Presentation for ANACOM

ANACOM bottom-up mobile cost model – Model documentation

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analysys mason

PUBLIC VERSION

Contents

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

- The Portuguese regulator ANACOM has commissioned Analysys Mason to develop a long-run incremental cost (LRIC) model, following the European Commission (EC) recommendation on termination, for the purposes of establishing and regulating the cost of mobile voice termination in Portugal
- This wholesale service falls under the designation of Market 7, according to the EC Recommendation on relevant markets
- 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 presented industry participants with the opportunity to contribute at various points during the project
- A consultation process has taken place during 2011 to define the main parameters driving the LRIC model, which has been responded by the main industry parties
- The cost model has been developed, reflecting this feedback
- This document accompanies the model developed for ANACOM
- It has the objective to:
  - introduce the mobile cost model
  - outline 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
  - results and outputs from the model

The model and documentation has been modified and updated after the public consultation

- A public consultation was launched in October 2011 to obtain the feedback from the industry, that was accompanied by a public version of the mobile model and its associated documentation
- Changes have been applied to the model as a result of responses to this consultation:
  - data consumption forecast has been revised and increased to 1050Mb/month in 2011 and 1100Mb/month in 2012, and HSUPA was updated accordingly at 25% of HSDPA
  - voice consumption forecast has been revised in line with data published by ANACOM
  - static channels reserved for GPRS traffic has been revised to 1.5
  - the cost recovery period of the model has been updated to reflect 45 years
- Furthermore, a series of additional changes have been introduced into the model:
  - some inputs have been changed from end of year (EoY) to year average (YA), including subscribers and yearly mobile data traffic
  - some inputs depending on subscriber numbers for their calculation – such as SMS per subscriber – have been affected by the above change, and forecasts had to be adjusted accordingly
  - 2G data technology was changed from EDGE to GPRS
  - minor errors were corrected, such as the result table being mistakenly shifted by one year
- As a result of the changes introduced with the above modifications, the model had to be re-calibrated
  - utilization and SNOCC factors were revisited accordingly
- The documentation has been revised and the explanation of the methodology for the calculation of the voice traffic distribution now reflects the model implementation

The present document has been updated accordingly to reflect modifications introduced to the model as a result of the public consultation

Inputs to the public model have been consistently modified for confidentiality reasons

- The model has been populated and calibrated partly based on information provided by ANACOM and the three MNOs (TMN, Vodafone, Optimus)
  - inputs derived from those sources are confidential in its majority
  - the model often uses numbers based on this information
- To protect the confidential information from the market, all inputs from the public model have been modified
  - inputs have been 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 have applied a further coarse rounding
- This will only 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

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The modelling principles have been consulted with the industry [1/2]

- The modelled operator has been defined based on Analysys Mason experience, ANACOM input and answers from industry players to a Concept Paper presenting the main modelling options
- **Methodology:** 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 operator achieving a scale of 20% in the short term, and growing to 33.3% by 2017, with subscriber and traffic demand parameters calculated from the total mobile market
  - the model reflects aspects such as a hypothetical (efficient) coverage and topology
- **Radio network:** 2G+3G networks and 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, BTS and NodeB
- **Core network:** We have modelled one core network architecture (transmission and switching) based on an all-IP (NGN) mobile core:
  - MGW and MSC(MSS) 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 voice
  - 3G voice
  - SMS and MMS
  - GPRS, R-99, HSPA data bearers
  - Economies of scope have been shared across voice and data in the LRAIC+ model

Source: Analysys Mason

The modelling principles have been consulted with the industry [2/2]

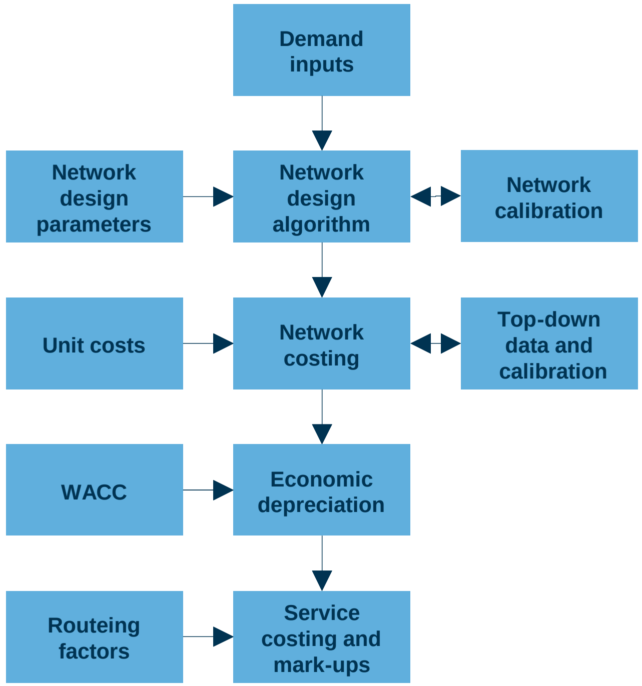
- **Wholesale network costs:** The model covers network activities plus common business overheads:
  - retail costs – handsets, subsidies, dealer payments, promotions, customer care, sales and marketing, etc. – have not been modelled
  - the LRAIC+ results include a share of business overheads
  - Pure LRIC results exclude all common cost components
- **Increments:** We have considered two Increments
  - *LRAIC+* – the average incremental cost of all traffic plus mark-up for common costs: network common costs defined as the minimum coverage requirements of mobile subscribers
  - *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's current Recommendation
- **Depreciation:** We have modelled economic depreciation expressed in real EUR and for discounted full time series over 45 years in real 2008 EUR[1]
  - this is the same functional form of economic depreciation that Analysys Mason has applied in similar regulatory cost models in The Netherlands, Denmark, Norway and Belgium, and satisfactorily tested by Ofcom during its economic depreciation considerations
- **WACC:** We have calculated a mobile WACC to reflect prevailing capital cost parameters, including:
  - 10-year risk-free rate
  - cost of debt
  - nominal tax rate
- **Years of calculation:** The models calculates costs over the lifetime of the business including on-going equipment replacements:
  - discounted over 45 years
  - terminal value beyond 45 years is assumed to be negligible

Note 1: real 2008 EUR used due to the availability of benchmark and operator data

