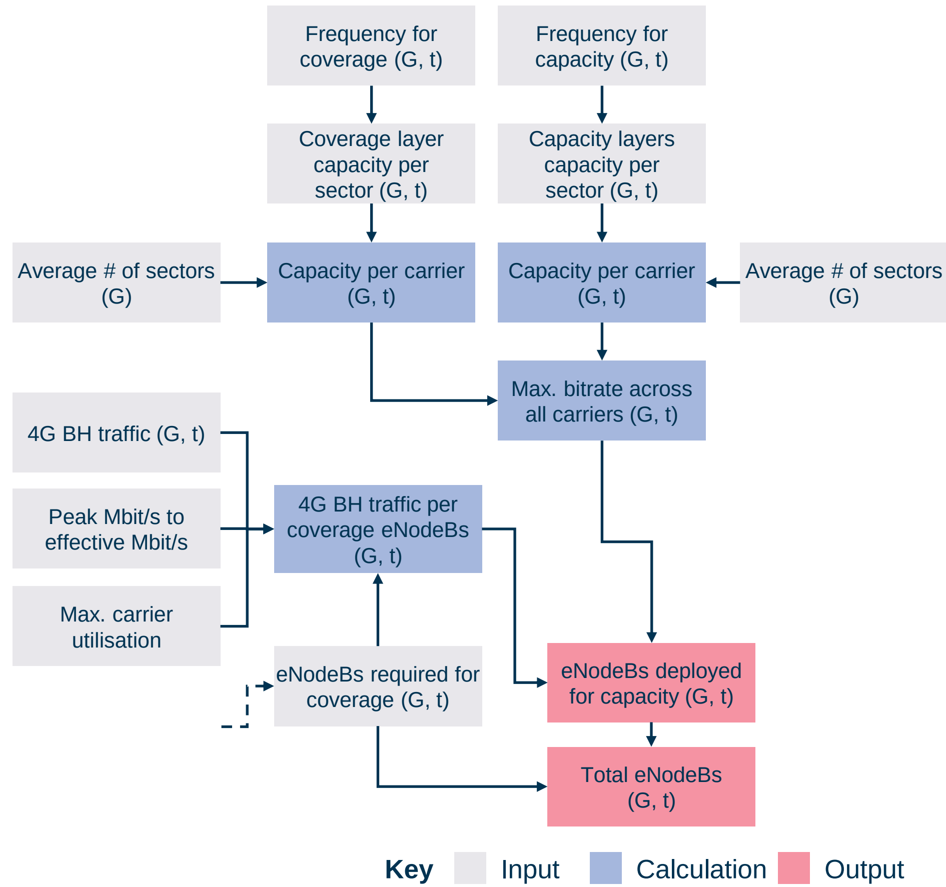
Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

analysys mason

Radio network: additional 4G sites deployed for capacity

- As for the UMTS and GSM networks, the first step is to calculate the traffic capacity of the coverage layer
- This capacity depends on two factors
  1. the effective Mbit/s capacity per sector, which is assumed to be 25% of the theoretical peak speed, in line with similar regulatory models published by other primary European NRAs and supported by the indications of Portuguese operators
  2. LTE technology upgrades adopted (see next slide for more detail)
- The modelled operator is expected to increment the capacity of the existing carrier by adopting new LTE releases before deploying additional carriers and sites, in order to reduce the capex required
  – therefore, the number of additional sites required for capacity is calculated assuming that the latest LTE release is installed on all the available carriers in all the coverage sites

Calculation of the additional sites required to fulfil capacity requirements and total number of sites



Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

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Radio network: 4G capacity calculations

- The LTE standard is expected to evolve over time, offering increasing capacity and speed with the same amount of spectral resources (and therefore carriers)
- The model includes six incremental upgrades capable of offering increasing peak speeds
- Peak speeds essentially depends on three key drivers:
  - the modulation adopted (e.g. QPSK, 16 QAM, 64 QAM, 128 QAM)
  - the amount of paired spectrum aggregated (which for LTE can be contiguous or not) in a carrier (e.g. 2 × 5MHz, 2 × 10MHz); the model does not take into consideration any spectrum that might be awarded in the future in Portugal
  - the multiple input/multiple output (MIMO) configuration (e.g. 1 × 1, 2 × 2, 4 × 4, 8 × 8)

LTE upgrades available in the model

Upgrade	Speed at peak in Mbit/s	Modulation	MHz paired spectrum	MIMO configuration
Upgrade 1	37	64 QAM	2×5MHz	2×2
Upgrade 2	75	64 QAM	2×10MHz	2×2
Upgrade 3	150	64 QAM	2×20MHz	2×2
Upgrade 4	225	64 QAM	2×30MHz	2×2
Upgrade 5	300	64 QAM	2×40MHz	2×2
Upgrade 6	600	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
Source: Analysys Mason model

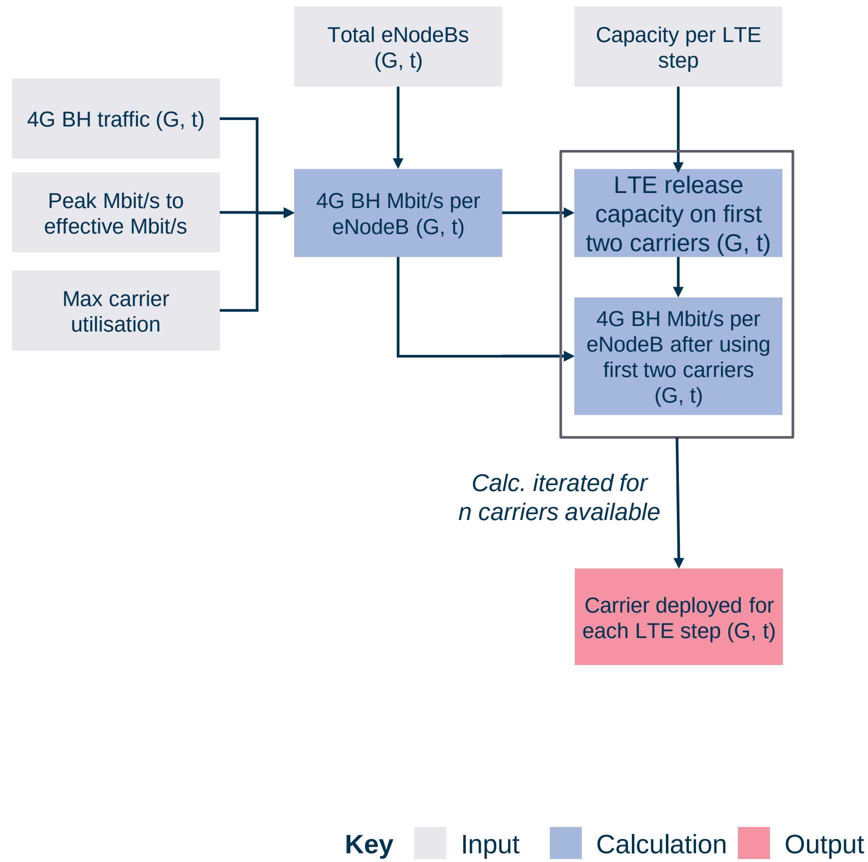
Radio network: 4G carrier requirements

- The model assumes that the hypothetical existing operator will roll out spectrum in the following bands:
  - 1 carrier in the 800MHz spectrum band (2 × 10MHz)
  - 1 carrier in the 2600MHz spectrum band (2 × 20MHz)
  - 1 carrier in the 1800MHz spectrum band (2 × 20MHz)
- LTE carriers are assumed to be rolled out following commercial considerations (e.g. coverage, advertised speed) rather than by the demand for additional capacity

Commercially driven roll-out of LTE upgrades

Speed at peak in Mbit/s	Year of adoption assumed in the model				
	Dense urban	Urban	Suburb.	Rural	Micro/ indoor
37	2012	2012	2012	2012	2012
75	2012	2012	2013	2013	2012
150	2013	2014	2016	2020	2013
225	2016	2018	2020	2024	2013
300	2018	2020	2022	N/A	2018
600	N/A	N/A	N/A	N/A	N/A

Calculation of the additional sites required to fulfil capacity requirements and total number of sites



Note: G = varying with geotype, t = varying with time. Source: Analysys Mason model

Radio network: total number of physical sites

- We have calculated the number of radio physical sites, thus taking into consideration 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 the capital expenditure. Radio sites can have the following technological configurations in the model:
  - 2G only, 3G only, 4G only, 2G + 3G, 2G + 4G, 2G + 3G + 4G and 3G + 4G
- The total number of physical locations required by the radio access network is the sum of all the possible configurations

Source: Analysys Mason model

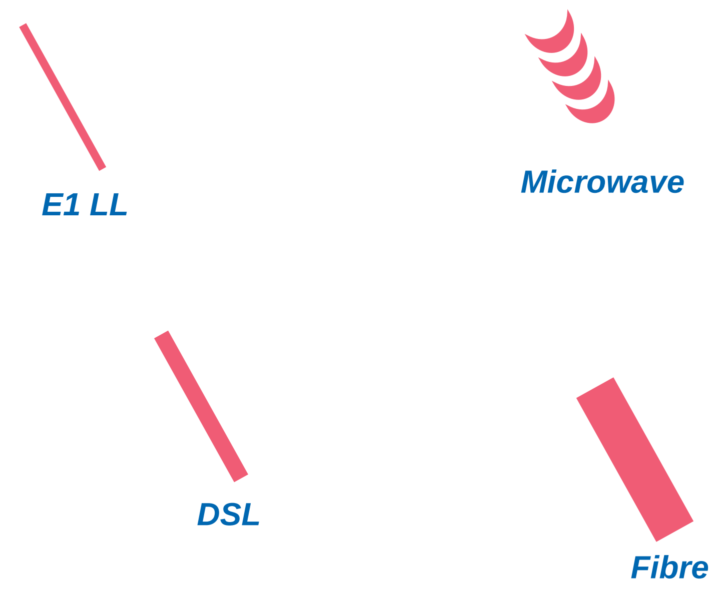
Transmission

- We have split the transmission network into three parts, each of which can be built using different transmission technologies
  - **Last-mile access (LMA)** network based on leased lines, DSL, microwave or fibre
    - this is used to collect the traffic from BTS/Node B/eNodeB and carry it to the nearest BSC/RNC/LTE-AP or transmission access point
  - **A regional backbone** based on self-provided microwave trees or fibre rings
    - this connects suburban and rural geotypes with the seven cities of the urban geotype
    - rings are used to carry the backhaul transit traffic, i.e. traffic between BSC/RNC/LTE-AP and transmission access points
  - **A national backbone** based on self-provided fibre rings
    - this connects the seven cities of the urban geotype
    - rings are used to carry inter-switch, interconnect and voicemail traffic
    - it can be set up to carry BSC–MSC, RNC–MSC, PCU–SGSN and LTE-AP to SGW traffic in the situation where a city may not have an MSC or an SGSN

Source: Analysys Mason model

Last-mile access

- Traditional last-mile access:
  - 120 circuits per E1
  - HSUPA service rate: 1.5Mbit/s
  - Microwave links capacity: 32Mbit/s
  - one circuit per TCH or per voice/R99 CE
    - plus GPRS channels
    - or EDGE channels are ×4 rate compared to GPRS
  - HSDPA at 1.8, 3.6, 7.2, 21.1, 42.2, 84.4Mbit/s
  - LTE for all six modelled upgrades
- Provided by:
  - leased E1s (n per site)
  - microwave links (up to 16 E1)
  - DSL (*n* E1s)
  - fibre link (*n* E1s)
- Additional rules:
  - indoor sites always linked with leased E1



Source: Analysys Mason model

Proportions for last-mile access: distribution of backhaul technologies by geotype and by mobile network technology (2G/3G/4G)

Split of last-mile accesses by technology and geotype

Last-mile technologies	Leased lines			Microwave			DSL			Fibre		
	2G	3G	4G	2G	3G	4G	2G	3G	4G	2G	3G	4G
Dense urban	-	0.0%	0.0%	0.0%	0.0%	10.0%	10.0%	10.0%	0.0%	90.0%	90.0%	90.0%
Urban	-	2.5%	2.0%	12.5%	12.5%	15.0%	1.0%	1.0%	0.0%	86.5%	84.0%	83.0%
Suburban	2.5%	2.5%	2.5%	13.5%	18.5%	17.5%	2.0%	2.0%	0.0%	82.0%	77.0%	80.0%
Rural	2.5%	2.5%	5.0%	32.5%	25.0%	25.0%	2.5%	2.5%	0.0%	62.5%	70.0%	70.0%
Micro/indoor	20.%	20.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	80.0%	80.0%	80.0%

- The last-mile distribution of technologies per geotype has been calculated based on information provided by operators during the data request, and Analysys Mason estimates

Source: Analysys Mason model, operator data

Regional backbones

- Regional backbones are self-provided: they pass through backhaul transit access points in suburban and rural geotypes (urban sites are directly connected to their BSC/RNC/LTA-AP co-located site)
- A proportion of sites is aggregated to regional backhaul transmission, through a regional transmission ring
- Access points are configured according to the number of sites that each one links up, which is itself based on the transmission technology used
- We model *resilience* of the transmission capacity using a utilisation factor lower than 50% – i.e. the provision of diverse transmission capacity

Source: Analysys Mason model

Regional backbones – distribution of traffic

- The length of fibre has been estimated based on road distances between the main points for each region
- Traffic is distributed among the different links based on the following estimates:
  - fibre LMA share of traffic is calculated based on population per geotype per region and a probability of fibre deployment per geotype
  - BSC/RNC/LTE-AP to core and backhaul access node share of traffic has been calculated based on total population distribution
  - access points share of traffic is distributed based on the proportion of urban, suburban and rural population in each region

Transmission backbone regions	Length (km) if fibre based	Fibre LMA share	BSC/RNC/LTE-AP to core share	Backhaul access node share	Access points share
Region North	305	12.71%	13.93%	13.93%	16.32%
Region Porto	162	27.68%	24.03%	24.03%	10.74%
Region Centre	489	15.09%	21.78%	21.78%	43.79%
Region Lisboa	133	9.83%	20.42%	20.42%	6.98%
Region Setúbal	465	26.31%	10.89%	10.89%	11.91%
Region Faro	220	3.82%	4.19%	4.19%	4.88%
Region Azores	1100	2.62%	2.41%	2.41%	4.07%
Region Madeira	168	1.94%	2.36%	2.36%	1.31%

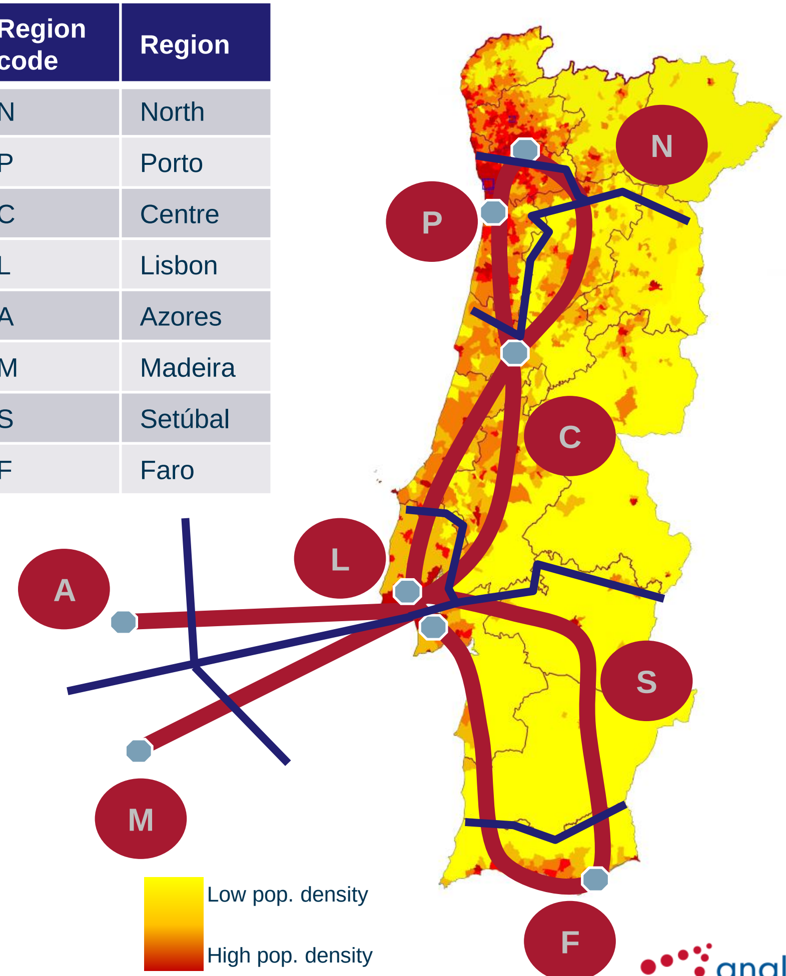
Source: Analysys Mason estimates

National backbone

- The national backbone is self-provided, and is based on fibre and STM-x connections
- It is composed of a fibre network connecting eight core transmission sites
  - furthermore, two submarine cable connections are included to account for the links between Lisbon, Madeira and the Azores
- The assumed length of the national backbone is 1472km for the full national backbone, not including the submarine links, and is based on Analysys Mason estimates

Regional networks for Portugal

Region code	Region
N	North
P	Porto
C	Centre
L	Lisbon
A	Azores
M	Madeira
S	Setúbal
F	Faro

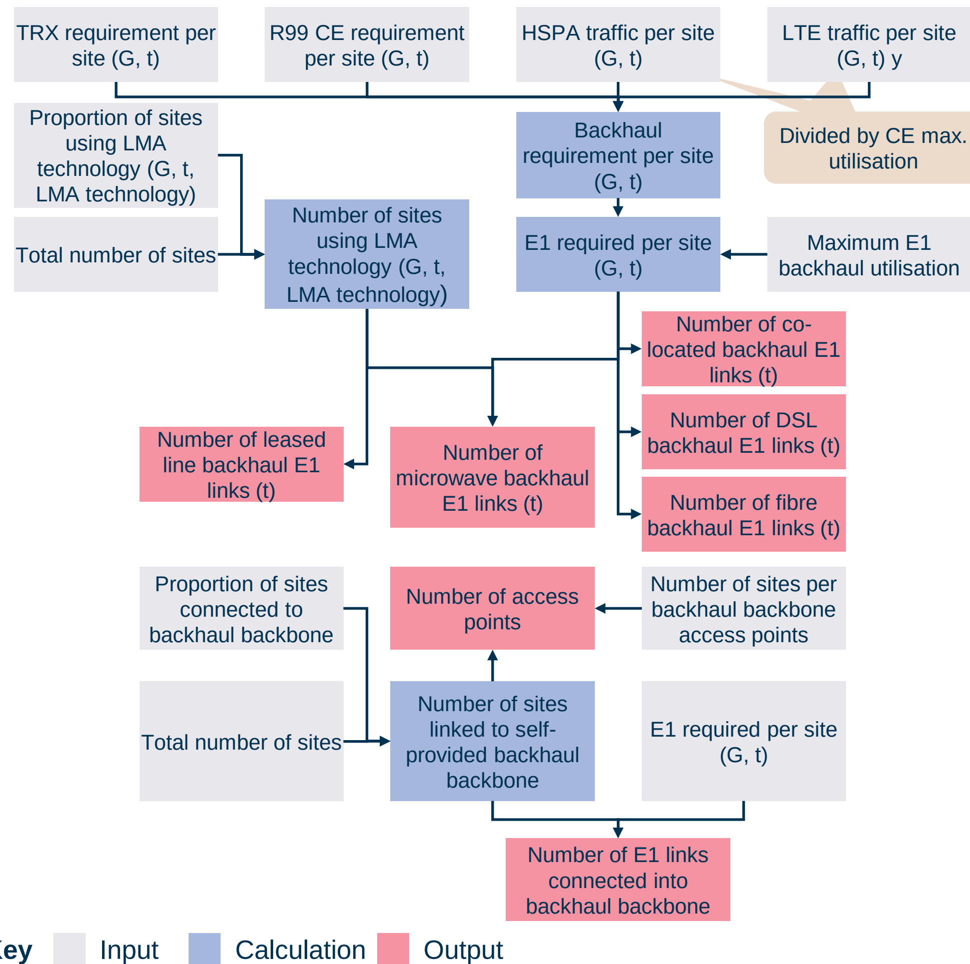


Source: Analysys Mason estimates

The dimensioning of the backhaul network involves a three-step process …

- First, the backhaul capacity required by site is calculated:
  - TRXs and R99 CEs drive the number of voice and GPRS/EDGE channels requiring backhaul
  - the HSPA and LTE backhaul effective traffic requirements is divided by the maximum utilisation factor
- Backhaul traffic is then allocated to the various last-mile access (LMA) technologies:
  - the proportion of LMA technologies is an input to the model
  - the number of E1s required per site (on average) differs by geotype but does not vary with the LMA technology used
- Finally, each part of the backhaul network is dimensioned:
  - microwave E1s are converted into microwave links (32Mbit/s equivalents)
  - leased-line E1s are identified separately by geotype as their price is distance-dependent
- A defined proportion of sites is assumed to require backhaul transit on the regional backbones

Backhaul calculation



Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

… as does the dimensioning of both the regional and national backbone networks

- First, the model summarises all traffic types to be carried over the backbone networks:
  - fibre backhaul last-mile access (LMA)
  - backhaul transit
  - BSC–MSC, PCU–SGSN, RNC–MSC, LTE-AP to SGW links when not co-located
  - MSC inter-switch and VMS access links when not co-located
- Traffic types are then allocated to the national and regional backbones
- We have modelled an NGN transmission for the national and regional networks
  - it is assumed that all national access points have 10GbE capability, all regional access points have 1GbE capability and submarine STM-4 connections are used to connect to Madeira and the Azores
  - the number of access points is calculated (directly from a model input for the national backbone and based on the number of radio sites for the regional backbones)
  - the fibre distance is calculated based on distances between the main points – measured as map lengths – covering each region

Source: Analysys Mason model

BSCs, PCUs, RNCs and LTE-AP

BSCs (2G)