Outline form of the model

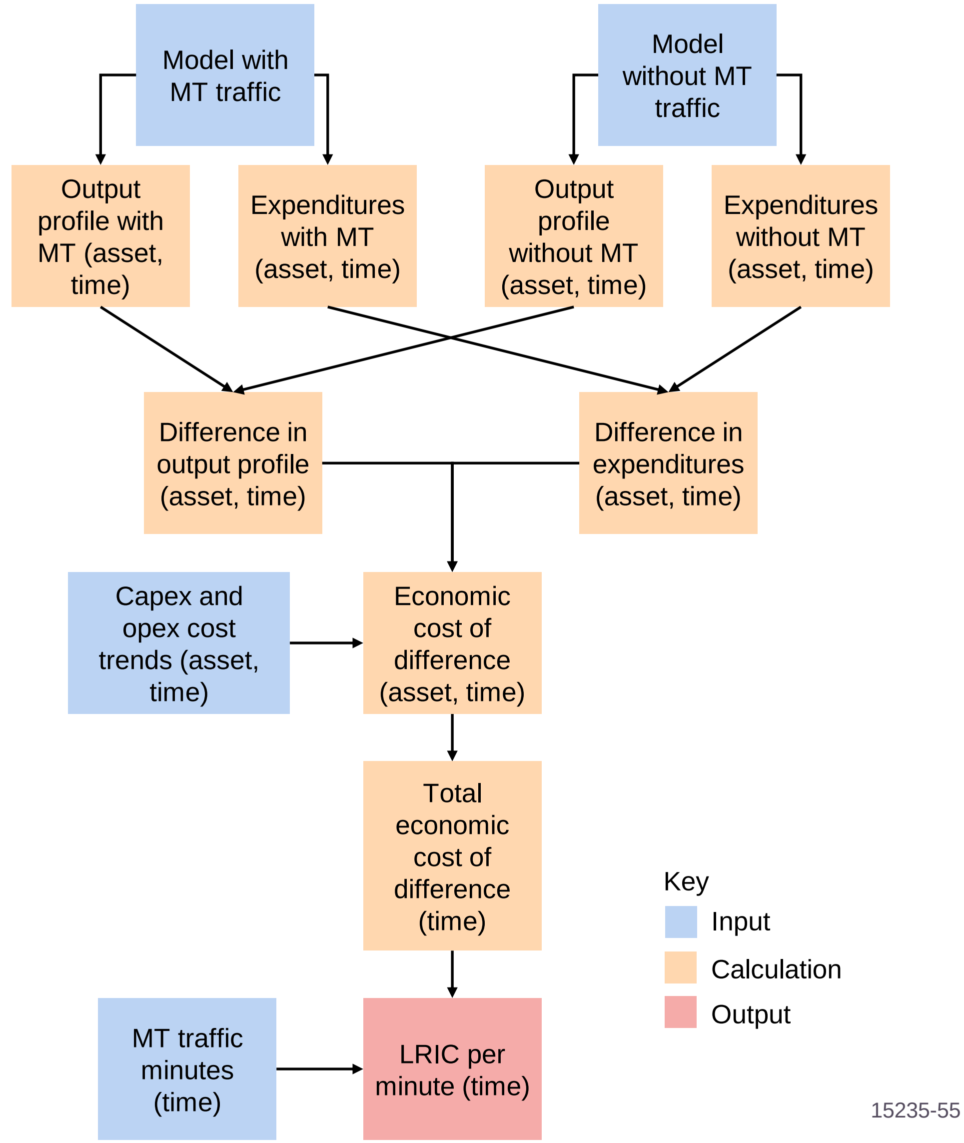
- **Demand inputs:** market subscribers and traffic for the operator
- **Network design parameters:** busy-hour factors, coverage parameters, switch capacities, network topology, etc.
- **Network design algorithm:** calculation of network element requirements over time
- **Network calibration:** check 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.

Bottom-up model flow



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:
    - lower minimum radio channel equipment, such as minimum number of TRX per sector and minimum number of channels per NodeB – R99
    - reduced number of special sites
    - "relaxation" of 3G cell breathing
- 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 ensure cost of capital employed)



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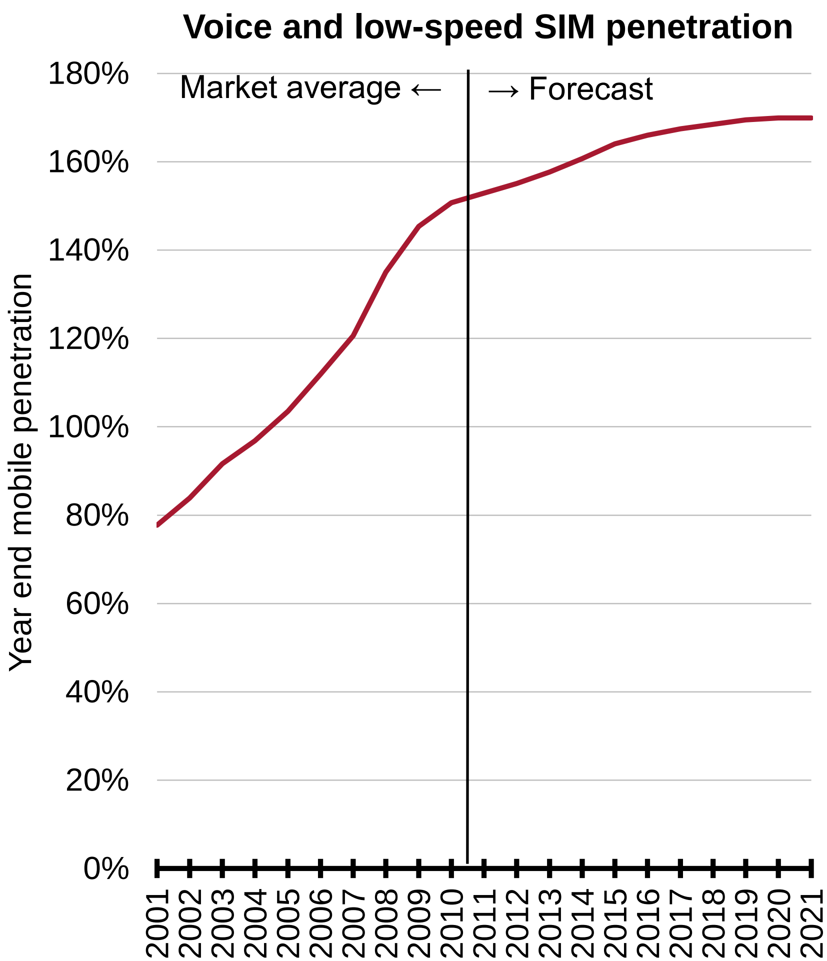
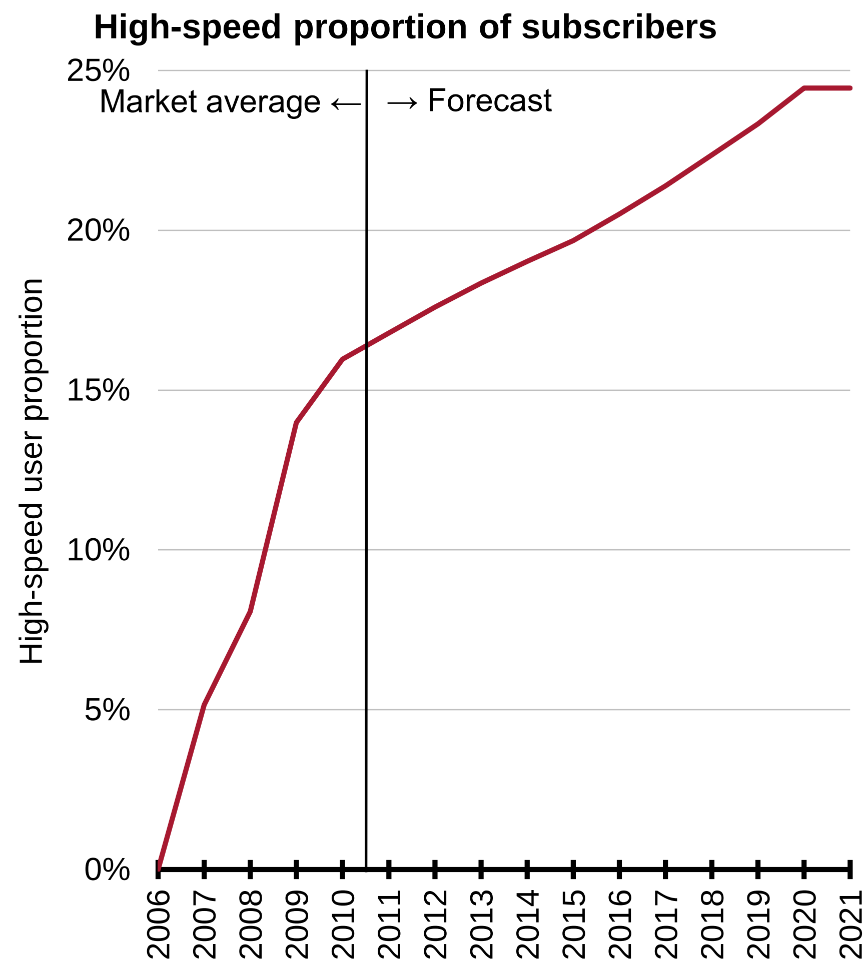
The market model forecasts subscribers, traffic and market share