- The number of BSCs is deployed on the basis of the number of TRXs, cells or E1 backhaul links, while the number of PCUs is driven by the number of BSCs
  - a parameter specifies the proportion of remote BSCs and co-located BSCs (i.e. deployed in the same building as an MSC)
    - this allows the model to calculate both the number of remote BSC–MSC links and the total number of MSC-facing BSC ports (i.e. including co-located links)
    - in the model we have assumed that there are no remote BSCs deployed by the hypothetical efficient operator

RNCs (3G)

- The number of RNCs is deployed on the basis of the 3G traffic load (downlink Mbit/s in radio layer) and according to the number of NodeB-facing E1 ports required
  - all RNCs are assumed to be co-located with the main switches
  - RNCs can then be connected to MSCs with either E1 or STM-1 ports

LTE-APs (4G)

- LTE does not require the equivalent of the RNC (for 3G) or BSC (for 2G) since the functionalities (e.g. routing) of this equipment are embedded in the eNodeB co-located at the sites
- Nonetheless, we have assumed the existence of an aggregation point (LTE-AP) where the LTE backhaul links converge to aggregate the traffic into more capable links connecting to the regional and national backbone
  - all LTE-APs are assumed to be co-located with RNCs and BSCs. LTE-APs are not decommissioned if BSCs or RNCs are decommissioned

Source: Analysys Mason model

Capacity measures for BSCs, PCUs and RNCs

Hypothetical efficient operator inputs

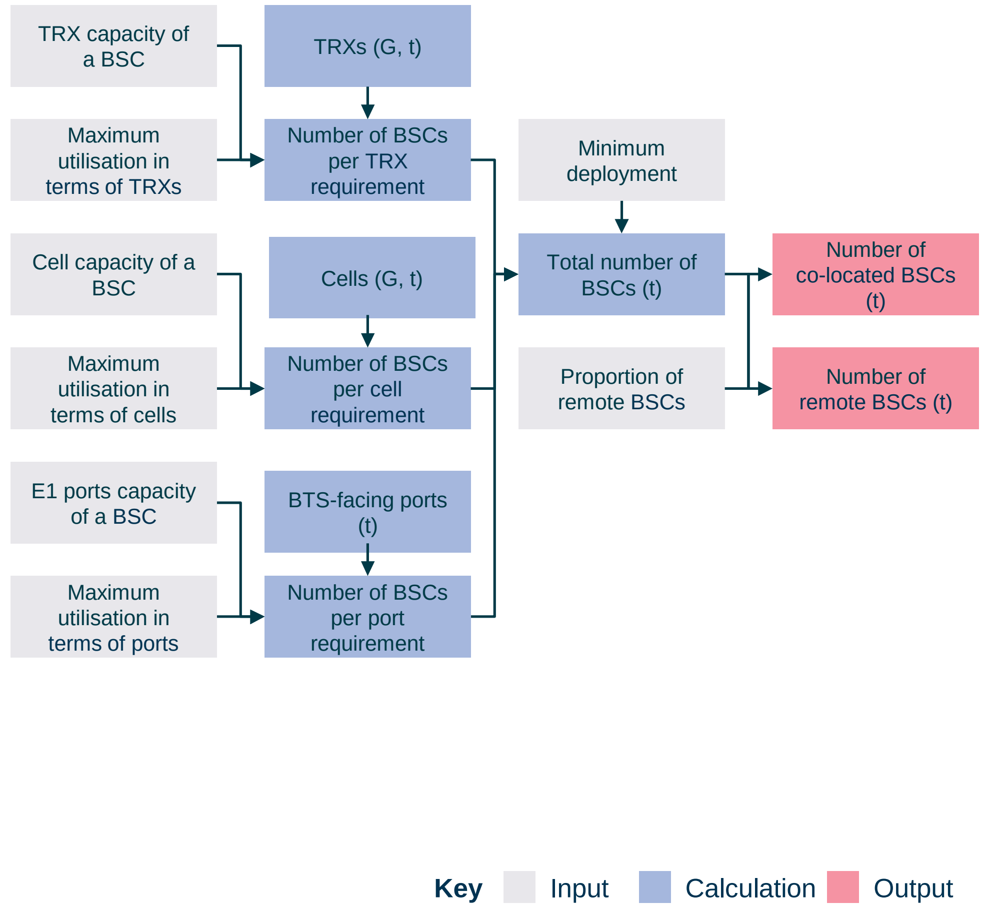
Item	Capacity measures	Minimum deployment	Source
BSC capacity in TRX	2000	8	Operator data
BSC capacity in E1 incoming ports	300		Analysys Mason estimates based on operator data
BSC capacity in cells	1000		Analysys Mason estimates based on operator data
PCU per BSC	3		Analysys Mason estimates
RNC capacity in Mbit/s	2458	8	Operator data
RNC capacity in E1 incoming ports	1450		Operator data
LTE-AP capacity in Mbit/s	N/A	# of RNCs	Analysys Mason estimate
LTE-AP capacity in E1 incoming ports	5000		Analysys Mason estimate

Source: Analysys Mason estimates, Analysys Mason model

BSC dimensioning

- BSC unit deployment is driven by four requirements:
  - maximum number of TRXs controlled, assuming a maximum utilisation
  - maximum number of cells controlled, assuming a maximum utilisation
  - maximum number of E1 ports connected, assuming a maximum utilisation
  - minimum number of two BSCs deployed in the network (for redundancy)
- Each of those four requirements leads to a different number of BSC units:
  - the total number of BSCs corresponds to the highest of those four values
- A proportion of BSCs can be designated as 'remote' (i.e. not co-located with an MSC)
  - although it is assumed that the modelled operator by default does not roll out remote BSCs

BSC deployment

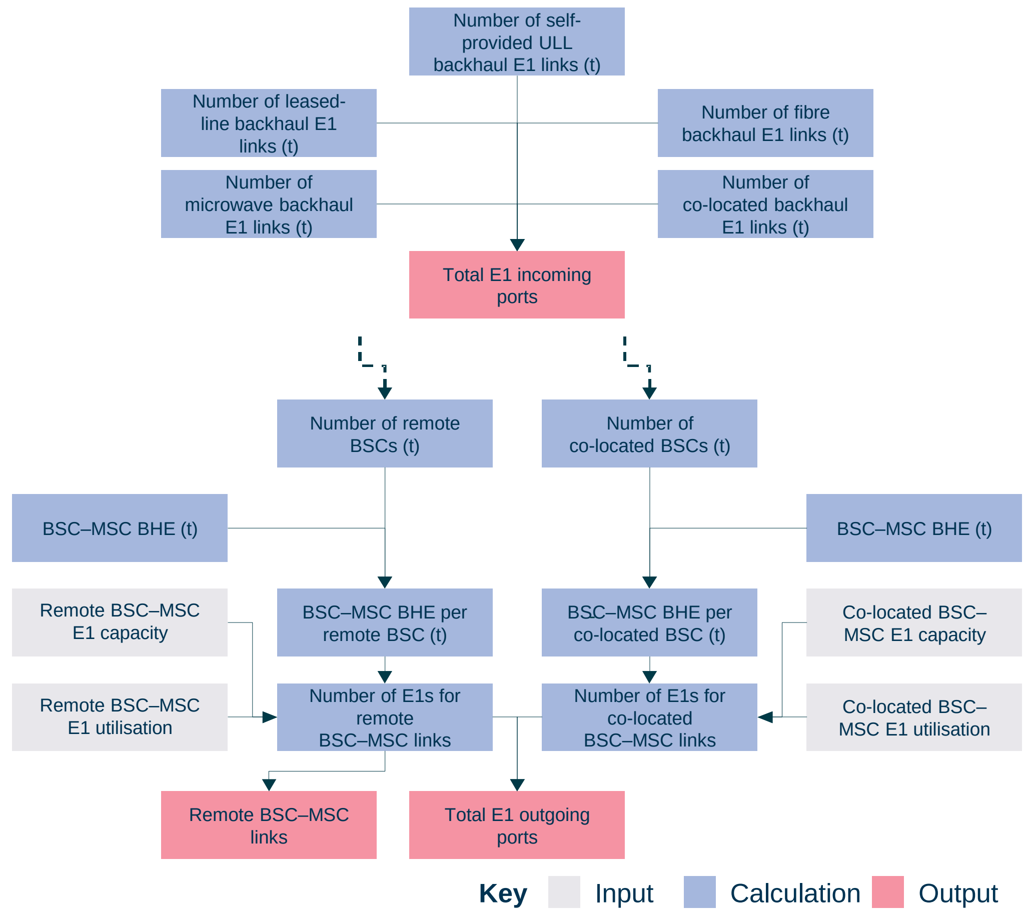


Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

BSC incoming and outgoing ports calculation

- BSC incoming ports (ports facing BTS) are directly derived from the number of backhaul E1 links, including all technologies
- Remote BSC–MSC traffic is first calculated as a proportion of total BSC–MSC traffic (based on the proportion of remote BSCs) and then dimensioned taking into account the capacity and utilisation of remote BSC–MSC links
- Co-located BSC–MSC traffic is first calculated as a proportion of total BSC–MSC traffic (based on the proportion of co-located BSCs) and then dimensioned taking into account the capacity and utilisation of co-located links
- Total BSC outgoing ports include both the remote and co-located links
- BSC–MSC transmission requirements correspond only to remote BSCs:
  - this number is expressed either in E1 or STM-1 equivalents depending on the capacity needed

BSC incoming and outgoing ports

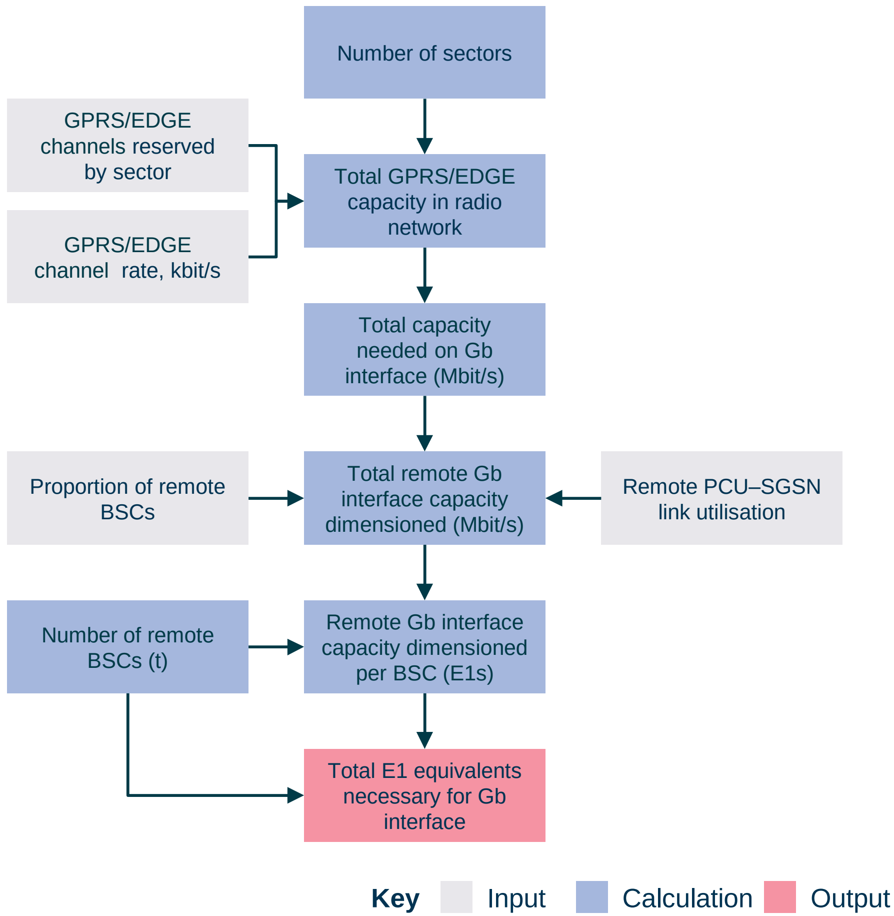


Note: t = varying with time
Source: Analysys Mason model

PCU–SGSN links dimensioning

- First, the Gb interface (PCU–SGSN links) is dimensioned in order not to be the network bottleneck
  - capacity needed on the Gb interface is assumed to be equal to the capacity that would be needed if all GPRS/EDGE channels reserved were simultaneously active on all sectors in the network
- Second, remote Gb traffic is calculated as a proportion of total PCU–SGSN traffic
  - based on the proportion of remote PCUs assumed to be equal to the proportion of remote BSCs
- Remote Gb traffic is then converted into E1 equivalents, taking into account the utilisation of remote PCU–SGSN links
- Finally, Gb links are added to the BSC–MSC links for the purpose of calculating the total capacity expressed either in E1 or STM-1 equivalents, depending on the needs

PCU–SGSN links (Gb interface)

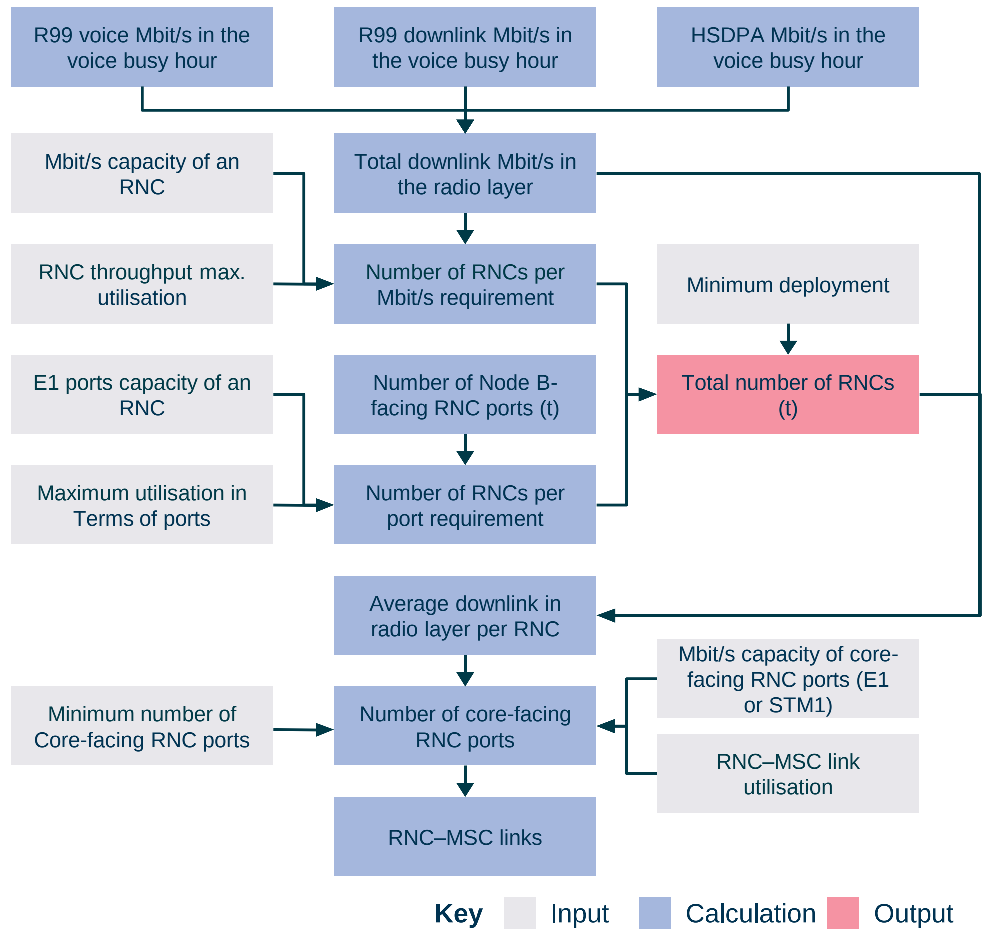


Note: t = varying with time
Source: Analysys Mason model

RNC dimensioning

- RNC unit deployment is driven by three requirements
  - maximum throughput in Mbit/s (assessed in the downlink direction), assuming a maximum utilisation
  - maximum number of E1 ports connected, assuming a maximum utilisation
  - minimum number of two 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 those three values
- RNC incoming ports (ports facing NodeBs) are directly derived from the number of backhaul E1 links, all technologies included
- RNC–MSC links and core-facing E1 or STM-1 ports are dimensioned based on the average RNC downlink throughput
  - taking into account a utilisation factor that reflects, among other things, the need for redundant ports and links

RNC deployment and port dimensioning

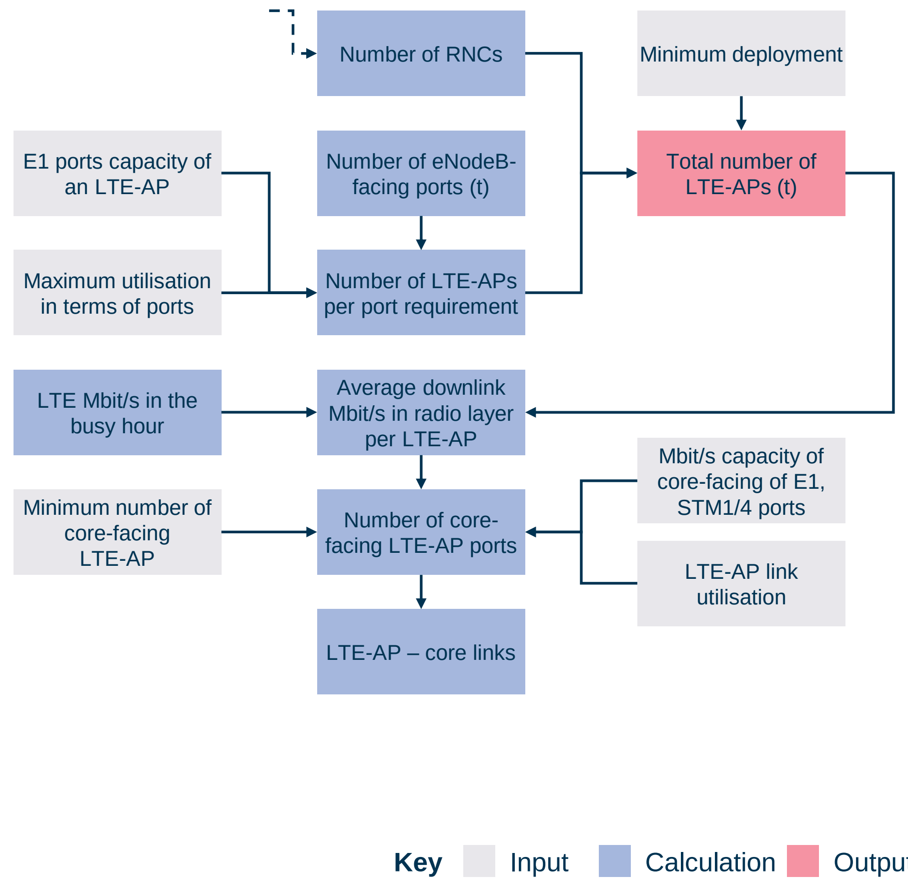


Note: G = varying with geotype, t = varying with time
Source: Analysys Mason model

LTE-AP dimensioning

- The number of LTE-APs deployed is driven by three inputs
  - the maximum number of LTE-APs required to support all E1 ports connected (facing eNodeB), assuming a maximum utilisation
  - the minimum number of LTE-APs deployed in the network for redundancy
  - the number of RNC locations
- The total number of LTE-APs is the highest of those three values
- Similarly to what happens with RNCs and BSCs, the number of incoming ports (ports facing eNodeBs) is directly derived from the number of backhaul E1 links, including all technologies
- The LTE-AP links facing the core are either E1 or STM-1/4 and are dimensioned on the basis of the average LTE downlink throughput
  - taking into account a utilisation factor that reflects, among other things, the need for redundant ports and links

LTE-AP deployment and dimensioning

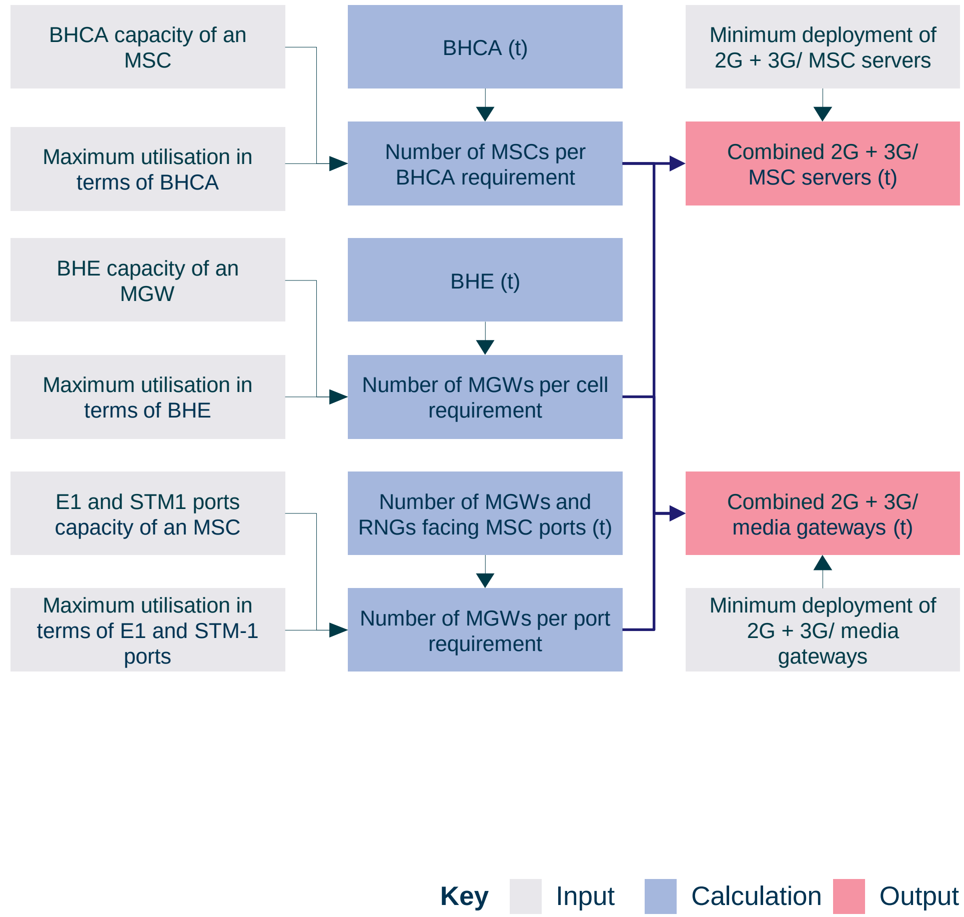


Source: Analysys Mason model

MSC dimensioning

- In the 3G layered architecture, MSC servers are driven by the processing capacity driver (BHCA) while MGWs are driven by the voice traffic load and the BSC/RNC port requirements
- Two parameters specify the maximum number of main switching sites and voicemail hosting sites
  - this is to model the point at which an operator starts doubling up MSCs in its switching sites