- Market demand is modelled based on data provided by the mobile operators in response to the data request, ANACOM's data and Analysys Mason and other research companies' forecasts:
  - for future years, a forecast market average is defined, towards which all operators converge by 2021
  - as part of the model finalisation, we have modelled a static market after 2021
- The market share of the modelled operator is expected to reach 20% in 2011 and keep growing to 33% in 2017:
  - the market share evolution is based on the decision made by ANACOM recognising the EC recommendation, and advised by Analysys Mason
- The number of active subscribers in the market is calculated using a projection of future population and penetration of digital mobile services:
  - the penetration is assumed to reach 170% by the end of the period, following a saturation formula
  - as part of the model finalisation, we have no additional growth of SIM penetration after 2021
- The forecast voice and SMS traffic demand for the market is determined by a projection of traffic per subscriber, multiplied by 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 2010
  - we have included a formula for taking into account the evolution of the proportion of termination traffic based on the market share of the operator
- We have calculated the number of low-speed and high-speed data subscribers based on ANACOM's statistics
  - low-speed data subscribers – considered to be on average *all* mobile consumers – consume up to 0.26MB per month
  - high-speed consumers – calculated based on ANACOM's statistics for historical data and on Analysys Mason research for forecasts – consume up to 1.1GB per month of HSDPA and 275MB per month of HSUPA per month

We have modelled voice and low-speed SIM penetration, as well as high-speed data users

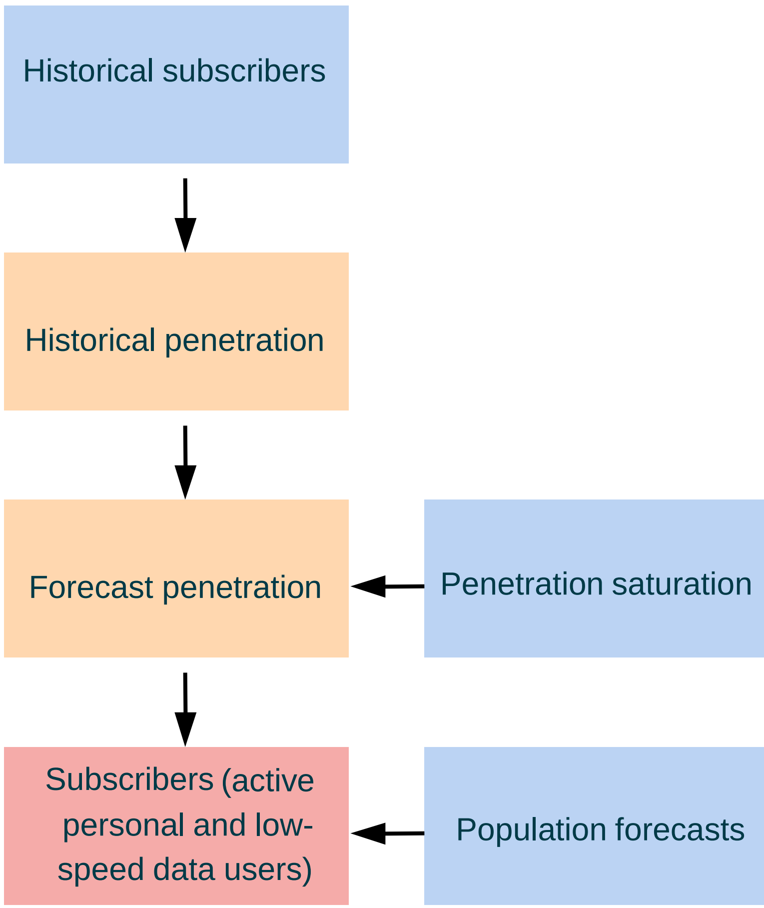




Source: Analysys Mason model, ANACOM

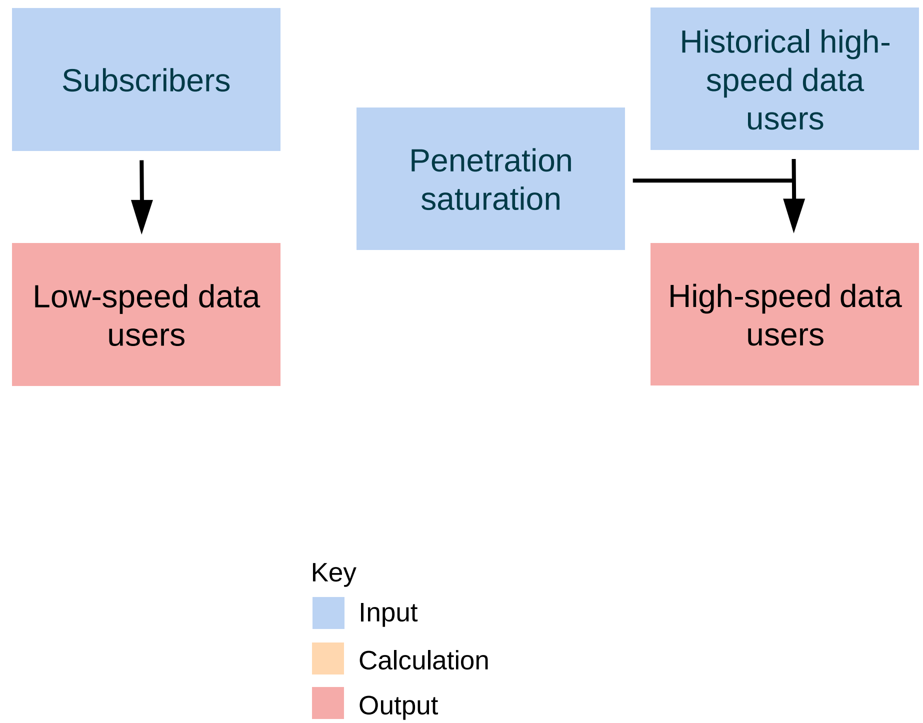
Active mobile subscribers are forecast first, from which ‘low-speed users’ and ‘high-speed data users’ are derived