MSC deployment



Note: G indicates varying with geotype, and t varying with time
Source: Analysys Mason model

The core network topology is based on a reference table linking the number of MSCs to key parameters

- The number of MSC locations takes into account a maximum number of MSC sites
- The number of inter-switch logical routes, based on the *fully meshed* formula n(n-1)/2 where *n* is the number of MSCs, is further split between remote and co-located routes based on the average number of MSCs per location
- The number of POIs takes into account the proportion of MSCs that act as POIs
  - the number of interconnected logical routes is based on the number of third parties connected in each POI and takes into account a maximum number of interconnection routes
- The number of VMS locations takes into account a maximum number of VMS sites
  - the number of VMS logical routes is based on a full mesh between all MSCs and the VMS
- The proportions of various traffic types transiting on inter-switch logical routes are based on operators' submitted data

Core network reference table

Increasing number of MSCs (not shown here)

TRUE	Units	Period	Note	2015
# MSC				14
# MSC locations				7
# MSC per location				2
# Inter-switch logical routes				91
# Inter-switch logical routes (remote)				84
# Inter-switch logical routes (coloc)				7
# POIs				14
# Interconnect logical routes				30
# VMS sites				2
# VMS logical routes				28
# VMS logical routes (remote)				26
% incoming traffic on inter-switch logical routes: INCLUDES inter-MSC				80.0%
% outgoing traffic on inter-switch logical routes: INCLUDES inter-MSC				68.6%
% on-net traffic on inter-switch logical routes: INCLUDES inter-MSC				60.0%
% international traffic on inter-switch logical routes: INCLUDES inter-MSC				92.9%

This MSC reference table is the main determinant of core network inter-switch dimensioning. Having calculated the number of MSC according to MSC capacity, we then use the reference table to find out how many MSC locations and how many routes of different types are needed; the proportions of traffic between switches; etc. This table aims to condense the complex core network topology upgrade process into a logical but reflective network design algorithm

Source: Analysys Mason model

MSC incoming/outgoing ports and outgoing transmission requirements are dimensioned

- The combined MSC servers have a capacity of 600 000 BHCA for MSCs (based on operator data), or 25 STM-1 for MGW (from Analysys Mason estimates based on operator data), with a minimum deployment of 4 of each
- MSC incoming ports (BSC- and RNC-facing) are directly derived from the BSC and RNC dimensioning calculations
- Interconnect ports are based on the number of logical routes (trunks) between operators and third parties and on the interconnect BHE load
  - incoming and outgoing ports are calculated separately
    - minimum of 2 MGW ports – RNC-facing, MGW ports – inter-switch and MGW ports – interconnection point based on Analysys Mason estimates
  - calculations assume an interconnect link utilisation factor
- Inter-switch traffic is first calculated as a proportion of total traffic, then allocated to either distant or co-located links based on the ratio between the number of switches and number of switching sites
- Voicemail ports are based on the number of logical routes between all MSCs and the number of VMS sites. It is assumed that VMS are hosted on one or several of the main switching sites
- MSC ports are expressed in E1 equivalents while corresponding transmission links are expressed in either E1 or STM-1 equivalents
- 25% of additional MGWs has been taken into account for redundancy and/or resiliency

Source: Analysys Mason model

Core network server deployment rules

Modelled operator inputs

Item	Deployment rule
SMSC HW	BHSMS/s (2G and 3G only)
SMSC SW	BHSMS/s (2G and 3G only)
MMSC	BHMMS/s
GGSN	PDP contexts (calculated from a proportion of the 2G and 3G subscriber base)
SGSN	SAUs (calculated from a proportion of the 2G and 3G subscriber base)
VMS	Subscribers
HLR, EIR, AUC	2G and 3G subscribers
VAS, WAP, IN	Subscribers
Wholesale billing	CDRs per day
NMS	Per ‘functional unit’ of the network: an NMS sub-system is deployed for each major unit of the network (e.g. 2G radio, 3G radio, 4G radio, LL, microwave, MSC, backup, LTE core systems, VoLTE core systems, etc.)

Source: Analysys Mason model

Core network server dimensioning parameters

Modelled operator inputs

Item	Capacity measures	Minimum deployment	Source
SMSC HW	4500 BHSMS/s	2	Operator data
SMSC SW	1500 BHSMS/s	2	Operator data
MMSC	60 BHMMS/s	1	Operator data
GGSN	675 000 PDP contexts	1	Operator data
SGSN (large)	4 000 000 SAUs	1	Operator data
VMS	2 000 000 subscribers	2	Operator data
HLR, EIR, AUC	6 000 000 subscribers	2	Operator data
VAS, WAP, IN	2 000 000 subscribers	1	Analysys Mason estimates
Wholesale billing	12 000 000 CDRs per day	1	Analysys Mason estimates

Source: Analysys Mason model

LTE and VoLTE core server deployment rules

Modelled operator inputs

Item	Deployment rule
MME hardware	SAU (calculated from a proportion of the 4G subscriber base)
MME software	SAU (calculated from a proportion of the 4G subscriber base)
SGW	4G voice + data traffic in the data busy hour (Mbit/s)
Data traffic manager	4G voice + data traffic in the data busy hour (Mbit/s)
HSS	4G subscribers (average of period)
SBC hardware	4G voice traffic in the voice busy hour (Mbit/s)
SBC software	4G voice traffic in the voice busy hour (Mbit/s)
Call server hardware	4G subscribers (average of period)
Call server software	4G subscribers (average of period)
TAS	4G subscribers (average of period)
VoLTE upgrades	Dependent on the number of systems that require the upgrade to be VoLTE capable

Source: Analysys Mason model

LTE and VoLTE core network dimensioning parameters

Modelled operator inputs

Item	Capacity measures	Redundancy	Minimum deployment	Source
MME hardware	12 500 000 SAUs	1	2	Operator data
MME software	12 500 000 SAUs	1	2	Operator data
SGW	40 000Mbit/s	1	4	Analysys Mason
Data traffic manager	30 000Mbit/s	1	2	Analysys Mason
HSS	1 000 000 subscribers	1	2	Operator data
SBC hardware	2000Mbit/s	2	1	Analysys Mason
SBC software	2000Mbit/s	2	1	Analysys Mason
Call server hardware	2 000 000 subscribers	2	1	Analysys Mason
Call server software	2 000 000 subscribers	2	1	Analysys Mason
TAS	25 000 subscribers	1	1	Analysys Mason

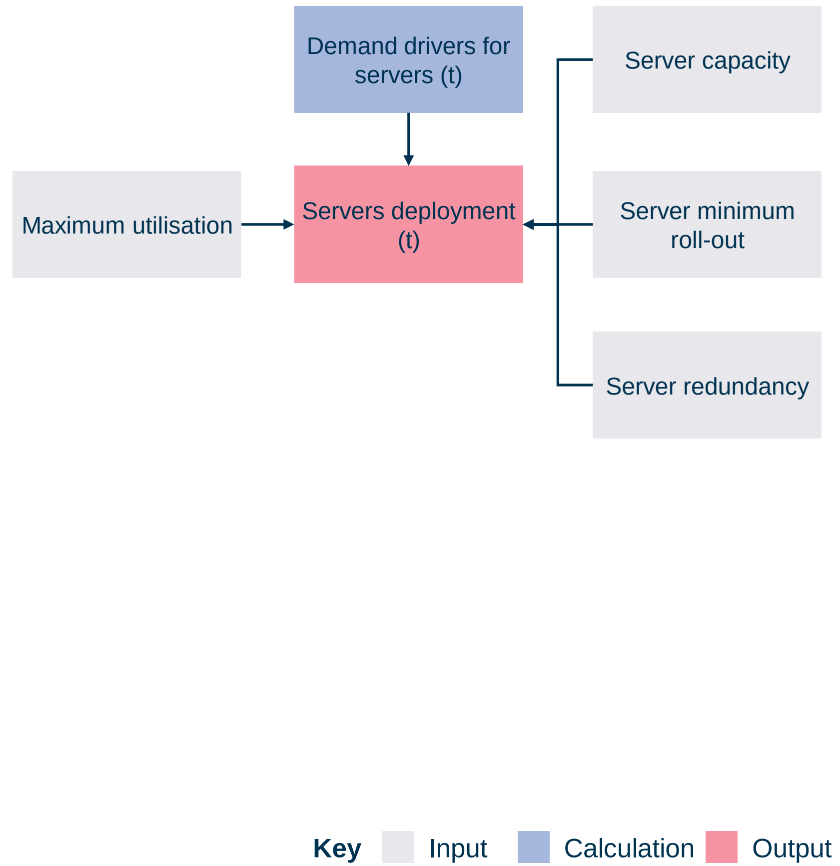
Net of redundancy

Source: Analysys Mason model

LTE and VoLTE core server dimensioning calculation

- The same methodology has been applied for the dimensioning of LTE and VoLTE core servers, but this has been done separately
- The total number of elements required is the maximum between the
  - minimum deployment
  - number of elements required to fulfil the demand, taking into account a maximum utilisation of the equipment
- Finally, the total number of elements previously calculated is multiplied by the redundancy factor that is used to ensure network resilience wherever required

Dimensioning of LTE and VoLTE core servers



Source: Analysys Mason model

Modelled operator's spectrum holding

2G	▪ The modelled operator has both 900MHz and 1800MHz spectrum in the same quantities as existing mobile operators in the Portuguese market – 2 × 8MHz of 900MHz spectrum – 2 × 5MHz of 1800MHz spectrum until 2018 ▪ The model assumes the GSM1800MHz spectrum to be re-farmed to LTE the first year when the share of GSM decreases below 50% of the total traffic voice Erlang in the voice busy hour
3G	▪ The modelled operator has 2100MHz spectrum in the same quantities as existing mobile operators in the Portuguese market – 2 × 20MHz of 2100MHz spectrum
4G	▪ The modelled operator has 800MHz, 1800Mhz and 2600MHz spectrum in the same quantities as existing mobile operators in the Portuguese market – 2 × 10MHz of 800MHz spectrum – 2 × 15MHz in the 1800MHz spectrum, 2 × 20MHz from 2018 – 2 × 20Mhz in the 2600MHz spectrum

Note: Vodafone also has additional spectrum in the 900MHz and 2600MHz frequency bands for 4G

Source: Analysys Mason, Operators' institutional websites, ANACOM, Analysys Mason model

Spectrum licence upfront payments

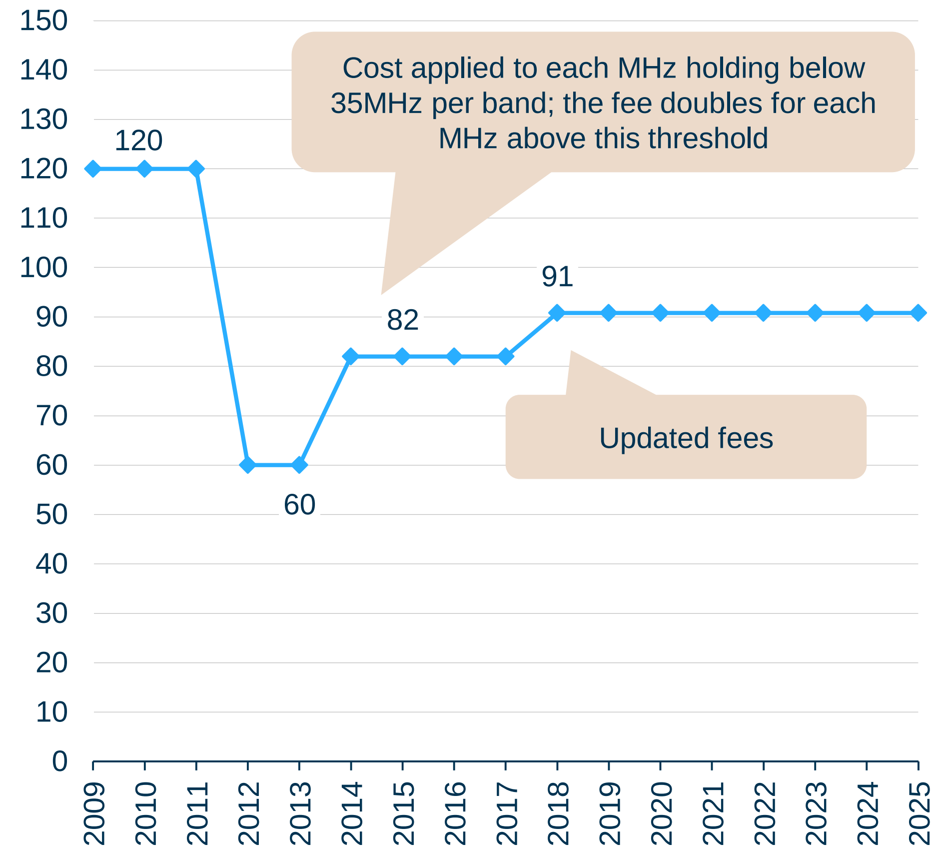
2G	▪ The GSM frequencies were given to Portuguese operators at no cost, and thus the modelled operator is not expected to pay for spectrum in the GSM band ▪ In the model, we have assumed that the spectrum assignment is automatically renewed every 15 years (at its expiry date) at no cost: – assignments occur in 2004, 2019, 2034 and 2049
3G	▪ We have assumed that the operator re-purchases its original spectrum allocation for the same fee as the original licence (PTE20 billion) adjusted for inflation – the same value is applied in real terms, meaning that the actual nominal payment increases with inflation ▪ In the model, we have assumed that the operator re-purchases its 2100MHz 3G licences every 15 years at the same price, adjusted for inflation: – purchases occur in 2004, 2019, 2034 and 2049
4G	▪ We have assumed that the modelled operator purchases the same amount of spectrum in the 800MHz, 1800MHz and 2600MHz of MEO and NOS which were awarded at the reserve price – we have, therefore, assumed that the modelled operator pays the same total amount of EUR113 million ▪ In the model, we have assumed that the operator re-purchases these spectrum licences every 15 years at the same price, adjusted for inflation: – purchases occur in 2011, 2026, 2041 and 2056

Source: Analysys Mason, ANACOM (http://www.anacom.pt/render.jsp?contentId=1106646#.VIcr07ktAaV)

Spectrum licence annual fees

- The model calculates annual fees by modelling two different methods (pre- and post-2009), as well as the migration between them
  - before 2009, based on a tax-per-base-station variable with its power, as well as a tax per mobile subscriber
  - after 2009, based on an annual fee per MHz of spectrum and a cost per reserved mobile number
- We have assumed that the methodology to calculate the spectrum management fees for the spectrum purchased in 2011 is the same used for the previous spectrum holding
  - Spectrum fees have been updated considering the latest values (Portaria nº 157/2017)
- In addition to the cost per MHz, the modelled operator pays EUR0.02 per subscriber
  - we have assumed this cost applies to 4G subscribers as well

Cost per MHz (EUR thousand) – Post-2009 methodology



Source: ANACOM, Ministerio da Economia Portaria nº 157/2017

Business overheads are modelled using simple expenditure inputs

- We have included business overheads expenditures
  - the modelled operator accounts for this expenditure in terms of capital or operating expenditure (capex or opex)
  - we assume that this expenditure (in real terms) is incurred each year of operation
- The business overheads have been calculated during the calibration process based on the level of overheads and costs experienced by real mobile operators

Business overheads inputs assumed for the modelled operator

Business overhead	Amount in EUR
Capex	2 500 000
Opex	10 000 000

Source: Analysys Mason Model

Introduction

Overview of principles

Market model

Network dimensioning

Portuguese geotype model

Network design

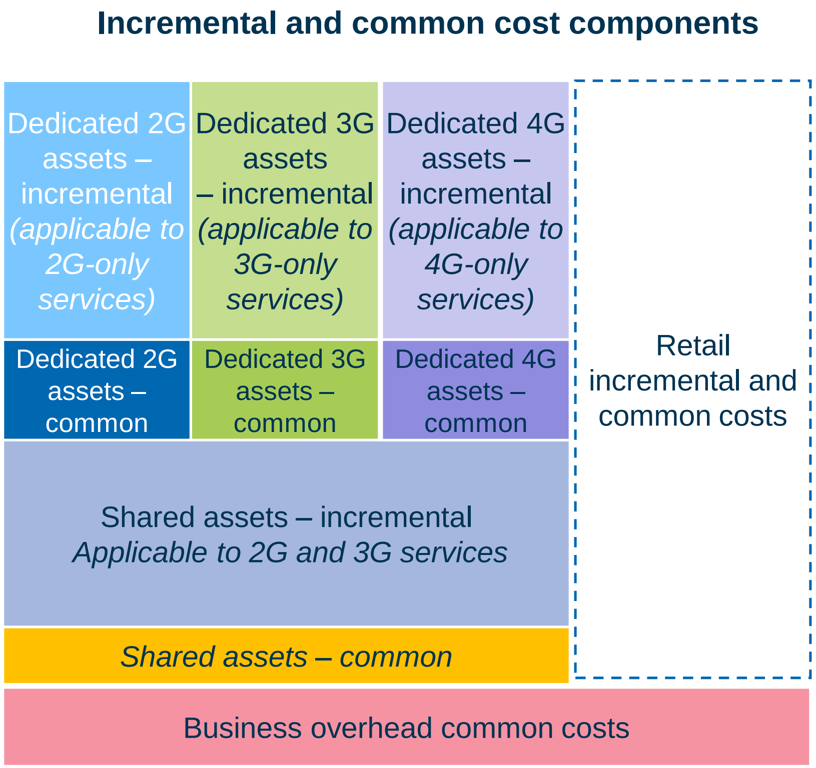
Network costing

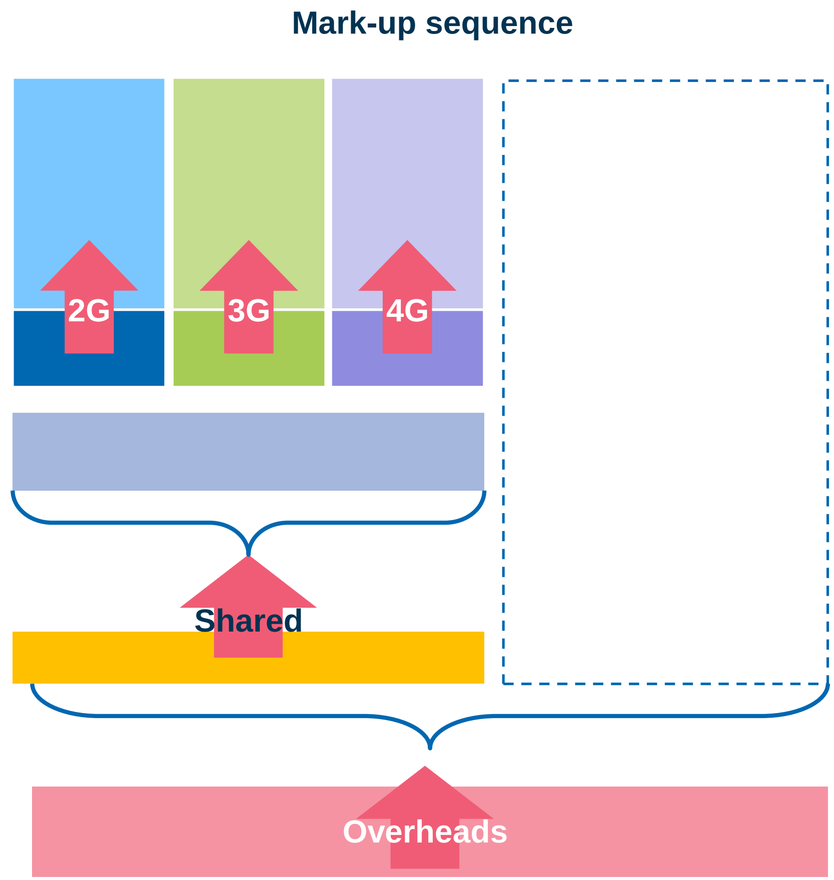
Model calibration

Model results

Annexes

The LRAIC+ model contains a four-part mark-up





- 2G, 3G, 4G common costs: licence fee
- Shared common costs: network management system
- Overheads: business overheads current split 60:40 between network and retail functions

Source: Analysys Mason

Indirect expenditures are estimated for the hypothetical efficient operator

- A mark-up has been applied to opex and capex items in order include indirect network costs
  - we apply this mark-up to all capex and opex costs per unit
  - the resulting per-unit costs are then used for the calculation of total costs and termination costs
- Mark-up values have been estimated based on the analysis of operator data and as part of the calibration process
  - mark-ups have been estimated based on operators' accounts, where they have been ask to identify their indirect costs for both capex and opex
  - mark-ups for the different operators have been calculated by taking their indirect costs and comparing them to the total costs
  - we have estimated an indirect capex mark-up of 40% for the hypothetical operator, and indirect opex mark-up of 10%

Source: Analysys Mason

Direct equipment prices have been obtained from submitted operator data or Analysys Mason estimates [1/4]

Direct costs used for radio/regional network (2017)

Asset	Capex (EUR)	Opex (EUR)
Own macro site location (acquisition, ancill, tower)	DATA REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION	
Third party macro site location (acquisition, ancill)		
Third party indoor site location (acquisition, ancill)		
Macro BTS 1-sector		
Macro BTS 2-sector		
Macro BTS 3-sector		
Micro BTS		
TRX		
Macro Node B 3-sector (excluding carrier equipment)		
Node B carriers (excluding channel kit)		
Node B Release 99 channel kit (16 CEs)		
Macro eNodeB (LTE)		
Indoor special BTS + distributed antenna		
Indoor special NodeB + distributed antenna		
Indoor special eNodeB+distributed antenna		
Site upgrade – 2G site upgrade facilities for 3G		
Site upgrade – 2G/3G site upgrade facilities for 4G		
Fibre LMA		
Leased E1 LMA Dense Urban		
Leased E1 LMA Urban		
Leased E1 LMA Suburban		
Leased E1 LMA Rural		
Leased E1 LMA Indoor		
Self-provided ULL E1		
Microwave link (up to 32 Mb/s)		
Microwave E1 activated		
Leased E1 – Remote BSC/PCU to MSC/SGSN		
Leased STM1 – Remote BSC/PCU to MSC/SGSN		
Leased E1 – MSC to MSC/VMS		
Leased STM1 – MSC to MSC/VMS		

	Capex baseline input	*Opex baseline input*
Own macro site location … Site upgrade – 2G/3G site upgrade facilities for 4G	Based on Portuguese operators' data and benchmarks from the previous version of the model, adjusted by inflation and cost trend	
Fibre LMA	Estimation based on cost of deploying fibre, both in owned ducts and PT's ducts, with a single fibre aggregating the traffic of several sites	
Leased E1 LMA Dense Urban … Self-provided ULL E1	Installation charges for a 2Mbit/s link from Portugal Telecom's Reference Offer	Derived from Portugal Telecom's Reference Offer price for a 2Mbit/s (E1) leased line
Microwave link (up to 32 Mb/s), Microwave E1 activated	Based on Portuguese operators' data and benchmarks from the previous version of the model, adjusted by inflation and cost trend	
Leased E1/STM1 – Remote BSC/PCU to MSC/SGSN, MSC to MSC/VMS	Connection prices from PT price list	Based on distance estimates and PT price list

Source: Analysys Mason model, operator data, Portugal Telecom's leased lines Reference Offer ("ORCA")

Direct equipment prices have been obtained from submitted operator data or Analysys Mason estimates [2/4]

Direct costs used for radio/regional network (2017)

Asset	Capex (EUR)	Opex (EUR)
Regional backbone access points STM1		
Regional backbone access points STM4		
Regional backbone access points STM16		
Regional backbone access points STM64		
Regional backbone distance (km)		
National backbone access points STM1		
National backbone access points STM4		
National backbone access points STM16		
National backbone access points STM64		
National backbone distance (km)		
LTE-AP		
BSC base unit		
Remote BSC sites		
BSC E1 ports (facing BTS)		
BSC E1 ports (facing MSC)		
RNC base unit		
RNC E1 ports (facing Node B)		
RNC E1 ports (facing core)		
RNC STM1 ports (facing core)		
Regional backbone access points 1GbE		
Regional backbone distance 1GbE (km)		
National backbone access points 10GbE		
National backbone access distance 10GbE (km)		
National backbone access submarine STM-4 connection		

DATA REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION

Capex baseline input | *Opex baseline input*

- Based on Portuguese operators' data and benchmarks
- Estimates based on fibre provider
- Based on Portuguese operators' data and benchmarks
- Approx. from operator's data
- Based on Portuguese operators' data and benchmarks
- Analysys Mason estimates for IP equipment based on other regulatory cost models
- Analysys Mason estimates for IP equipment | Estimate based on benchmark of transatlantic routes

Source: Analysys Mason model, operator data, Portugal Telecom's leased lines Reference Offer ("ORCA")

Direct equipment prices have been obtained from submitted operator data or Analysys Mason estimates [3/4]

Direct costs used for radio/regional network (2017)

Asset	Capex (EUR)	Opex (EUR)
Main switching sites		
2G MSC	DATA REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION	
2G MSC software		
MSC E1 ports (facing RAN)		
MSC STM1 ports (facing RAN)		
MSC E1 ports (facing other MSC)		
MSC STM1 ports (facing other MSC)		
MSC E1 ports (facing POI)		
MSC E1 ports (facing VMS, etc.)		
2G/3G MSC combined		
2G/3G MSC combined software		
MGW		
MSC remote BSC facing E1 transcoders 16-64kbit/s		
Data traffic manager (DTM)		
Mobility management entity-HW (MME)		
Mobility management entity-SW (MME)		
Serving gateway (SGW)		
Home subscriber server (HSS)		
Call server hardware		
Call server software		
TAS		
SBC hardware		
SBC software		
VoLTE upgrades to HLR		
VoLTE upgrades to MSC-S		
VoLTE upgrades to NMS		

Capex baseline input	*Opex baseline input*
Approx. from operators' data	
Approx. from operator's data	Approx. from operator's data
Approx. from operator's data	
Approx. from operator's data	Approx. from operator's data
Approx. from operator's data	

Source: Analysys Mason model, operators' data

Direct equipment prices have been obtained from submitted operator data or Analysys Mason estimates [4/4]

Direct costs used for radio/regional network (2017)

Asset	Capex (EUR)	Opex (EUR)
IN (SCP + SMP)	DATA REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION	
Voice Mail System (VMS + IVR)		
HLR		
AUC		
EIR		
SMSC HW		
SMSC SW units		
GPRS/EDGE-PCU		
GPRS/EDGE/UMTS-GGSN		
GPRS/EDGE/UMTS-SGSN (small capacity)		
GPRS/EDGE/UMTS-SGSN (large capacity)		
Billing system (wholesale)		
Network management system (HW)		
Network management system (SW)		
VAS/Content platforms		
MMSC		
HDSPA step for: 1.8		
HDSPA step for: 3.6 & 42.2		
HDSPA step for: 7.2		
HDSPA step for: 10.1		
HDSPA step for: 14.4		
HDSPA step for: 21.1		
HSUPA upgrade HW per Node B		
LTE step for: 10.8		
LTE step for: 16.2		
LTE step for: 21.6		
LTE step for: 32.4		
LTE step for: 43.2		
LTE step for: 86.4		

Capex baseline input

Opex baseline input

Approx. from operator's data

Approx. from operator's data

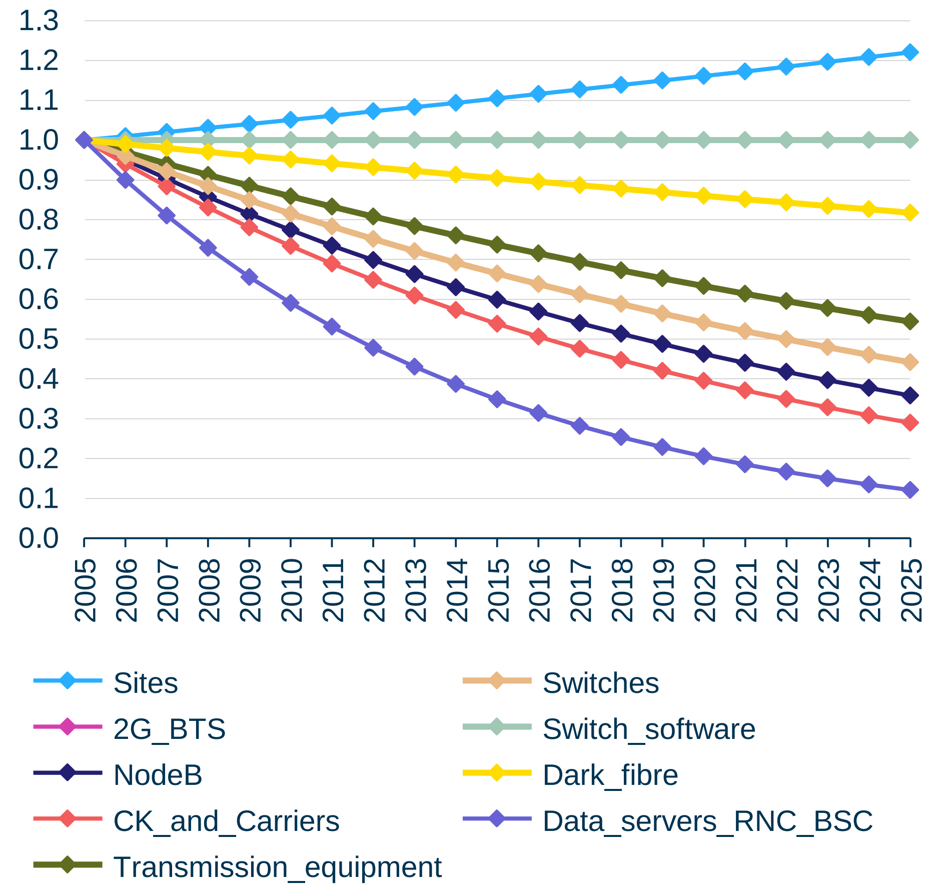
Source: Analysys Mason model, operators' data

The model contains updated 2017 input prices and an assumed price trend in real terms

- There is a capital and operating expenditure input for each modelled network element
  - asset groups have been created with different cost trends
- For 2G, 3G and 4G network elements we have used cost trends based on Analysys Mason estimates
- Most price trends are declining, reflecting increasing competition among vendors, economies of scale and maturation of technologies
  - the only exceptions are site acquisition, preparation and maintenance, which increase due to labour costs and the growing difficulty of finding suitable sites

Real-terms price trend	CAGR, 2005–2050
Sites	1.0%
2G BTS	-5.0%
NodeB / eNodeB	-5.0%
CK and carriers	-6.0%
Transmission equipment	-3.0%
Switches	-4.0%
Switch software	-%
Dark fibre	-1.0%
Data servers RNC BSC	-10.0%
2G TRX	-6.0%

Unit capex real cost trends used in the model (2005 = 1)

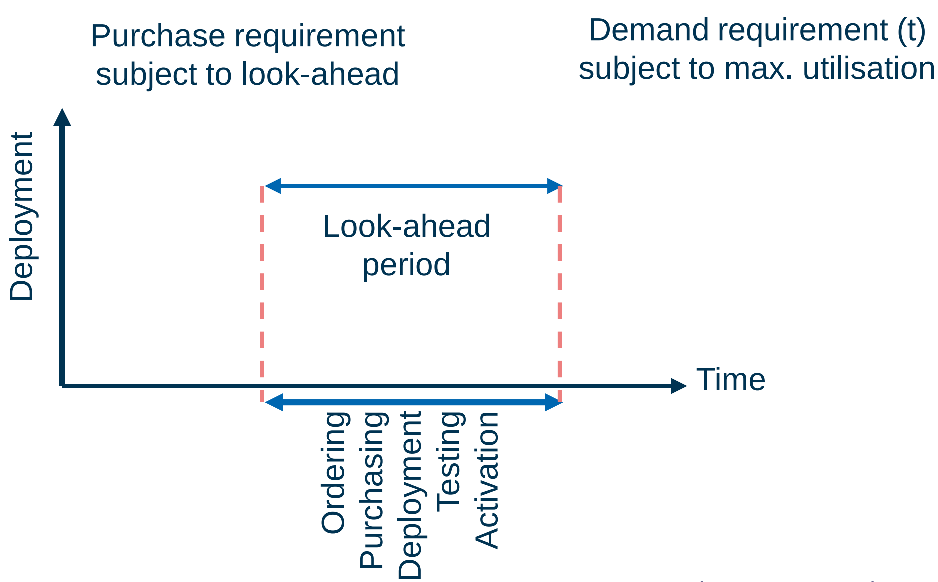


Sheets: Asset_input, CostTrends
Source: Analysys Mason estimates

Asset purchase is driven by *(1)* deployment lead times and *(2)* replacement lifetimes

- The model calculates active network assets at mid-year
- Capital expenditure on assets occurs between 1 and 18 months in advance of activation
  - the exact period depends on lead times and the size of the network assets
- Operating expenditures are incurred once the asset is activated
- Replacement lifetime (between 3 and 20 years) determines when an asset is replaced at current cost

Lead-time expenditure profile



Overview of lifetime assumptions for the modelled operator (in years)

Lifetime	Network elements
20	Own macro site Switching sites
15	Third-party macro and indoor sites
10	Fibre rings eNodeB, Node B and equipment BTS equipment Leased lines, microwave equipment, access points and transmission links
8	MSC, HLR, LTE servers, VoLTE servers
7	BSC, RNC equipment and ports MGW, MSC ports
6	VMS, AUC, EIR, GPRS, network management system
5	IN, SMSC, VAS, MMSC
3	MSC software, HSDPA software, billing system

Source: Analysys Mason estimates

Purchasing, replacement and capex planning periods

Overview of planning period assumptions for the modelled operator

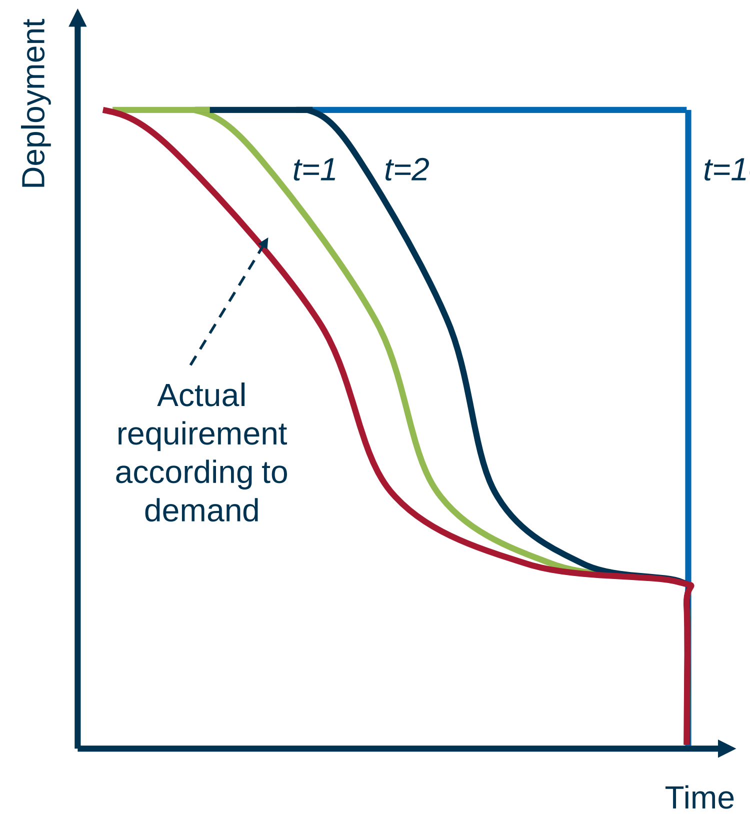
Planning period	Network elements
18 months	Switching sites
12 months	Access points and transmission links Fibre rings
9 months	Own macro site Third-party macro site BSC, RNC equipment MSC, MGW Billing
6 months	Third-party indoor sites IN, VMS, HLR, AUC, EIR, GPRS, VAS
3 months	BTS, NodeB and eNodeB equipment HSPA and LTE releases Microwave equipment BSC, MSC ports SMSC, MMSC, core LTE servers, VoLTE servers
1 month	TRX, UMTS-R99 carriers, NodeB channel kits, leased lines

Note: The planning period is the period of time elapsed between the first deployment expenditure activities for a network element and the time when the network element becomes operational
Source: Analysys Mason estimates

Network elements are retired when no longer required – subject to a retirement profile

- Due to migration off the network, traffic-driven assets *may* become unnecessary, although coverage rules still apply
- The rate at which assets are removed from the network is an input to the model
- Removal saves:
  - asset replacement costs
  - operating expenditures
- Investment costs are still fully recovered, but removal is considered to have no costs and no scrap value

Retirement options



Source: Analysys Mason model

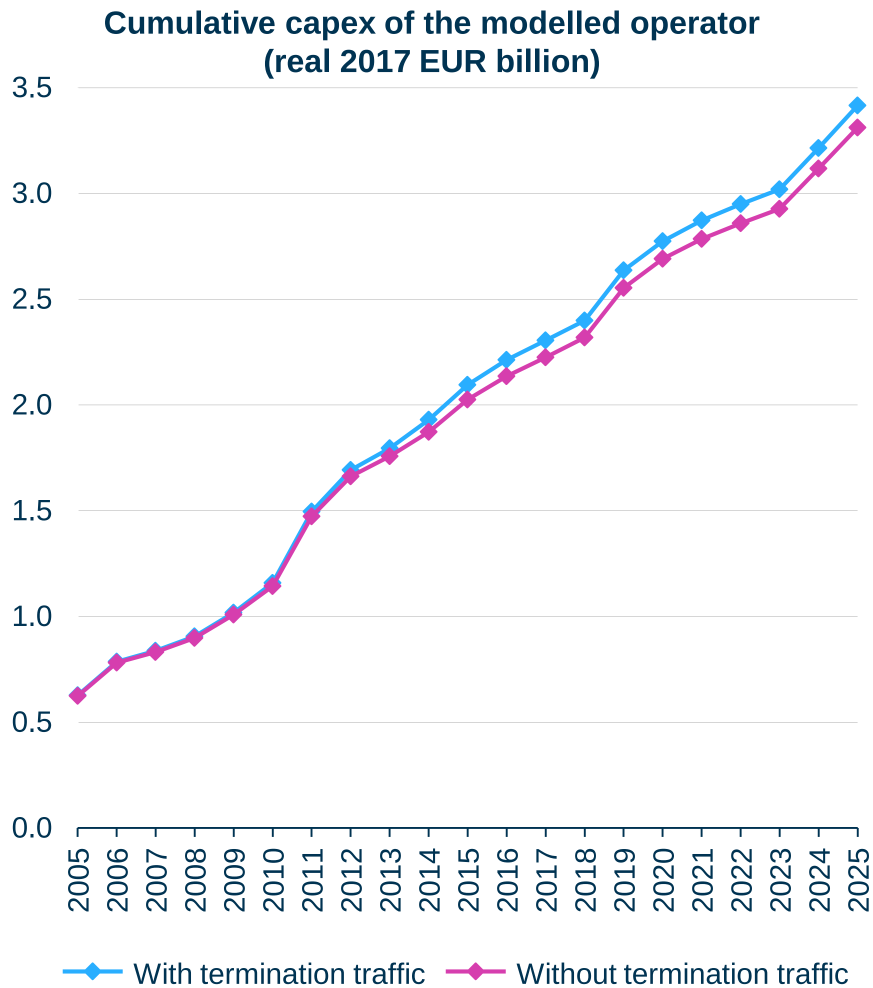
Retirement algorithm

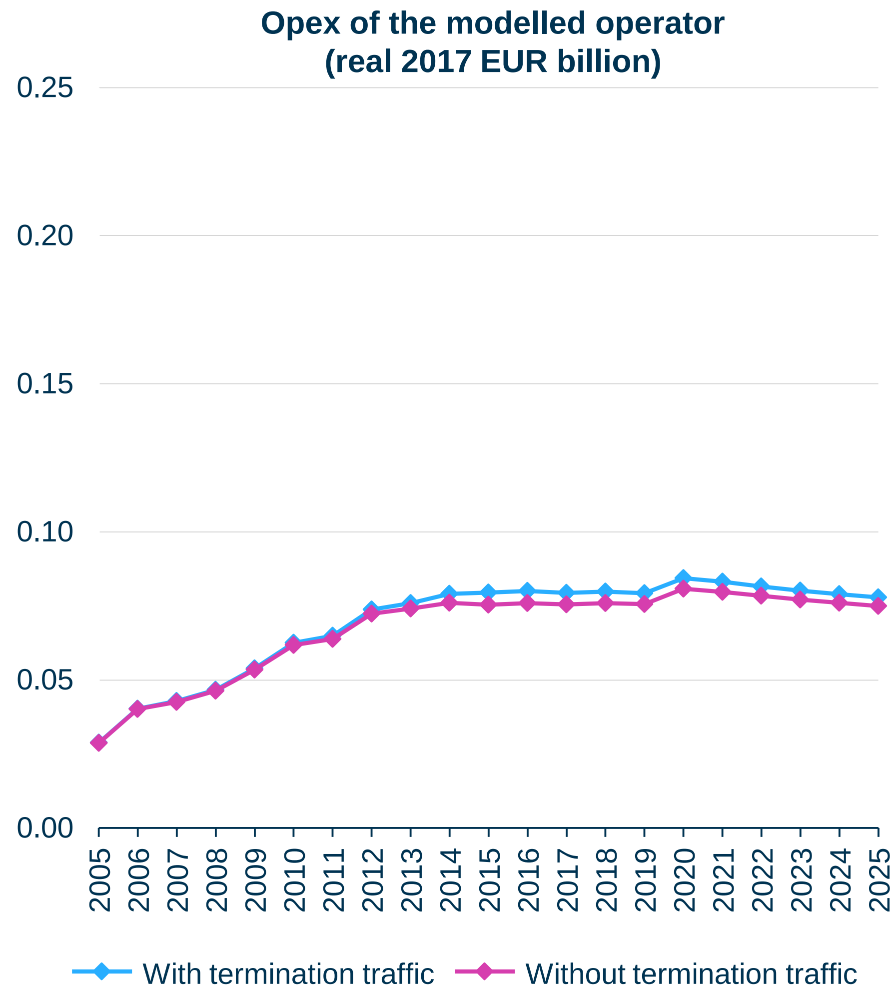
Overview of retirement period assumptions for the modelled operator

Retirement period	Network elements
Retained in network until shutdown date, if any	Owned, third-party macro and indoor sites BTS, NodeB, eNodeB equipment and carriers Fibre last-mile access Regional and national backbone access points
Retired from network 2 years after demand decline	BSC, RNC, LTE-AP equipment Switching sites GPRS
Retired from network 1 year after demand decline	TRX, NodeB channel kits, leased lines Access points and transmission links MGW, 2G/3G MSC combined, BSC, RNC, MSC ports NMS, IN, VMS, HLR, AUC, EIR, VAS, SMSC, MMSC, billing system LTE and VoLTE core servers
Retired from network immediately after demand decline	NodeB or 2G MSC software Licence fees

Source: Analysys Mason estimates

Cumulative capex and annual opex of the modelled operator: with and without voice termination traffic





Source: Analysys Mason model

Capital and operating expenditures are annualised according to the *economic depreciation* method

- **Level of economic costs determined by:**
  - total expenditure divided by output, in the form of a (net) present value calculation