Subscriber forecast calculation



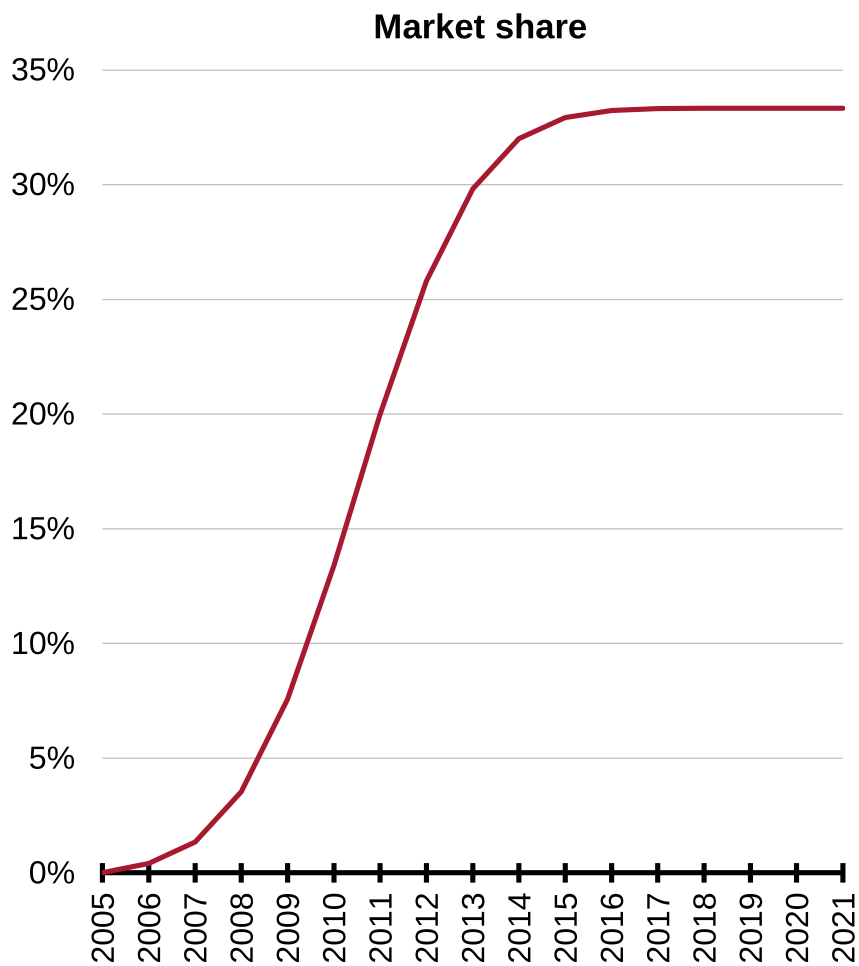
Sheet: Operator_Demand, Rows 5–23

Low-speed subscriber and high-speed data usage calculations



Sheet: Operator_Demand, Rows 44–59

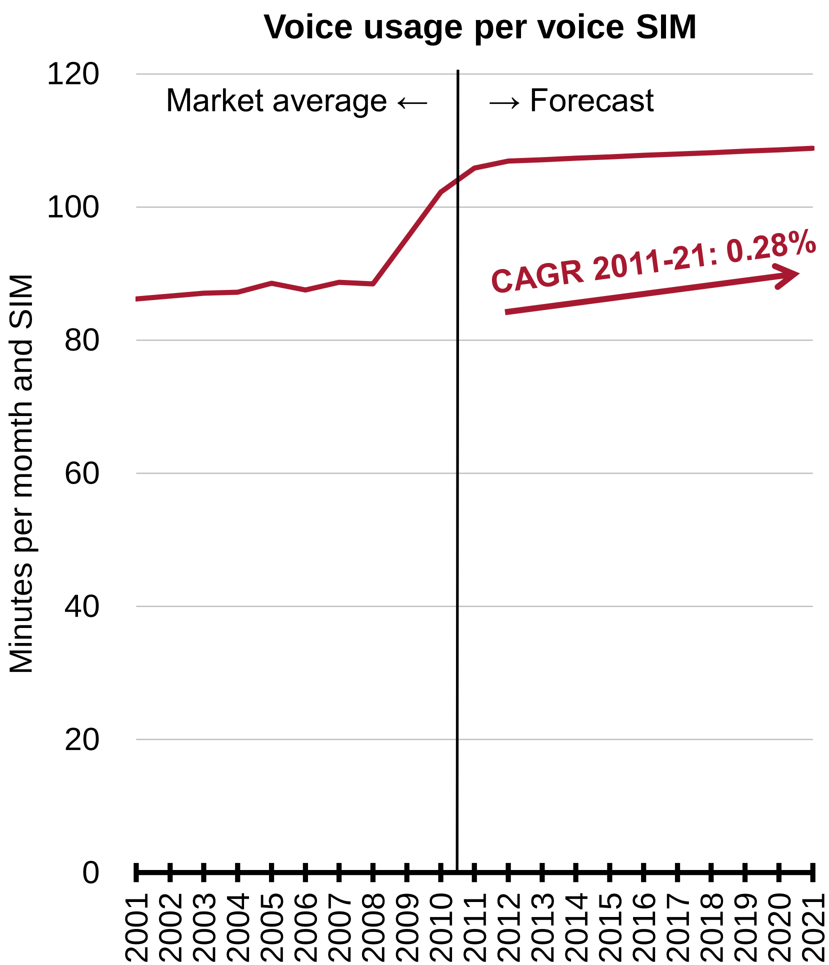
Market share is forecast to reach 20% in 2011 and converge steadily to 33%



- The model includes a hypothetical efficient-scale operator defined as:
  - 2005: start of network deployment
  - 2006: beginning of operations
  - gaining market share to reach:
    - 20% after 5 years
    - 33.3% from 2017 and in the long term
- The hypothetical operators' growth in voice traffic is proportional to its market share and the overall size of the Portuguese market

Source: Analysys Mason model, ANACOM

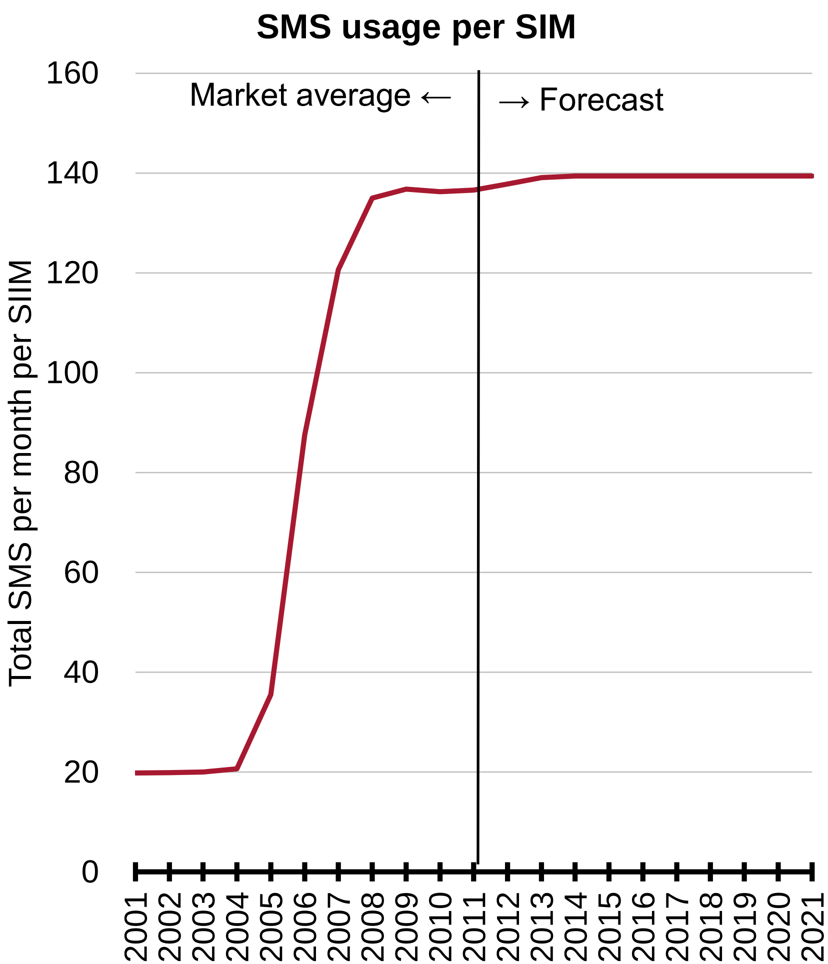
Voice usage per SIM is modelled using actual market history and forecasting its growth until 2021