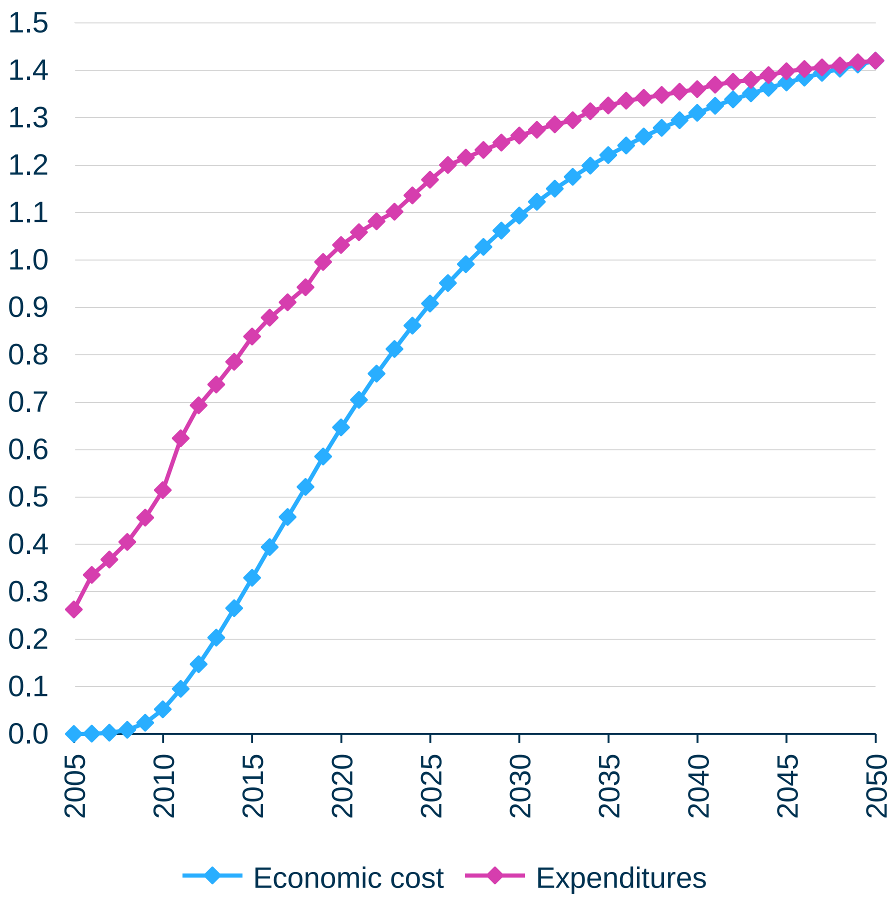
$$\frac{PV\ (expenditures)}{PV\ (network\ element\ output)}$$

- **Shape of economic costs determined by:**
  - underlying capital and operating expenditure price trends assumed for the network elements, which go into supporting the network element usage of an individual service
  - overall, if underlying equipment price trends fall by 5% in a year, the economic cost per unit of traffic also falls by 5% per year

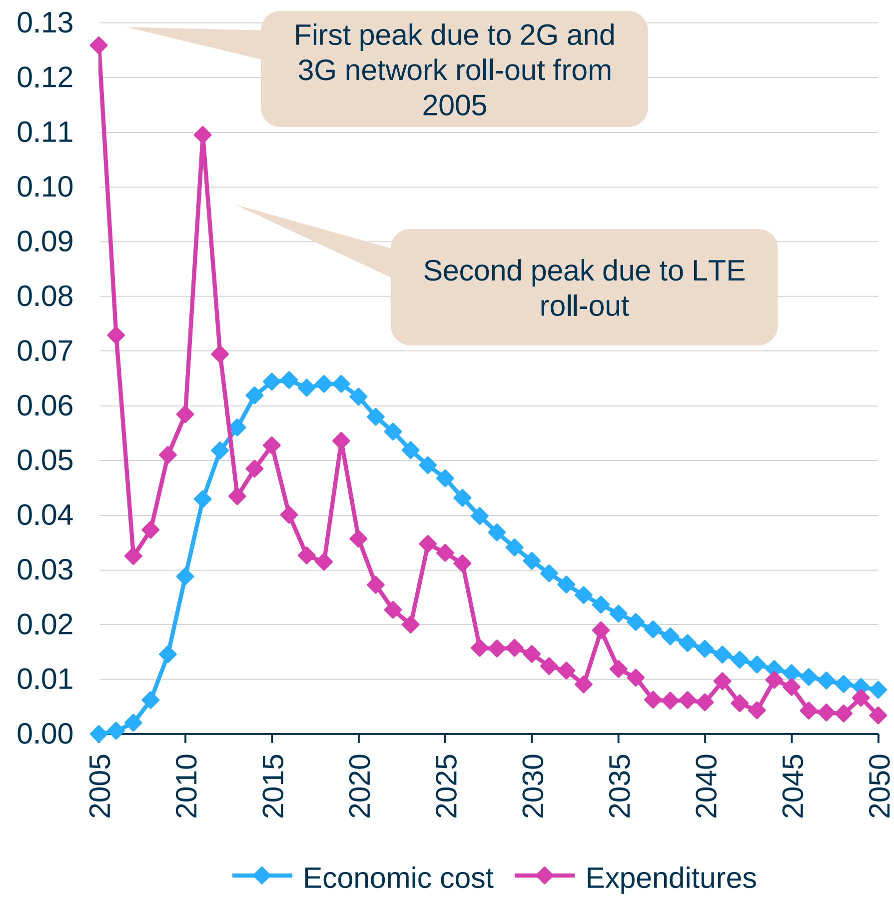
Source: Analysys Mason model

The cumulative costs recovered over time allow full cost recovery to be achieved over the lifetime of the business

Cumulative present value of expenditures and economic costs (real 2017 EUR billion)



Present value of expenditures and economic cost (real 2017 EUR billion)



Source: Analysys Mason model

We have used a mobile WACC as an input, using the same methodology and sources as in the 2014 model, and have updated inputs

- We have used a WACC estimated by Analysys Mason
  - this estimation followed the methodology described in ANACOM's Decision regarding the methodology to be used in the determination of MEO nominal WACC

Overview of the main WACC components

Parameter of WACC calculation	Value	Source
Cost of debt		
Debt premium	1.5%	Benchmark of debt premiums adopted by other Western European telecoms regulators
Gearing	57.6%	Average 2012–2016 gearing of Western European mobile operators
Nominal tax rate	29.5%	ANACOM
Cost of equity		
Risk-free rate	2.8%	ANACOM
Equity risk premium	7%	ANACOM
Beta	0.35	Average of mobile operators' beta (Mobistar, Telenor ASA, TeliaSonera AB, Vodafone, Mobile Telesystems)
Pre-tax nominal WACC	7.63%	
Inflation	1.45%	Euromonitor, average for 2015–2025
Pre-tax real WACC	**6.09**%	

Source: ANACOM

The regulatory fees paid by the operators are included in the pure LRIC termination cost calculated by the model

Regulation

- The regulatory annual fees paid by the Portuguese operators are calculated according to their size in terms of annual revenue
  - for this purpose, they are split in three tiers: Tier 0 operators (with revenue below EUR250k) do not pay any fee; Tier 1 operators (revenue between EUR250k and EUR1,500k) pay a fixed fee of EUR2,500; Tier 2 operators (with revenue higher than EUR1,500k) pay a variable regulatory fee T_2, as a percentage of their revenue, i.e. $T_2 = t_2 \times R_2$, where t_2 is the fee rate (expressed as a percentage of revenue) and R_2 is the relevant revenue, which excludes VAT, sales of terminals (equipment), transactions between entities of the same group and revenue from the universal service
- The percentage of revenue t_2 is calculated as $t_2 = \frac{C-(t_1 \times n_1)}{\sum R_2}$, where
  - C represents the cost to execute the regulatory activity incurred by ANACOM
  - $t_1 \times n_1$ represents the fees paid by Tier 1 operators, being t_1 the fixed EUR2500 fee and n_1 the number of Tier 1 operators (28 in 2013)
  - $\sum R_2$ is the sum of the relevant revenue for all Tier 2 operators in the previous year

Model

- To include the above in the fixed BU-LRIC model, we made the following assumptions:
  - in light of the scale of the modelled operator, it is reasonable to model it as a Tier 2 one
  - the regulated mobile termination rate applied is a cost-oriented value, and then the (unit) revenue from termination equals the (unit) termination cost calculated by the model
- The regulatory fees paid by the operator attributable to the fixed termination service can be calculated as $T_2 = t_2 \times Termination\ cost$, and consequently the termination cost including the regulatory fees is calculated as $Termination\ cost_{with\ regulatory\ fees} = Termination\ cost \times (1 + t_2)$ (this applies to both pure LRIC and LRAIC+)
- In light of the actual values, a long-term value of 0.7% for t_2 appears reasonable

Source: ANACOM, Analysys Mason

Routeing factors: 2G radio access equipment and transmission

Routeing factors for the 2G network

Network element		2G on-net voice minutes	2G out voice minute	2G in voice minutes	2G SMS	Packet data Mbytes
Radio equipment		$2 \times (1 + RT)$	$1 + RT$	$1 + RT$	~0.001	5.74
Backhaul		$2 \times (1 + RT)$	$1 + RT$	$1 + RT$	~0.001	5.74
BSC		$2 \times (1 + RT)$	$1 + RT$	$1 + RT$	~0.001	5.74
MSC		7 per BHCA	2 per BHCA	5 per BHCA	1 per BHSMS	-
National transmission	A 94%	~0.59	~0.67	~0.79	-	-
	B 6%	1	-	1	-	-

- The national transmission's routeing factor is the weighted average of:
  A. the routeing factor for "interswitch-facing E1 links required"
  B. the routeing factor for "the VMS facing E1 links required"
- The weights are calculated as the average share of E1-equivalent circuits of the above two drivers over the model period

RT = ring time per conveyed minute

Source: Analysys Mason model

analysys mason

Routeing factors: 3G radio access equipment and transmission

Routeing factors for the 3G network

Network element		3G on-net voice minutes	3G out voice minutes	3G in voice minutes	3G SMS	R99 Mbytes	HSDPA Mbytes	HSUPA Mbytes
Radio equipment		$2 \times (1+RT) \times (1+SH)$	$(1+RT) \times (1+SH)$	$(1+RT) \times (1+SH)$	~0.0003	9.21	1.68	3.30
Backhaul		$2 \times (1+RT) \times (1+SH)$	$(1+RT) \times (1+SH)$	$(1+RT) \times (1+SH)$	~0.0003	9.21	1.68	-
RNC		$2 \times (1+RT) \times (1+SH)$	$(1+RT) \times (1+SH)$	$(1+RT) \times (1+SH)$	~0.0003	9.21	1.68	-
MSC		7 per BHCA	2 per BHCA	5 per BHCA	1 per BHSMS	-	-	-
National transmission	A 94%	~0.59	~0.67	~0.79	-	-	-	-
	B 6%	1	-					

- The national transmission's routeing factor is the weighted average of:
  A. the routeing factor for "interswitch-facing E1 links required"
  B. the routeing factor for "the VMS facing E1 links required"
- The weights are calculated as the average share of E1-equivalent circuits of the above two drivers over the model period

RT = ring time per conveyed minute
SH = an additional 20% soft-handover Erlangs for circuit-switched 3G traffic
Source: Analysys Mason model

analysys mason

Routeing factors: 4G radio access equipment and transmission

Routeing factors for the 4G network

Network element		4G on-net voice minutes	4G out voice minutes	4G in voice minutes	4G SMS	LTE Mbytes
Radio equipment		$2 \times (1 + RT)$	$1 + RT$	$1 + RT$	~0.0003	1.68
Backhaul		$2 \times (1 + RT)$	$1 + RT$	$1 + RT$	~0.0003	1.68
LTE-AP		$2 \times (1 + RT)$	$1 + RT$	$1 + RT$	~0.0003	1.68
National transmission	A 94%	~0.58	~0.69	~0.77	-	-
	B 6%	1	-	1		

- The national transmission's routeing factor is the weighted average of:
  - A. The routeing factor for "interswitch-facing E1 links required"
  - B. The routeing factor for "the VMS facing E1 links required"
- The weights are calculated as the average share of E1 equivalent circuits of the above two drivers over the model period

RT = ring time per conveyed minute
Source: Analysys Mason model

Routeing factors: core network

Routeing factors for the core network

Network element	On-net voice minutes	Out voice minutes	In voice minutes	SMS	Low-speed Mbytes	High-speed Mbytes
IN	2	1	1	in, out on	1	-
VMS	1	-	1	-	-	-
HLR	1	-	1	in, on	-	-
AUC	2	1	1	in, out, on	-	-
EIR	1	1	-	on, out	-	-
SMSC	-	-	-	1 only in & out	-	-
GPRS	-	-	-	-	1	-
Wholesale billing	-	1	1	in, out	-	-
NMS	1	1	1	1	1	1
VAS	1	1		on, out	1	-
VoLTE servers	2	1	1	2 (on-net) 1 (off-net)	-	-
Business overheads	1	1	1	1	1	1
Licence fees	as 2G, 3G or 4G radio assets					

Source: Analysys Mason

Certain traffic calculations are used as inputs to the routeing factor table …

Routeing factor component	Method of derivation
Ringing time per minute	$\left(\frac{1}{avg.\,call\,duration}\right) \times call\ attempts\ per\ successful\ call\ \times ring\ time\ per\ call\ attempt$
Soft handover	Assumed to be 20% for UMTS voice and low-speed R99 data
Busy-hour call attempts for a service and year	$\left[\frac{A \times B}{C}\right] \times \left[\frac{D \times E}{F}\right]$ **A** = annual minutes for the particular service and year **B** = proportion of calls in weekdays **C** = number of typical weekdays **D** = proportion of calls in the busy hour **E** = call attempts per successful call **F** = average call duration
BSC–MSC E1 links (remote BSC)	Uses the routeing factors for the 2G backhaul circuits, in turn equal to those of the radio layer, including ringing time
VMS-facing E1 links required (distant VMS only)	Only routed to on-net and incoming calls
Inter-switch-facing E1 links required (distant MSC)	Erlang-weighted average inter-switch BHE (including ringing time) over the lifetime of the network

Source: Analysys Mason model

… as are conversion factors between data and voice traffic [1/2]

Routeing factor component		Value	Method of derivation
Conversion factor (SMS per minute)	2G SMS	**0.0009**	$\frac{Bits\ per\ SMS\ (320)}{SDCCH\ channel\ rate\ in\ bits\ per\ minute\ (368\ 160)}$
	3G SMS	**0.0003**	$\frac{Bits\ per\ SMS\ (320)}{Radio\ channel\ rate\ in\ bits\ per\ minute\ (960\ 000)}$
	4G SMS	**0.0003**	$\frac{Bits\ per\ SMS\ (320)}{Radio\ channel\ rate\ in\ bits\ per\ minute\ (960\ 000)}$
Conversion factor (Mbit/s per minute)	GPRS	**5.7397**	$Minutes\ to\ transfer\ 1MB\ of\ data\ (7.65) \times proportion\ in\ downlink\ (75\%)$
	R99	**7.6768**	$Minutes\ to\ transfer\ 1MB\ of\ data\ (10.24) \times proportion\ in\ downlink\ (75\%)$

Source: Analysys Mason model

… as are conversion factors between data and voice traffic [2/2]

Routeing factor component		Value	Method of derivation
Conversion factor (Mbit/s per minute)	1.8	2.7766	$$\frac{1MB\ of\ raw\ data\ at\ the\ air\ interface\ in\ bits\ (8\,000\,000) \div (1 - IP\ overhead\ (14.63\%))}{Seconds\ in\ a\ minute\ (60) \times HSDPA\ rate \div minimum\ number\ of\ channels}$$
	3.6	2.7766	
	7.2	3.0369	
	10.1	2.1650	
	14.4	1.5185	
	21.1	1.0363	
	42.2	1.0363	
	84.4	1.0363	

Source: Analysys Mason model

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The calibration process is a multi-step and somehow iterative process, aimed at cross-checking the model results against the cost data received

- The model calibration process is a multi-step (and somehow iterative) process

1

- The first step of the process *(asset calibration)* is to populate the model with all of the inputs received from the operators (e.g. market shares, technical inputs, etc.) and flex the model's parameters until the number of network elements calculated by the model are consistent with the inputs provided
  - the flexed parameters have been used as the base for the calibration of the modelled operator
- Unfortunately, Portuguese MNOs have not provided all of the required inputs; therefore, some of the inputs have been estimated either through benchmarks or by applying the equivalent input provided by other operators
  - this naturally decreases the accuracy of this step on the calibration

2

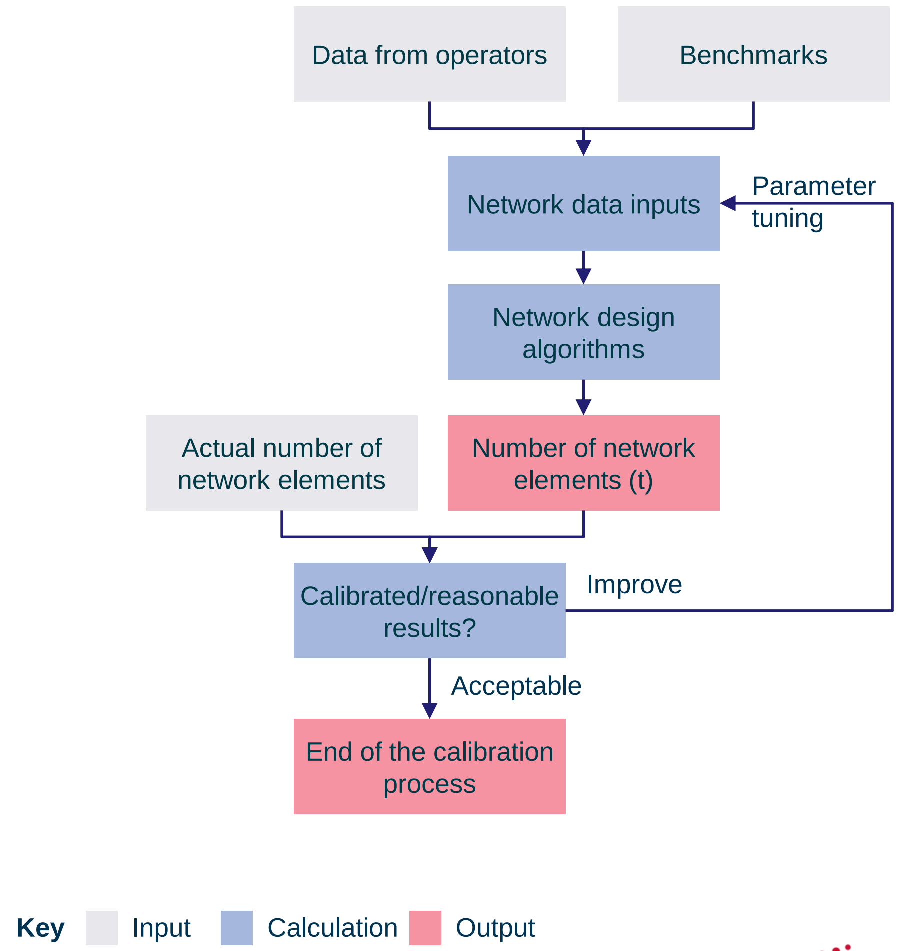
- The second step *(financial calibration)* is to reconcile as much as possible the costs calculated by the model with the ones provided by the operators; a perfect reconciliation is naturally not possible
  - getting to cost figures which are comparable to the accounting data provided by the operator is a good indicator of the reasonability of the model

Source: Analysys Mason

The asset calibration process involves a number of network design inputs which are unknown/uncertain

- The scorched-node calibration process is necessary because some network design inputs are unknown or uncertain. For example:
  - many network design aspects are not explicitly modelled (or the modelling would be overly complex at such a high level of detail)
  - maximum utilisation of equipment capacity can be defined in different ways
  - real networks are not perfectly captured by theoretical models
- The process involves:
  - assuming some reasonable estimates for unknown/uncertain data inputs
  - comparing the number of network elements calculated with the actual numbers
  - modifying the inputs and parameters to understand, and where relevant reduce, the discrepancy between modelled and actual number of network units
- Calibration cannot be expected to be completely accurate
  - for instance, equipment capacities have increased over time resulting in the network design algorithms forecasting fewer, higher-capacity units than actual numbers

Scorched-node calibration process



Source: Analysys Mason model

The access network calibration shows a good correlation between model results and operator's data …

Calibration of radio access network elements

CONTENT REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION

Source: *Analysys Mason*

… while the modelled modern core network results in lower numbers of elements compared to those for real operators in most of the cases

Calibration of core network elements

CONTENT REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION

Source: Analysys Mason

We have also performed a financial calibration based on capex and opex comparison with existing operators' data

- The model has been calibrated with top-down accounting data provided by the three mobile operators
- Initially, the bottom-up model was populated with input direct equipment prices (capex and opex) provided by the mobile operators or based on Analysys Mason estimates
- Using these direct costs, we identified the expenditures calculated by the model that were different from the top-down expenditures submitted by the mobile operators, and modified capex and opex indirect costs
  - due to lack of detailed information from Vodafone, only MEO and NOS data have been used in the model
  - for most asset types we have used the average of costs of MEO and NOS as an input for the hypothetical existing operator
- We have considered the main cost categories of opex and capex
- Indirect network costs have been equally distributed among cost centres
  - the indirect mark-up resulting from indirect network costs over considered costs has been calculated for the three operators for opex and capex
  - the mark-up has been applied to each unit cost of the modelled operator
- We have excluded the cost of licences and business overheads in this test, which are added separately

Note: The information provided by Vodafone was not sufficient to proceed with its calibration