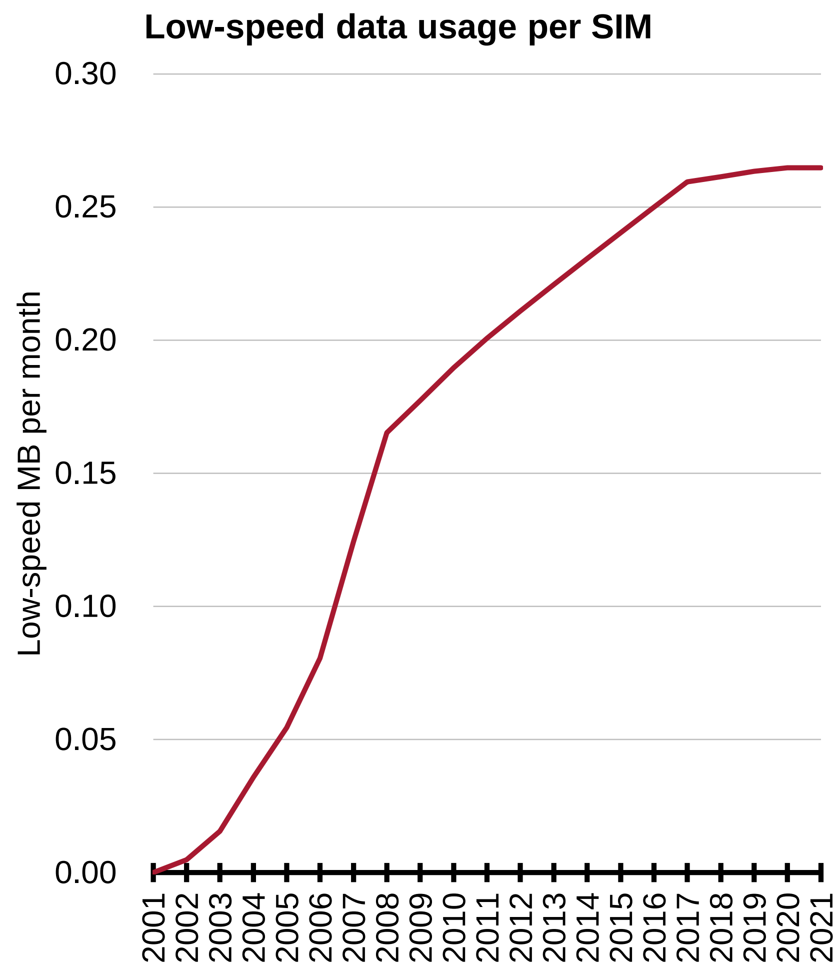


- We assume a steady growth in traffic per SIM after 2010
  - a conservative approach in forecasts decreases the risk of introducing uncertainties in the model's calculations
- Around 79% of mobile origination is currently on-net
- For traffic to other networks (i.e. excluding on-net):
  - around 3% is to international numbers
  - around 4% is to the fixed network
    - this has declined from around 12% in the early years
- In addition, we project the total volume of roaming in origination and termination traffic at 3% of total traffic

Source: Analysys Mason model, ANACOM

Voice and low-speed data users generate SMS messages and low-speed data (GPRS, EDGE, R99)

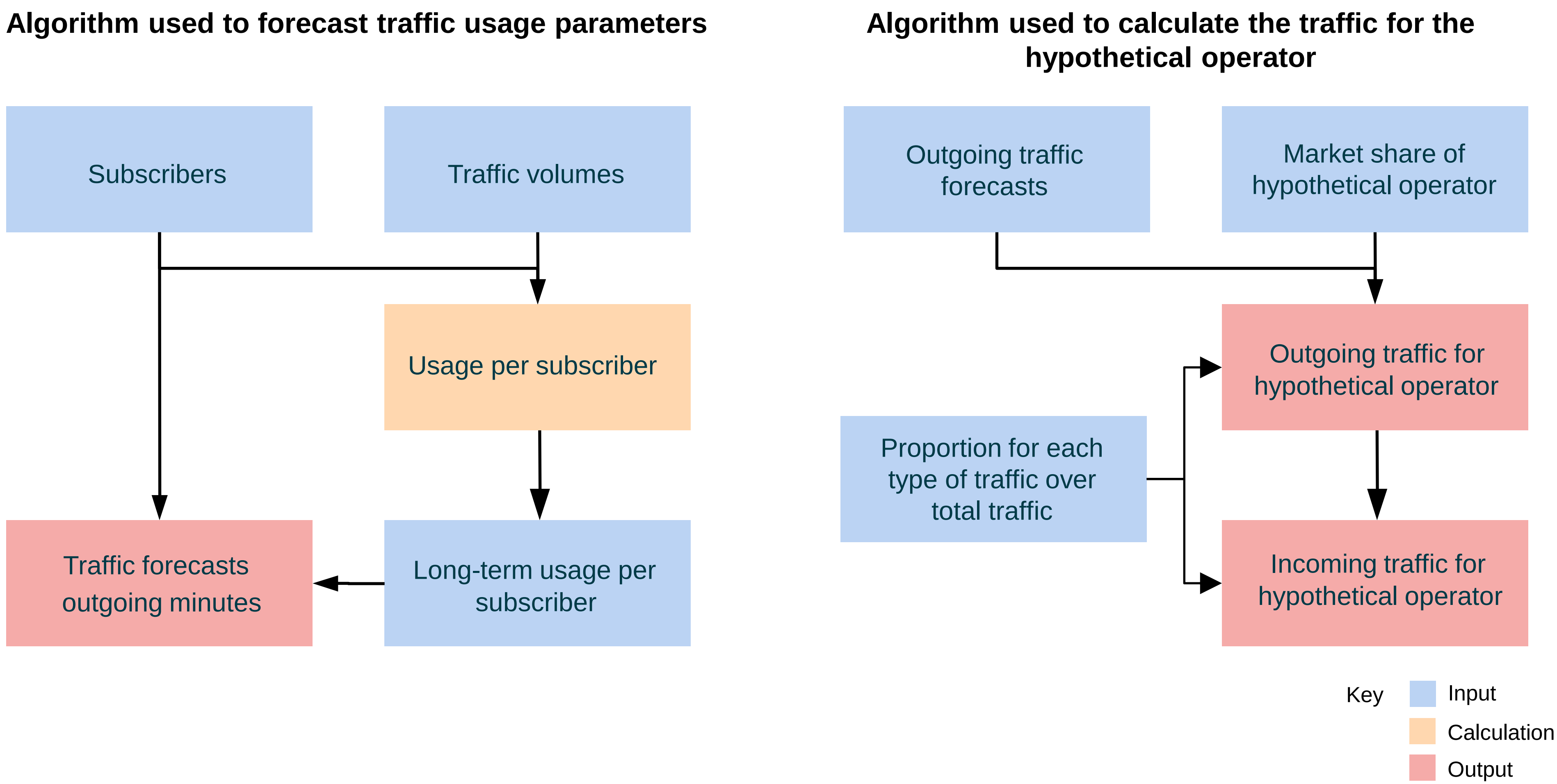




Source: Analysys Mason model, ANACOM

Note: Low-speed data usage per SIM has been based on estimations from Analysys Mason