Source: Analysys Mason

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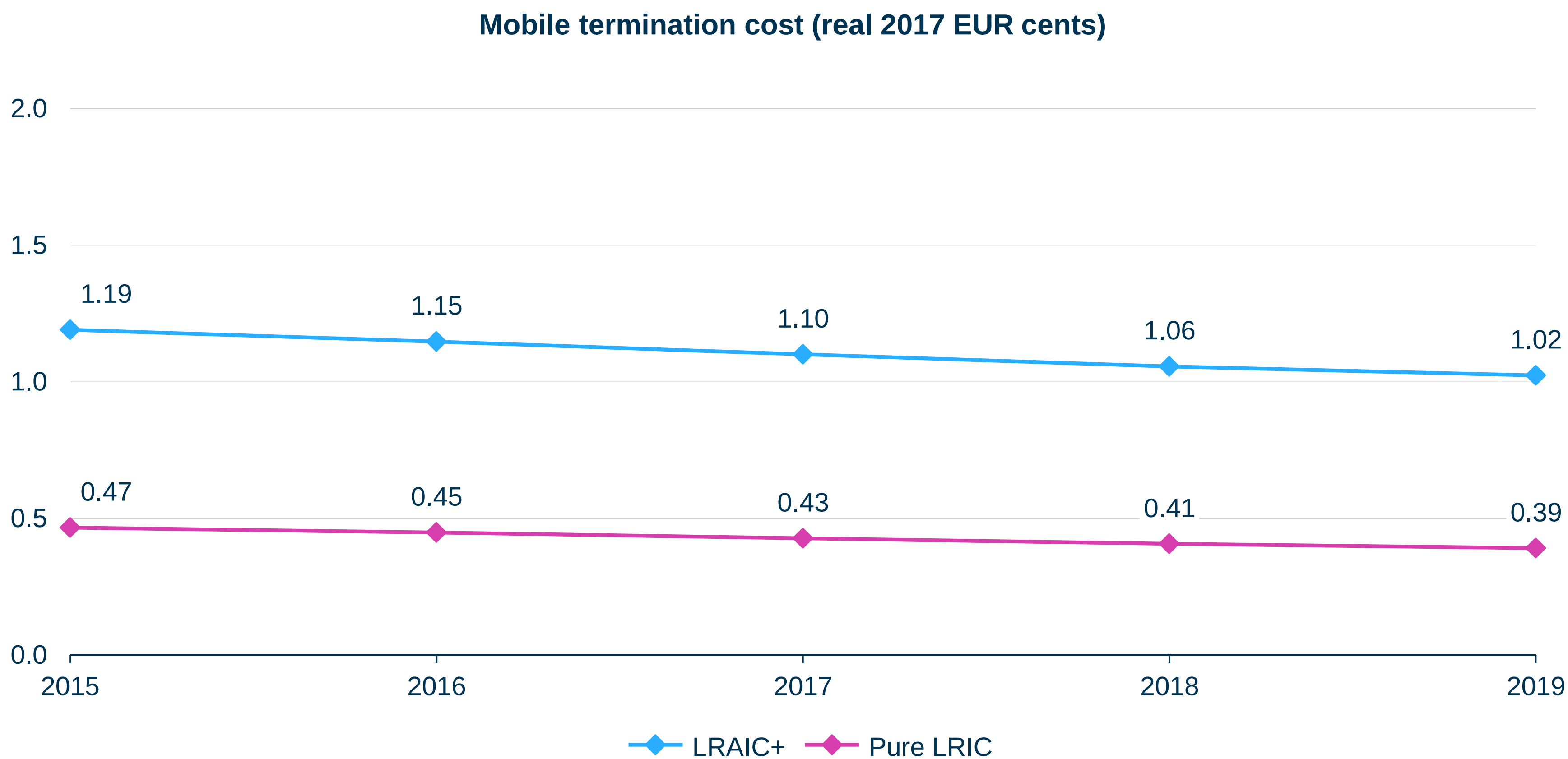
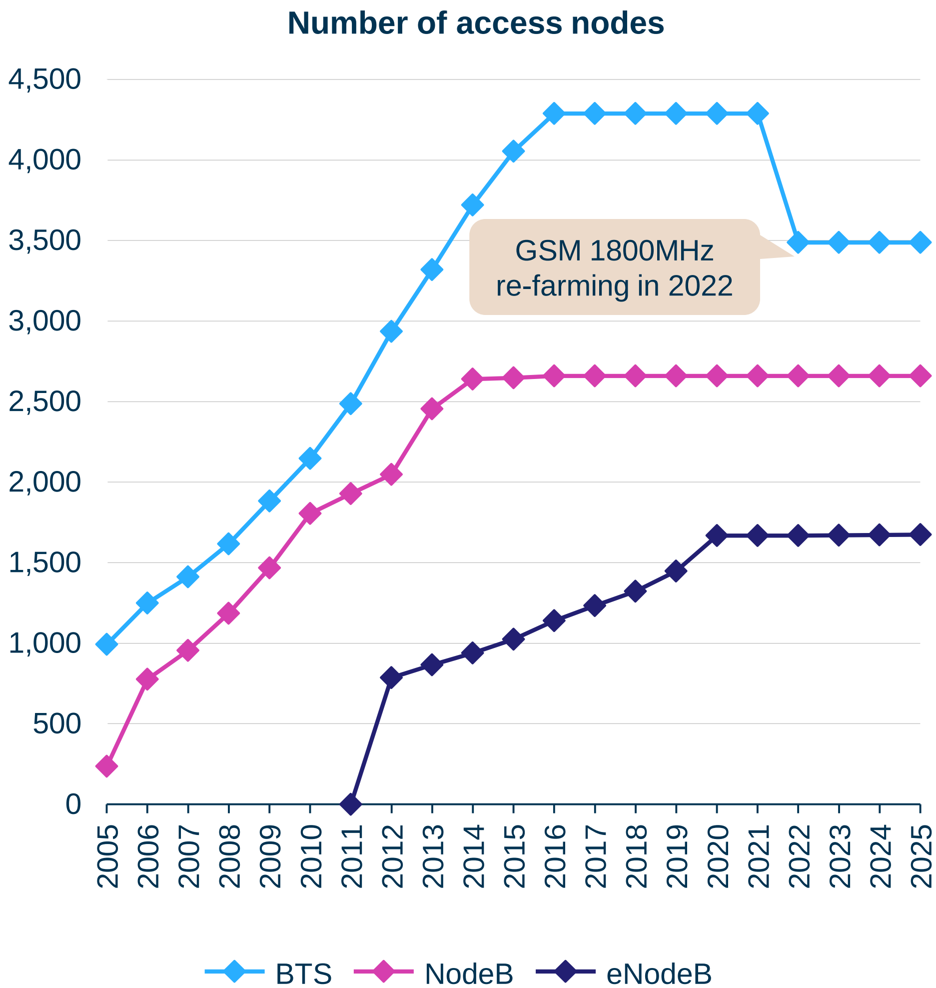
The mobile termination pure LRIC for 2017 is real 2017 EURcents0.43 per minute

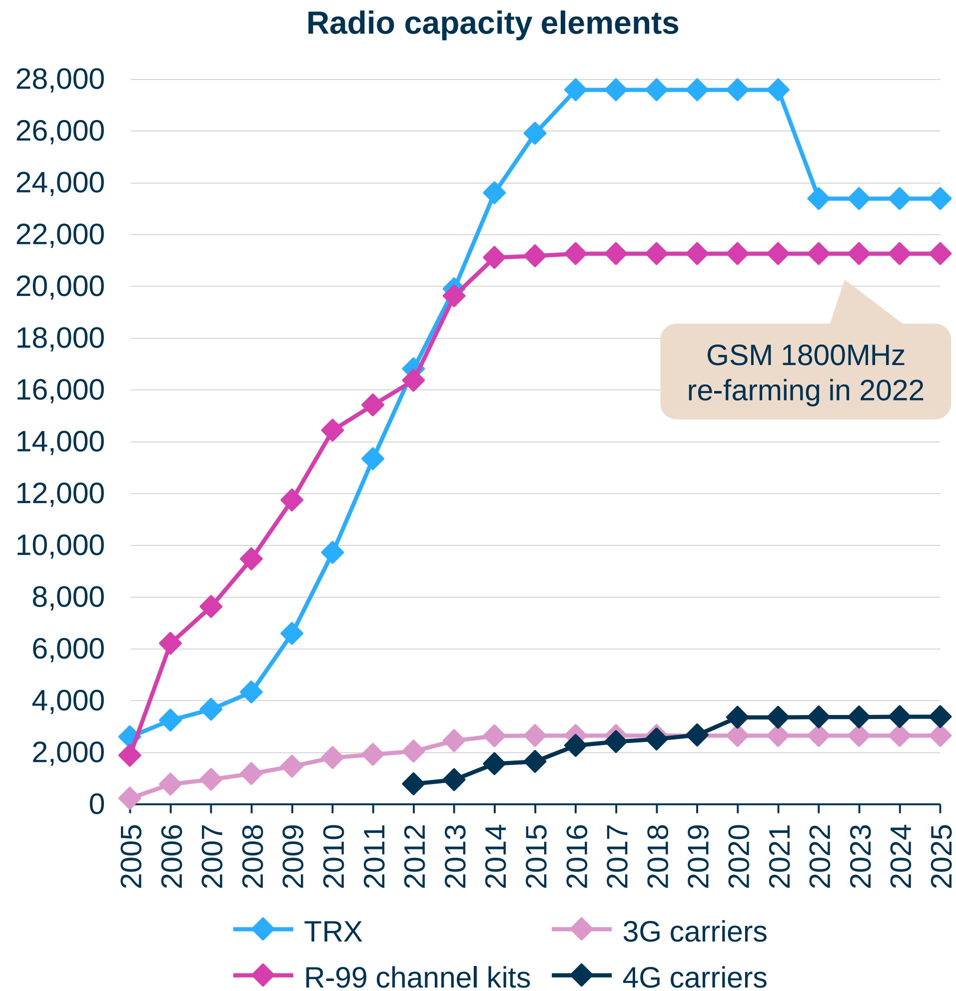


Unit cost results from the model are presented in real 2017 EUR terms.
This means that inflation for future years needs to be applied

Source: Analysys Mason model

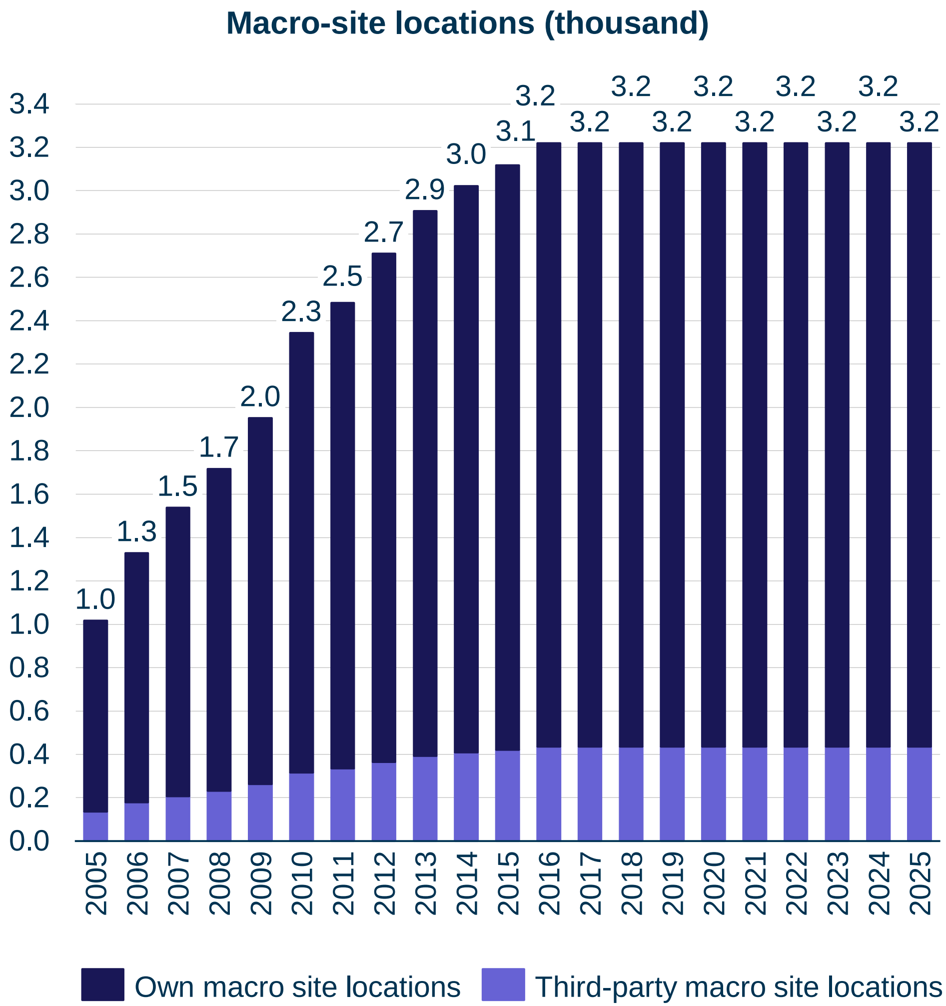
The number of nodes grows driven by the increase in geographical coverage and capacity requirements

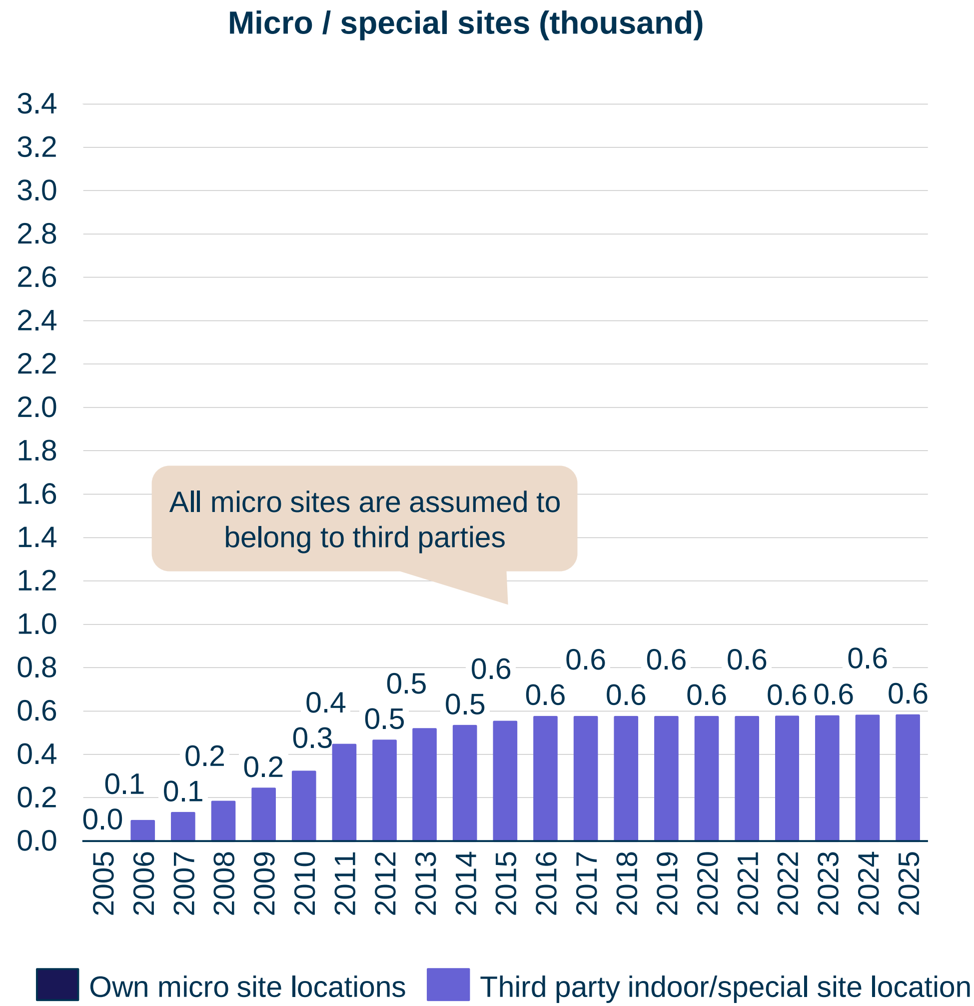




Source: Analysys Mason model

Owned macro sites represent a large percentage of total sites, while own micro sites remain a minor proportion





Source: Analysys Mason model

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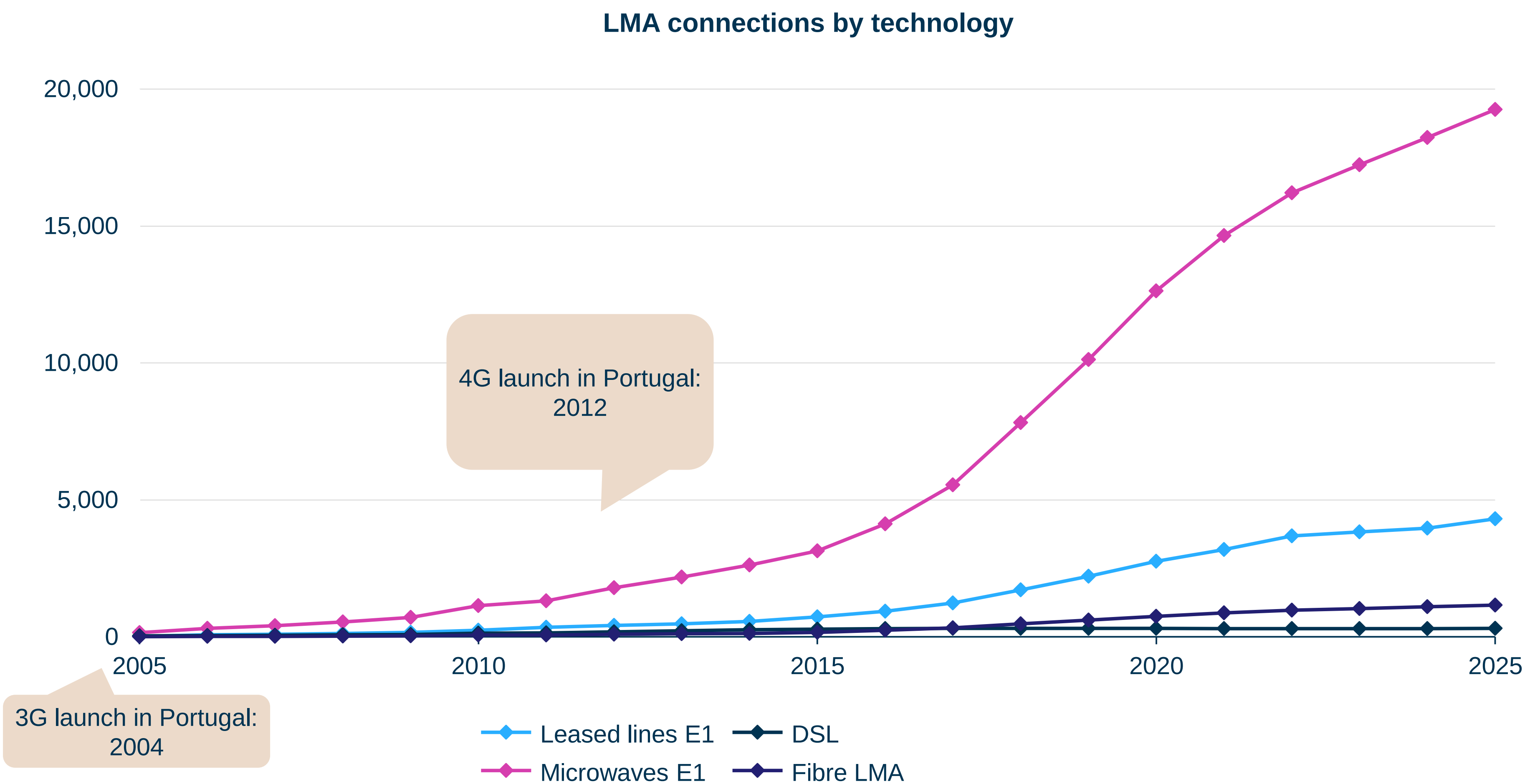
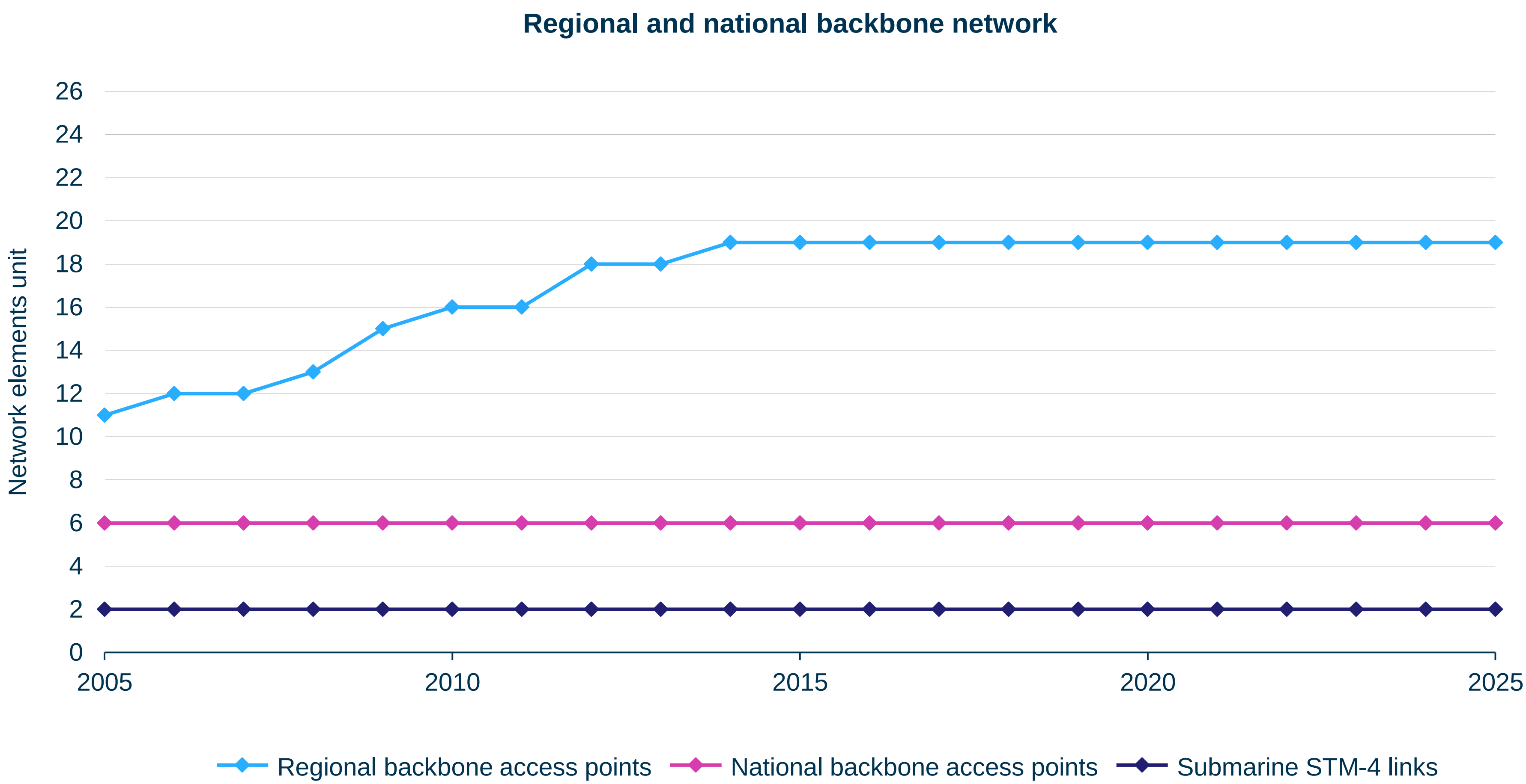
Last-mile access capacity increases steeply following the 3G launch (first) and 4G (later)