We estimate outgoing and incoming traffic for the hypothetical operator from the total traffic of the market

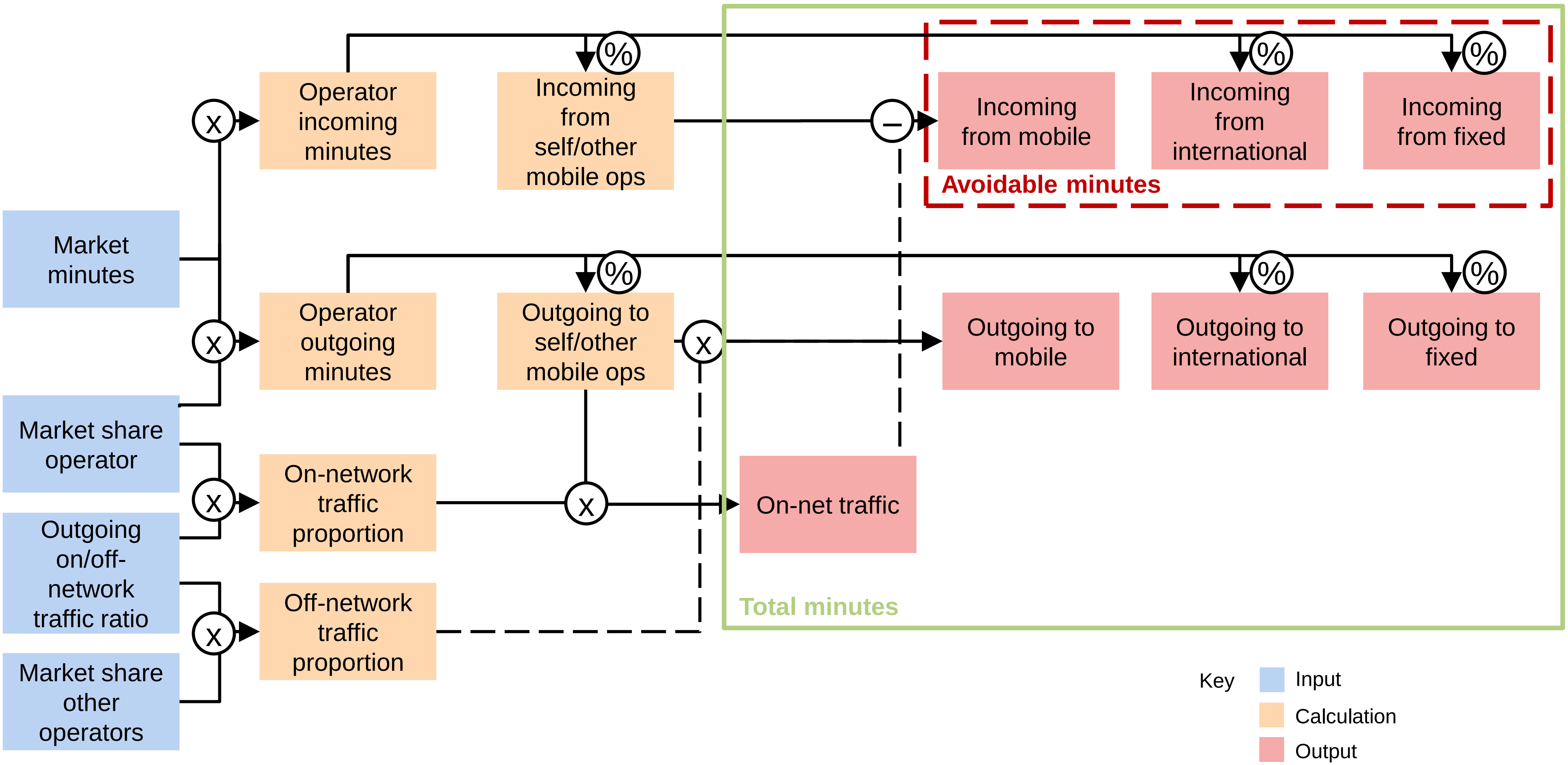


Sheet: Operator_Demand, Rows 27–42

Sheet: Operator_Demand, Rows 63–104

The traffic distribution is calculated taking into account the market share of the hypothetical operator…

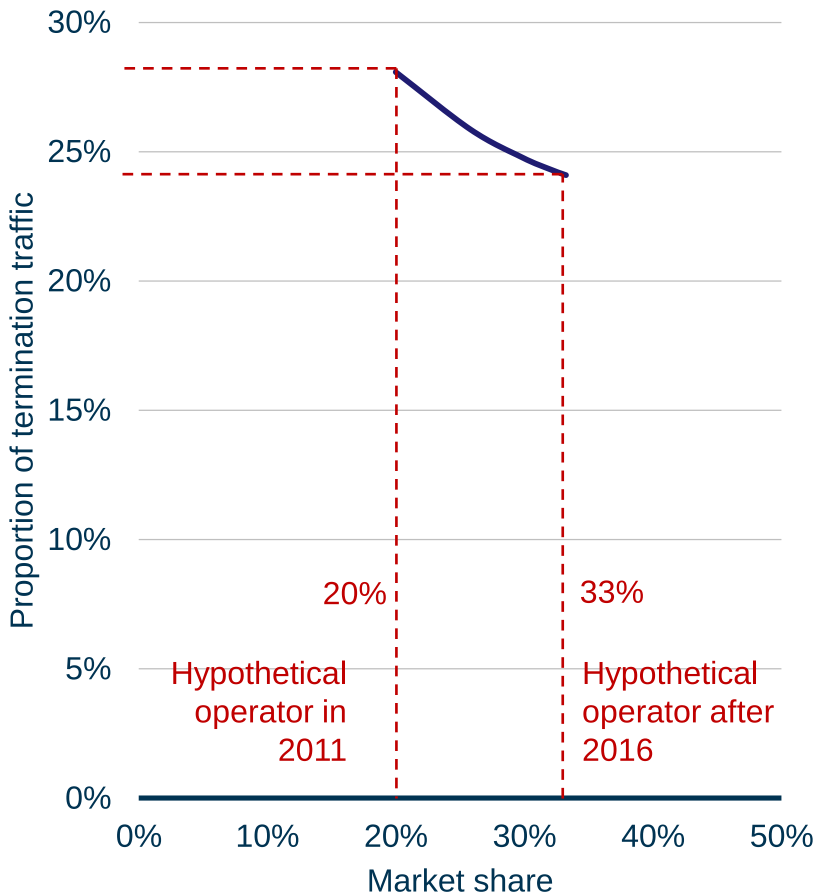
Algorithm used to calculated the distribution of voice traffic of the modelled operator



Sheet: Operator_Demand, Rows 71–104

… and results in a level of incoming traffic which is comparable with the Portuguese market in 2009

Relationship in the model between market share and proportion of termination traffic



- Termination traffic is usually not constant among operators with different market shares
  - in Portugal, the differences among operators are relatively small
  - according to ANACOM market information, mobile termination traffic as a % of total mobile traffic has declined in the last ten years
- The uncertainty associated with subscriber behaviour makes it difficult to predict the potential evolution of termination traffic proportion over total traffic
- The model calculates the proportion of termination traffic for the hypothetical operator, and has a higher termination proportion when the hypothetical operator is small (lower market share meaning less on-net traffic)
- The relationship between the hypothetical operator market share and termination proportion is shown opposite.
- We believe that keeping a broadly constant proportion of termination traffic in the long-term is a plausible and neutral solution

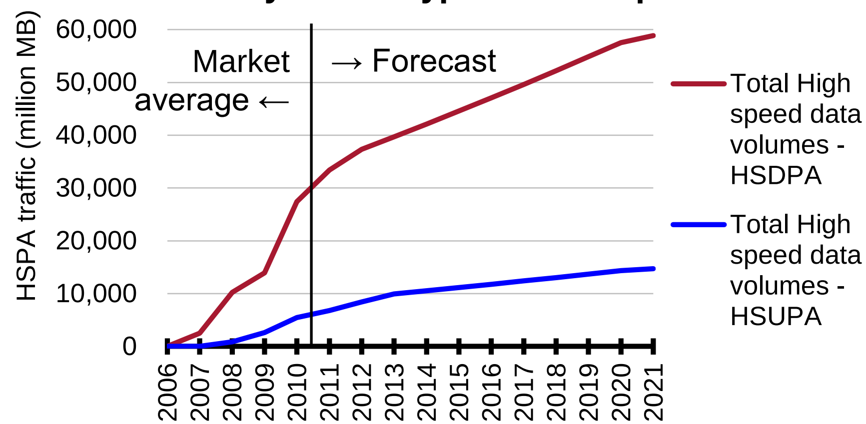
The market forecast model uses a set of inputs from ANACOM, Analysys Mason and other sources

Input	*Source historical data*	*Source forecast data*
Population	Euromonitor, ITU, EIU	Euromonitor, ITU, EIU
Mobile penetration	ANACOM, ITU	Analysys Mason
Subscribers	ANACOM	Analysys Mason
Traffic mobile on-net	ANACOM	Analysys Mason
Outgoing traffic mobile to fixed	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
MMS	ANACOM	Analysys Mason
Low-speed data volumes	Analysys Mason	Analysys Mason
High-speed data subscribers	ANACOM	Analysys Mason
High-speed data volumes	ANACOM	Analysys Mason

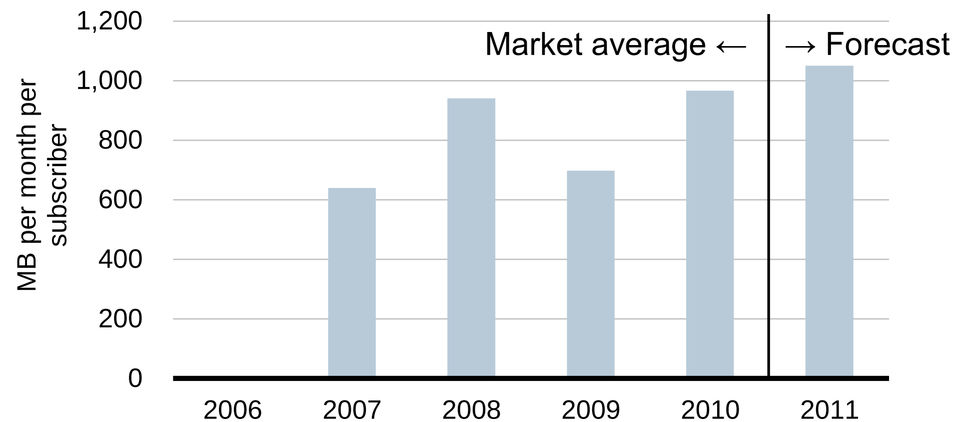
Each high-speed data user generates HSDPA Mbytes, and HSUPA traffic (when deployed)

- HSPA services were launched in 2007. We assume:
  - 1100Mbytes HSDPA per user per month by 2012, based on the evolution of historical data consumption in the last 4 years
  - 275Mbytes HSUPA per user per month by 2013, which represents a 4:1 ratio of down/uplink
- To put this in context, our hypothetical efficient mobile operator carries:
  - approx. 17 billion MB in 2009
  - approx. 33 billion MB in 2010
  - stabilising at around 73.6 billion Mbytes per annum in the long term
- This traffic is carried according to the HSDPA rates (1.8, 3.6, 7.2, 21.1 and 42.2) assumed to be rolled out in the network over time

HSDPA Mbytes for hypothetical operator



HSDPA Mbytes per month and subscriber for hypothetical operator



Source: Analysys Mason model, ANACOM

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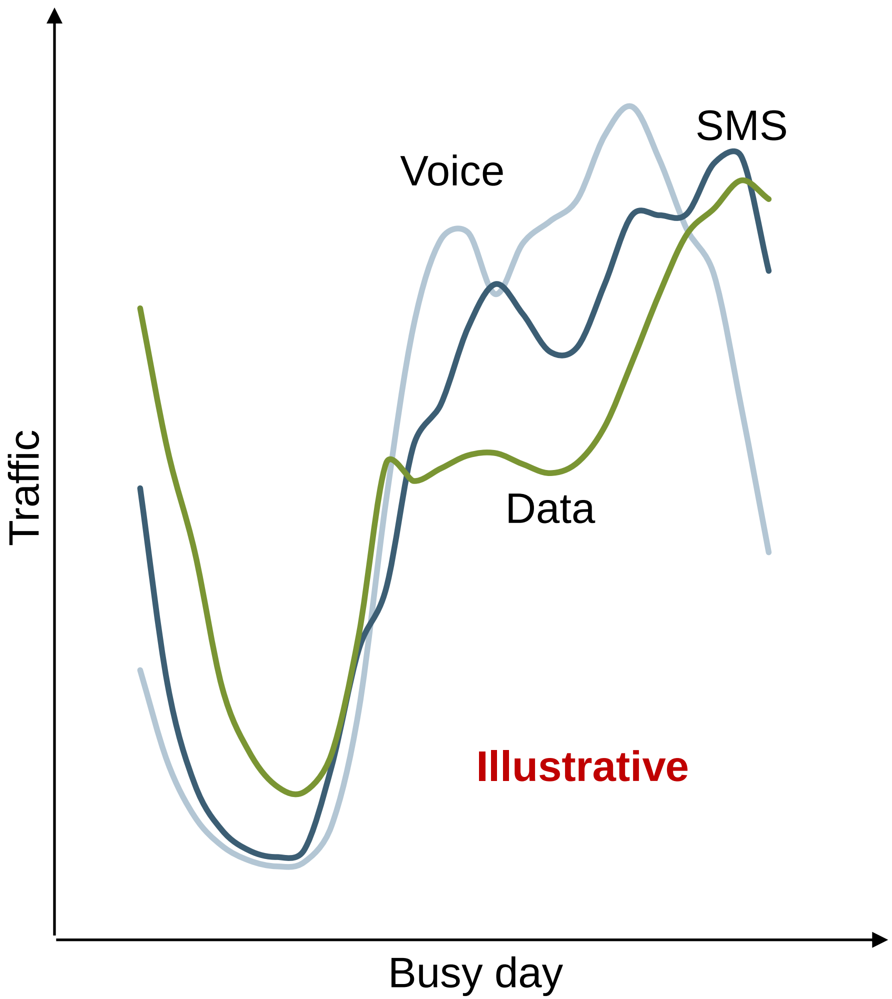
Voice, SMS and data traffic is converted into a busy-hour load using three inputs