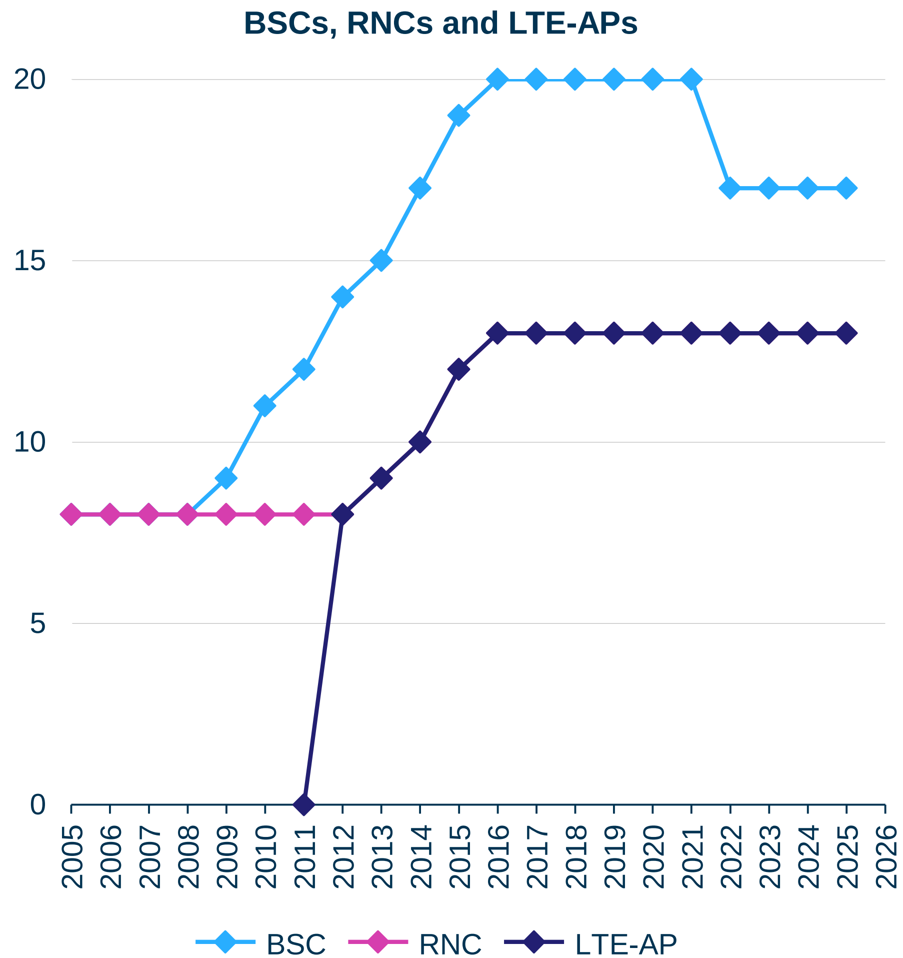
Source: Analysys Mason model, TeleGeography

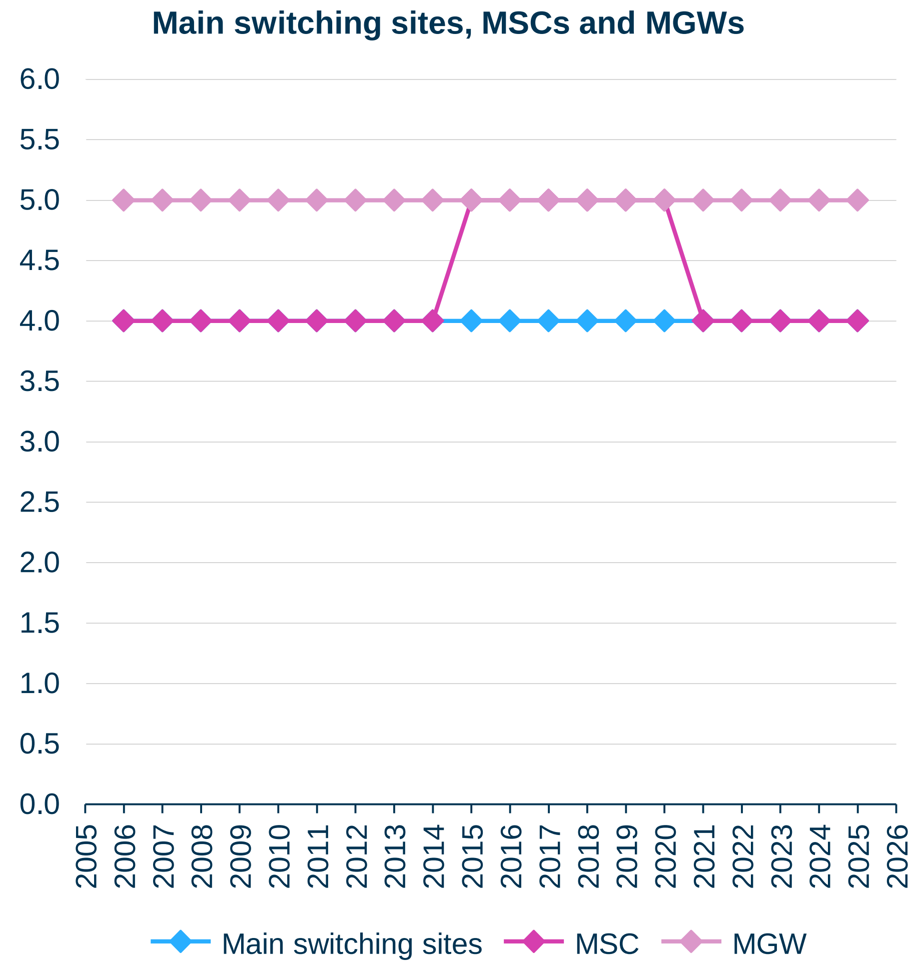
The national backbone was deployed when the operator launched, while the regional backbone has been developing gradually



Source: Analysys Mason model

BSCs, RNCs, LTE-APs and switching elements growth is based on network loading, while switching sites remain constant over time

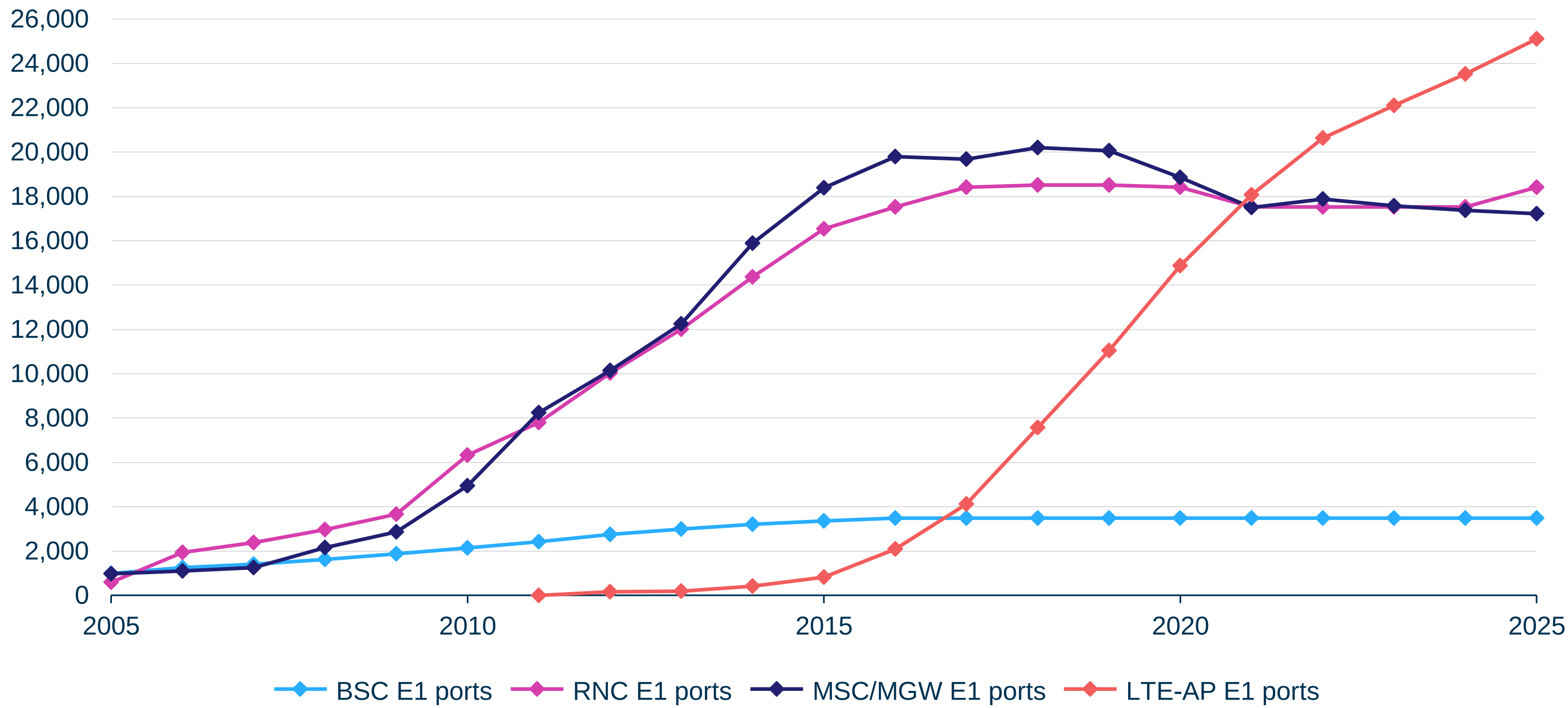




Source: Analysys Mason model

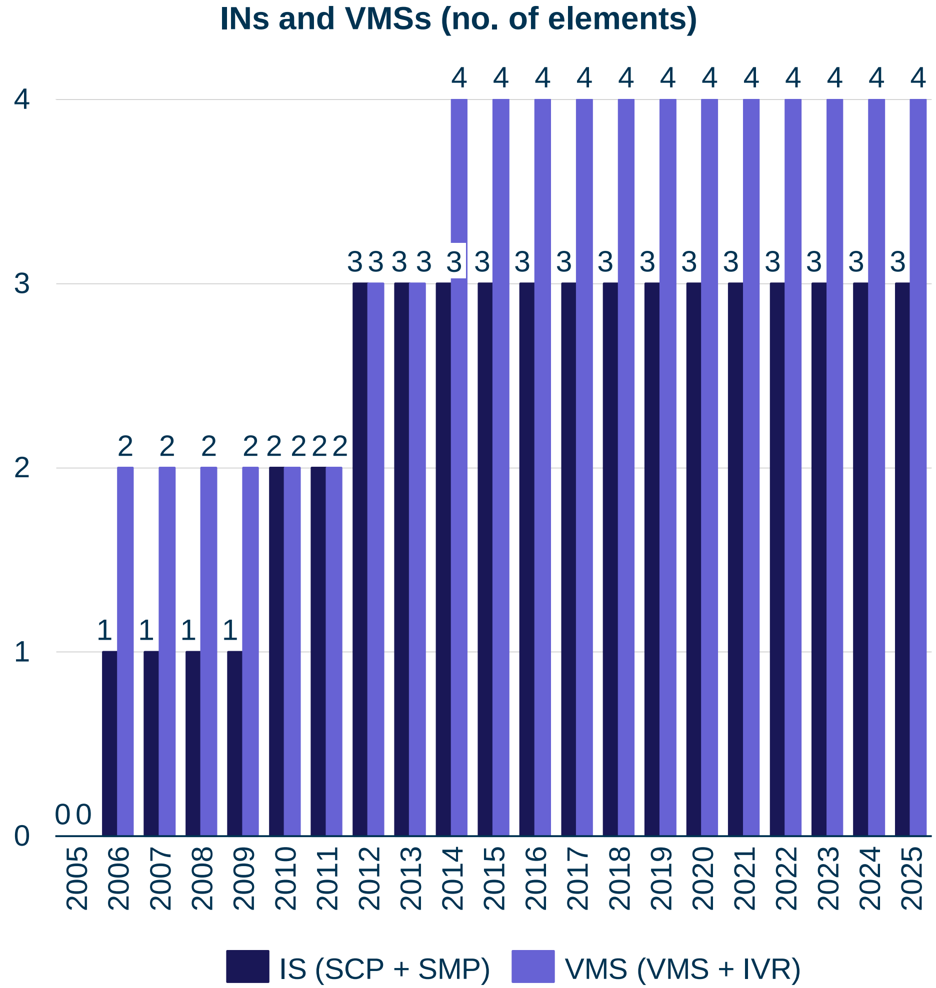
LTE data traffic is the main driver for E1-equivalent port growth

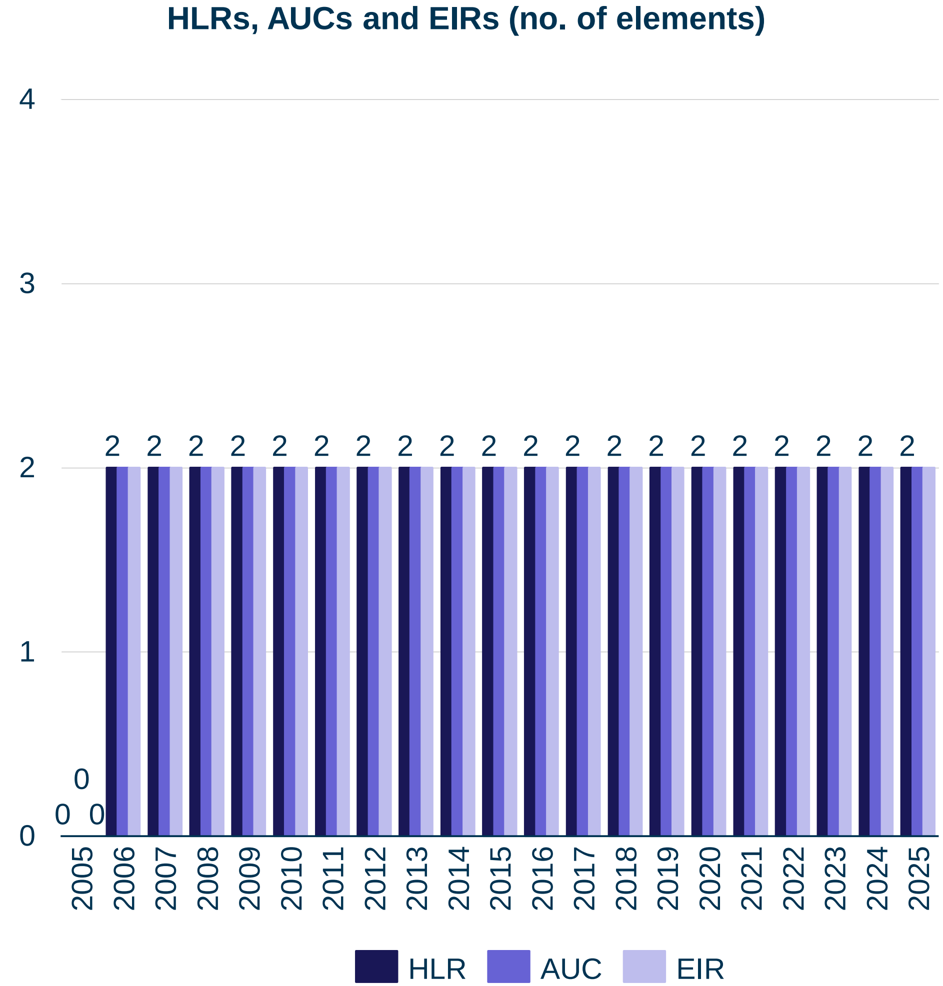
BSC, RNC, LTE-AP and MSC/MGW E1-equivalent ports



Source: Analysys Mason model

Core network elements [1/3]

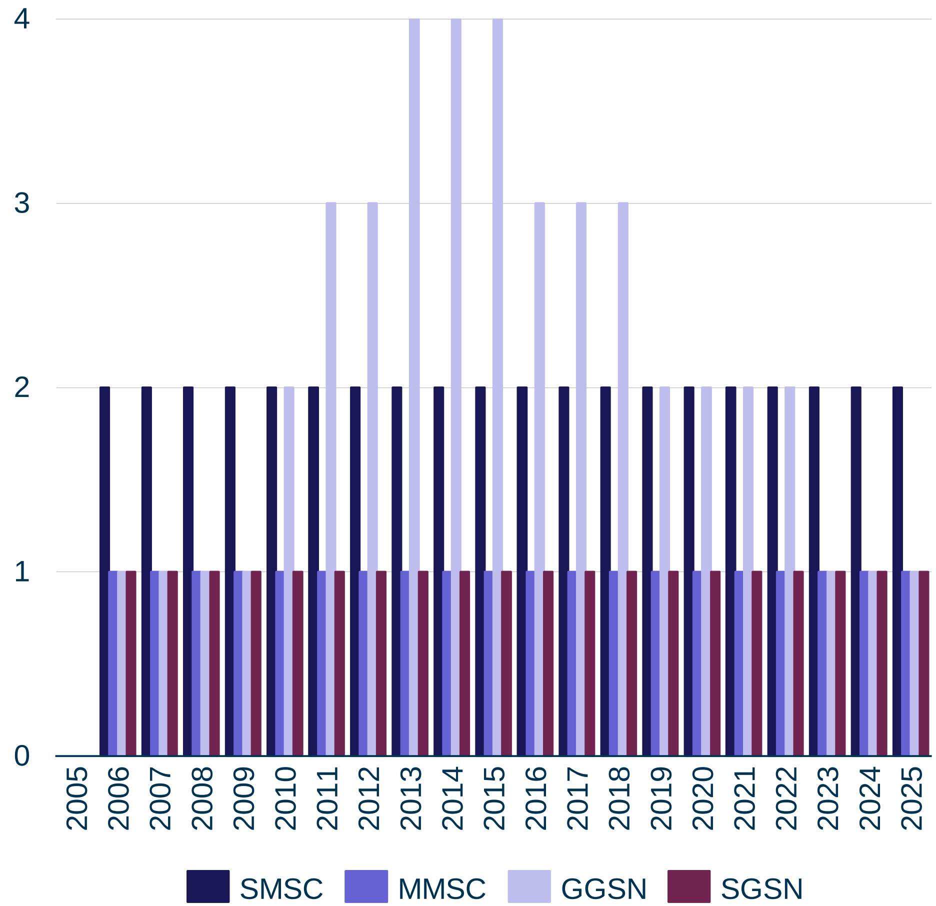




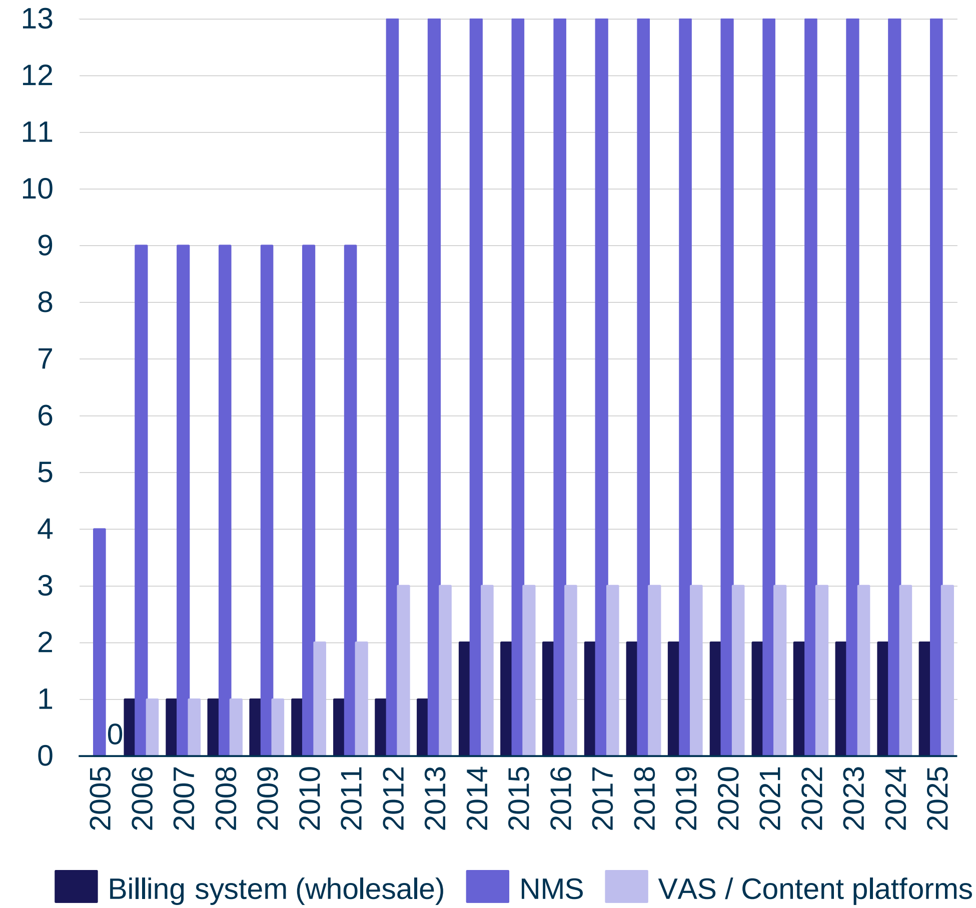
Source: Analysys Mason model

Core network elements [2/3]

SMSCs, MMSCs, GGSNs and SGSNs (no. of elements)



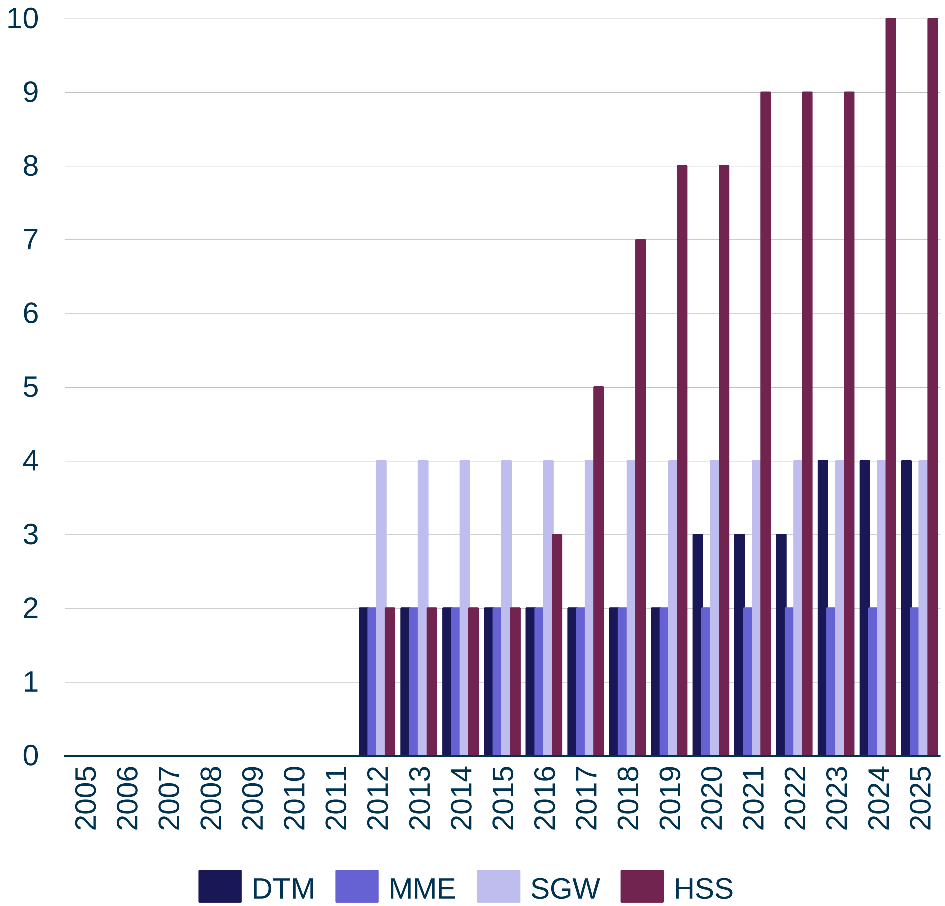
Billing system, network managements system and VAS/content platforms (no. of elements)



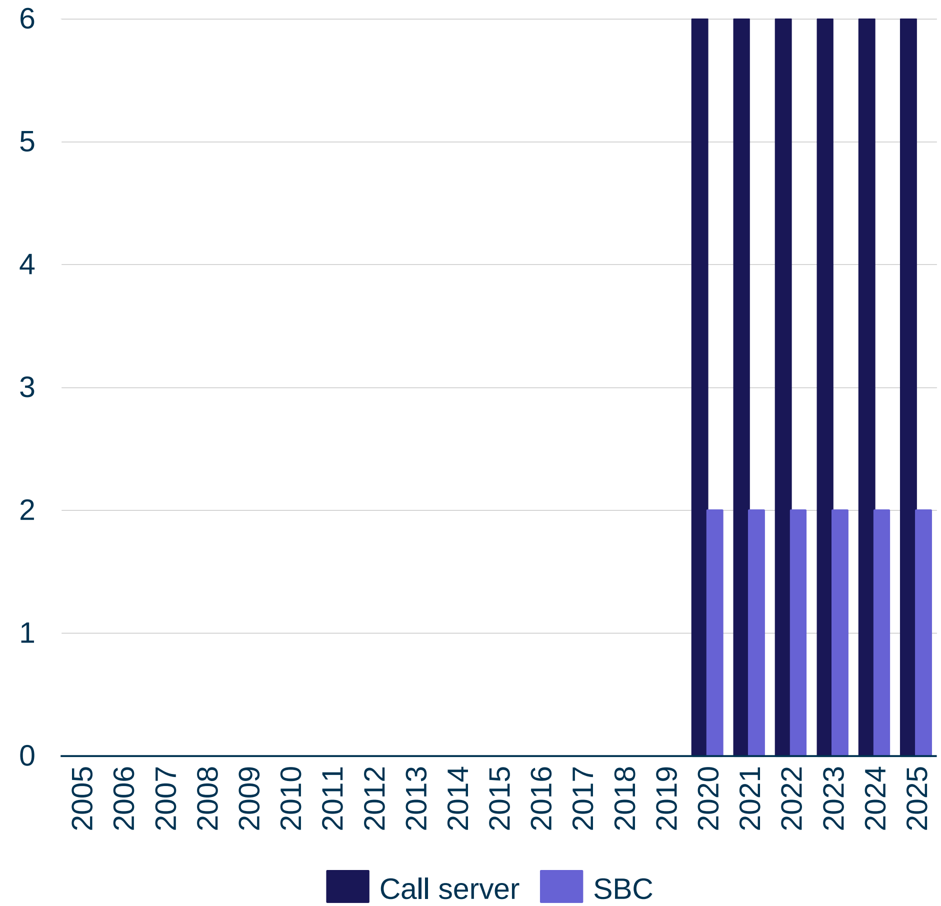
Source: Analysys Mason model

Core network elements [3/3]

LTE core servers (no. of elements)



VoLTE core servers (no. of elements)



Source: Analysys Mason model

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Acronyms used in this document [1/3]

- **2G**: Second generation of mobile telephony
- **3G**: Third generation of mobile telephony
- **4G**: Fourth generation of mobile telephony
- **AUC**: Authentication centre
- **BH**: Busy hour
- **BHCA**: Busy-hour call attempts
- **BHE**: Busy-hour Erlangs
- **BHSMS**: Busy-hour SMS
- **BSC**: Base-station controller
- **BTS**: Base transmitter station or base station
- **CE**: Channel element
- **CK**: Channel kit
- **CS**: Call server
- **CSCF**: Call server call function
- **DNS**: Domain name system
- **DTM**: Data traffic manager
- **E1**: 2Mbit/s unit of capacity
- **EC**: European Commission
- **ED**: Economic depreciation
- **EDGE**: Enhanced data rate for GSM evolution
- **EIR**: Equipment identity register
- **eNodeB**: Evolved Node B
- **ENUM**: Enumeration
- **EPC**: Evolved packet core
- **EPMU**: Equi-proportional mark-up
- **E-UTRAN**: Evolved universal terrestrial radio access network
- **FAC**: Fully-allocated cost
- **GGSN**: Gateway GPRS serving node
- **GPRS**: General packet radio system
- **GSM**: Global system for mobile communications
- **GSN**: GPRS serving node

Acronyms used in this document [2/3]

- **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
- **ANACOM**: Portuguese Telecommunication Authority
- **IMS**: IP multimedia subsystem
- **IN**: Intelligent network
- **IP**: Internet protocol
- **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
- **MME**: Mobility management entry
- **MMS**: Multimedia message service
- **MMSC**: MMS centre
- **MSC**: Mobile switching centre
- **MSS**: MSC server
- **MT**: Mobile termination
- **MTR**: Mobile termination rate
- **MVNO**: Mobile virtual network operator
- **NDA**: Non-disclosure agreement
- **NGN**: Next-generation network
- **NMS**: Network management system
- **NodeB**: Denotes the UMTS equivalent of a BTS
- **NRA**: National regulatory authority
- **OTT**: Over-the-top service
- **PCRF**: Policy and Charging rules function
- **PCU**: Packet control unit
- **PDP**: Packet data protocol
- **PGW**: Packet data network gateway
- **PoI**: Point of interconnect

Acronyms used in this document [3/3]

- **PS**: Packet-switched
- **PV**: Present value
- **QAM**: Quadrature amplitude modulation
- **QPSK**: Quadrature phase-shift keying
- **R99**: Release-99
- **RNC**: Radio network controller
- **SAU**: Simultaneous active user
- **SBC**: Session border controller
- **SDCCH**: Stand-alone dedicated control channel
- **SGSN**: Subscriber GPRS serving node
- **SGW:** Serving gateway
- **SMS**: Short message service
- **SMSC**: SMS centre
- **SNOCC**: Scorched-node coverage coefficient
- **STM**: Synchronous transport module
- **TAS**: Telephony application server
- **TCH**: Traffic channel
- **TRX**: Transceiver unit
- **UMTS**: Universal mobile telecommunications systems
- **UTRAN**: UMTS terrestrial radio access network
- **VAS**: Value-added services
- **VLR**: Visitor location register
- **VMS**: Voicemail system
- **VoLTE**: Voice over LTE
- **WACC**: Weighted average cost of capital
- **WAP**: Wireless application protocol

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Description of sheets that compose the mobile termination model [1/5]

Excel sheet	Description
Control	Control panel where the model can be run and the main options can be defined
Lists	Lists the names of commonly used lists in the model
Operator_Demand	Calculates the past, present and future state of the Portuguese market and the modelled operator within the period considered in our model, in terms of traffic, mobile penetration and market shares
Throughput_inputs	Input estimates of SMS, GPRS, R99, HSDPA and LTE service parameters such as channel rates, IP overheads and conversion factors
Load_inputs	Defines loading network load parameters such as: ▪ busy days per year ▪ voice, SMS and data traffic profile in a typical busy day ▪ share of voice, messaging, low-speed and high-speed data traffic by network (incl. fall-back) ▪ average call duration, call attempts per call and ring time ▪ PDP context activity proportion ▪ Simultaneous active users

Description of sheets within the mobile termination model [2/5]

Excel sheet	Description
NwDes_Inputs	Defines input network load parameters such as: ▪ spectrum ▪ cell radii and scorched node factors ▪ radio blocking probability ▪ population coverage ▪ cell and site deployment proportions ▪ voice and data traffic distribution ▪ special / indoor sites distribution and share of indoor carried traffic ▪ average number of sectors per site ▪ radio capacity ▪ HSPA / LTE upgrade activation ▪ soft-handover factor ▪ switch capacity parameters ▪ transmission capacity parameters ▪ transmission proportions ▪ core network servers dimensioning parameters ▪ licence fees ▪ business overhead capex–opex ratio

Description of sheets within the mobile termination model [3/5]

Excel sheet	Description
Operator.NwDes	Summarises the technical parameters for the modelled operator
Utilisation_inputs	Defines the maximum capacity utilisation factor for various parts of the network
Asset_input	Defines different parameters for each type of asset, such as: ▪ network element name, type (2G, 3G, 4G, shared) and category ▪ network element lifetime, planning period, retirement delay ▪ direct capex and opex per network element ▪ indirect capex and opex multipliers/discounts
Geotypes	Lists the *freguesias* considered in our model and their main characteristics, such as population, area and geotype definition
Cov	Calculates the input traffic proportion by geotype as well as the traffic by geotype over time, according to roll-out profile of GSM, UMTS and LTE networks
DemCalc	Calculates the demand on the network: ▪ radio BHE (total, 2G, 3G, 4G) ▪ MSC BHCA (total, 2G, 3G) ▪ SMS in the busy hour (BHSMS and SMS/s) ▪ data kbit/s, equivalent Erlangs, BH Mbit/s ▪ wholesale billing system
SubsCalc	Calculates the low-speed data user proportion of voice subscribers and active PDP contexts and SAU

Description of sheets within the mobile termination model [4/5]

Excel sheet	Description
Nw_Des	Calculates network requirement for each part of the mobile network according to detailed network design algorithms, demand drivers and network design inputs, including: ▪ 2G, 3G and 4G radio network ▪ radio sites ▪ main switching ▪ transmission ▪ other network elements
Full_nw	Collates the number of network elements required in each year according to demand drivers and network design rules
NwDeploy	Calculates a smoothed number of network elements, and switches network element requirements as well as the number of network elements purchased in each year according to planning period and network element lifetime
Nw_cmp	Compares the number of network elements of an operator with and without its termination traffic
Dem_In	Collates demand by service
RouFacs	Input values and calculations specifying routeing factor load of each service on each network element
NwEle_Output	Multiplies demand by service with routeing factors to obtain total network element output over time
DiscFacs	Accumulates WACC to give discounting series, provides input inflation rates and accumulates inflation rates to give real-to-nominal conversion factors

Description of sheets within the mobile termination model [5/5]

Excel sheet	Description
CostTrends	Defines the capex and opex cost trends, and calculates a price index for each network element (annual and cumulative)
UnitCapex	Calculates capex per network element according to base price and capex trend
TotCapex	Calculates total capital expenditures by multiplying unit capex by the number of network elements purchased in each year
UnitOpExp	Calculates opex per network element according to base price and opex trend, including an allowance for working capital
TotOpex	Calculates total operating expenditures by multiplying unit opex by the number of network elements operated in each year
EconDep	Calculates annualised costs over time, in total and per unit output, according to PV of expenditures and PV of (production output × price index)
Common	Defines common costs (spectrum, NMS, business overheads) and calculates incremental and common costs per service, including mark-ups
LRAIC+	Summarises marked-up unit average incremental costs for all services over time, including blended termination services
LRIC_costs	Calculates pure incremental costs in total and divided by volumes
LRIC_outputprofile	Calculates the expenditures and annualisation of avoidable (LRIC) costs
Erlang	Erlang look-up table used by network design calculations

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Annexes

Glossary

Description of model sheets

List of model inputs

The sources for the model inputs are mainly based on ANACOM, operator data and Analysys Mason estimates

- This annex sets out the sources of the main inputs to the model
- The main sources for the model inputs include:
  - ANACOM statistics on the Portuguese market data and regulation – e.g. on annual spectrum costs
  - operator data whenever available, which can be used as an average, or as an indicator from which an Analysys Mason estimate is produced
  - Analysys Mason estimates, based on our broad experience of many costing models from different geographies, and our knowledge and research of the Portuguese market
- Other sources of data include data research companies, such as:
  - Analysys Mason Research, Euromonitor, ITU, etc.
- For each model input, we indicate the model sheet on which it is located, as well as the source of the model input
  - some of the inputs presented are grouped together. For instance, the input "ring time per call" includes the ring time per call for on-net calls, outgoing and incoming calls, international calls and roaming calls
- We have used the name of the input for ease of reference in the model whenever possible

List of model inputs [1/11]

Model sheet	Model inputs	Source
Operator_Demand	Please see the “Market model” section	

List of model inputs [2/11]

Model sheet	Model inputs	Source
Throughput_inputs	Application packet size	Information based on technology standards
	SNDPC	Information based on technology standards
	LLC payload size	Information based on technology standards
	LLC overhead size	Information based on technology standards
	RLC/MAC packet size	Information based on technology standards
	RLC/MAC overhead	Information based on technology standards
	Voice codec rate	Analysys Mason estimates / technical standard
	Prop data transferred downlink	Analysys Mason estimates
	Number of bytes per SMS	Analysys Mason estimates
	Voice channel rate for SMS message (SDCCH)	Analysys Mason estimates / technical standard
	UMTS voice radio channel rate	Analysys Mason estimates / technical standard
	R99 radio channel rate	Analysys Mason estimates / technical standard
	HSDPA Radio channel rate for different speeds	Information based on technology standards
	Proportion of HSPA data transferred downlink	Analysys Mason estimates

List of model inputs [3/11]

Model sheet	Model inputs	Source
Throughput_inputs	Voice codec rate	Analysys Mason estimates / technical standard
	Number of bytes per SMS	Analysys Mason estimates
	MMS to data conversion factor	Analysys Mason estimates
	Proportion between the average sector throughput and throughput at peak	Analysys Mason estimates on operators' data
	LTE throughput per upgrade	Analysys Mason estimates / technical standard
Load_Inputs	Busy days per year	Analysys Mason estimates
	Voice traffic profile	Analysys Mason estimates based on Portuguese data provided by operators
	SMS traffic profile	Analysys Mason estimates based on Portuguese data provided by operators
	Mobile data traffic profile	Analysys Mason estimates based on Portuguese data provided by operators
	Weekday proportions of voice, SMS and data in the busy hour	Analysys Mason estimates

List of model inputs [4/11]

Model sheet	Model inputs	Source
Load_inputs	Voice migration profile	Analysys Mason estimates
	SMS migration profile	Analysys Mason estimates
	Low-speed data migration profile	Analysys Mason estimates
	High-speed data migration profile	Analysys Mason estimates
	Average call durations	Analysys Mason on Portuguese data provided by operators
	Call attempts per successful call	Analysys Mason on Portuguese data provided by operators
	Ring time per call	Analysys Mason estimates
	Subscriber loading proportions	Analysys Mason on Portuguese data provided by operators
	Simultaneous active users (SAUs)	Analysys Mason estimates
NwDes_Inputs	Spectrum holding (paired)	Operator data
	2G / 3G / 4G primary spectrum	Operator data
	# of channels per spectrum band	Analysys Mason estimates / technical standard
	Cell loading radius effect (cell breathing)	Analysys Mason estimates based on Portuguese data provided by operators
	Theoretical and effective coverage radii	Analysys Mason estimates and calibration process
	SNOCC	Analysys Mason estimates and calibration process

List of model inputs [5/11]

Model sheet	Model inputs	Source
NwDes_Inputs	Air interface blocking probability	Operators’ data average
	Population coverage	Analysys Mason estimates based on Portuguese data provided by operators
	Voice traffic proportions per geotype	Analysys Mason estimates based on and validated through benchmarks
	Data traffic proportions per geotype	Analysys Mason estimates based on and validated through benchmarks
	Number of special / indoor sites	Analysys Mason estimates based on Portuguese data provided by operators
	Share of traffic carried by indoor / special sites	Analysys Mason estimates based on Portuguese data provided by operators
	Distribution of indoor / special sites	Analysys Mason’s estimate
	Average sectorisation per macro site	Operators’ data average
	Technology overlay deployments parameters	Analysys Mason estimates based on Portuguese data provided by operators

List of model inputs [6/11]

Model sheet	Model inputs	Source
NwDes_Inputs	GSM sectoral spectrum re-use limit	Analysys Mason estimates based on Portuguese data provided by operators / technical standard
	Minimum TRX per GSM BTS sector	Analysys Mason estimates based on Portuguese data provided by operators
	Maximum TRX per sector - physical BTS capacity	Analysys Mason estimates
	GSM channelization for voice, data and signalling	Analysys Mason estimates based on Portuguese data provided by operators / technical standard
	UMTS minimum channel deployments (voice, data, HSPA, rate)	Analysys Mason estimates based on Portuguese data provided by operators
	HSPA data activation per speed and geotype	Analysys Mason estimates based on Portuguese data
	UMTS R99 soft handover	Analysys Mason estimates / technical standard
	LTE upgrades activation by geotype	Analysys Mason estimates based on Portuguese data
	Radio site deployment types	Analysys Mason estimates based on rounded average Portuguese data provided by operators

List of model inputs [7/11]

Model sheet	Model inputs	Source
NwDes_Inputs	BSC, capacity in TRX, ports, cells, and other characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	RNC, capacity in Mbit/s, ports, and other characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	LTE-AP capacity in E1 equivalents and minimum deployment	Analysys Mason estimates
	Main switching and VMS sites	Analysys Mason estimates based on Portuguese data provided by operators
	2G/3G combined MSC servers and media gateways	Analysys Mason estimates based on rounded average Portuguese data provided by operators
	% share of MSCs that are POIs	Analysys Mason estimates
	Max number of interconnect logical routes (IN + OUT)	Analysys Mason estimates
	Incremental interconnect logical routes per MSC (IN + OUT)	Analysys Mason estimates
	Network blocking probability	Analysys Mason estimates
	MSC local traffic multiplier	Analysys Mason estimates

List of model inputs [8/11]

Model sheet	Model inputs	Source
NwDes_Inputs	National backbones parameters (number of core transmission sites ,ring length, STM-4 submarine cables)	Analysys Mason estimates
	Distribution of BSC-MSC transmission distance	Analysys Mason estimates
	Distribution of MSC-MSC transmission distance	Analysys Mason estimates
	Number of radio sites connected per BSC/RNC or per backbone access point	Analysys Mason estimates
	Regional transmission backbones (length, fibre LMA share, BSC/RNC-MSC share, backhaul access node share, access points share)	Analysys Mason estimates
	Backhaul transit	Analysys Mason estimates
	Distribution of last mile transmission distance to access point (may be BSC/RNC site or backhaul backbone PoP)	Analysys Mason estimates
	Backhaul technologies per geotype	Analysys Mason estimates based on operator data
	Leased line prices	ANACOM and Analysys Mason estimates

List of model inputs [9/11]

Model sheet	Model inputs	Source
NwDes_Inputs	SMSC characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	MMSC characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	GGSN characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	SGSN characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	VMS characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	HLR characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	VAS platform characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	Wholesale Billing System characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	LTE servers characteristics	Analysys Mason estimates / data from operators
	VoLTE servers characteristics	Analysys Mason estimates

List of model inputs [10/11]

Model sheet	Model inputs	Source
NwDes_Inputs	Initial spectrum payments	ANACOM and Analysys Mason estimates
	Spectrum yearly fees	ANACOM and Analysys Mason estimates
	Business overhead expenditures	Analysys Mason estimates and calibration process
Utilisation_inputs	Utilisation inputs	Analysys Mason estimates and calibration process
Asset_input	Asset inputs	Analysys Mason estimates based on averaged Portuguese data provided by operators whenever available and calibration process
Geotypes	Area per freguesia	MapInfo data
	Population per freguesia	Census 2011
	Geotype per freguesia	Analysys Mason estimates based on density analysis of freguesias
Nw_Des	RNC minimum number of ports	Analysys Mason estimates
RouFacs	Service routeing factors for IN, VMS, HLR, AUC, EIR, SMSC, MMSC, GGSN, SGSN, billing system, network management system, VAS, business overheads,	Analysys Mason estimates

List of model inputs [11/11]

Model sheet	Model inputs	Source
DiscFacs	Real discount rate of change	Set to zero (disabled)
	Real discount rate	Analysys Mason calculation based on PwC methodology for fixed WACC calculation
	Inflation	Euromonitor
CostTrends	Cost trends	Analysys Mason estimates based on recent regulatory models

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