- **Busy days per year**: 250
- **Weekday proportion of traffic**: roughly 80% for voice, 70% to 75% for SMS and data traffic, based on Analysys Mason estimations
- **Busy-day traffic profile**: approximately as shown, based on data provided by operators
- For 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 estimations
- Peak-hour proportions are based on data provided by operators:
  - voice: approx. 8%
  - SMS: approx. 7%
  - data: approx. 5%

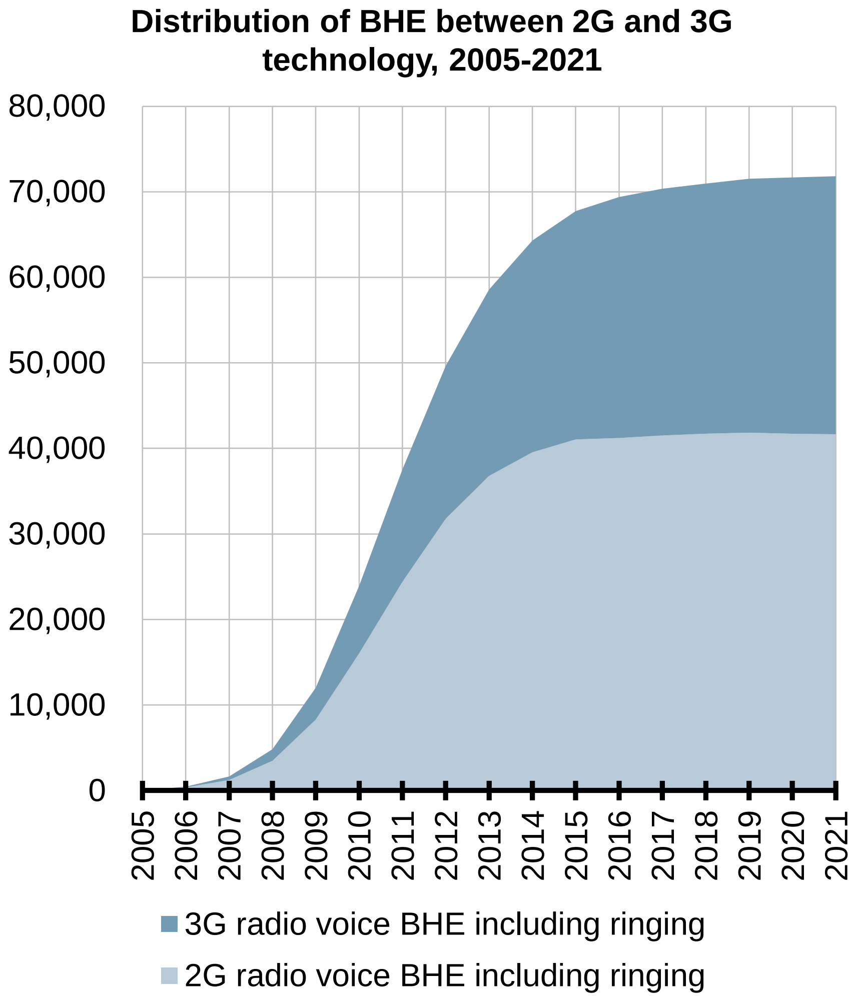
Traffic profile for voice, SMS and mobile data

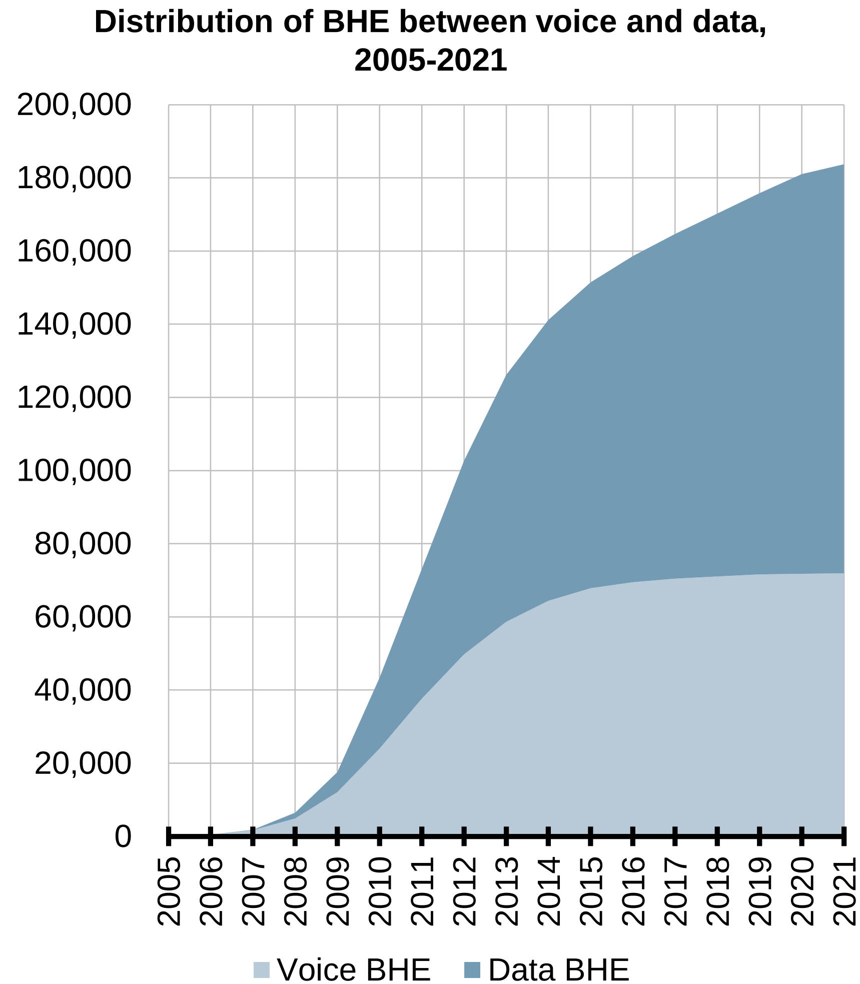


We apply further loading factors to calculate voice Erlangs and call attempts

- **Ring time per call**: approximately 7 seconds is added to the Erlang load of voice minutes based on Analysys Mason estimates
- **Average call duration**: approximately 2 minutes based on operators' data and Analysys Mason estimates
  - does vary slightly by call type
- **Call attempts per successful call**: around 1.8 based on operators' data and Analysys Mason estimates
  - varies by call type
  - combined with average call duration to calculate the number of busy hour call attempts
- **Erlangs per minute**:
  - 2 for on-net traffic
  - 1 for incoming and outgoing off-net traffic

We expect data to represent the majority of traffic by 2021



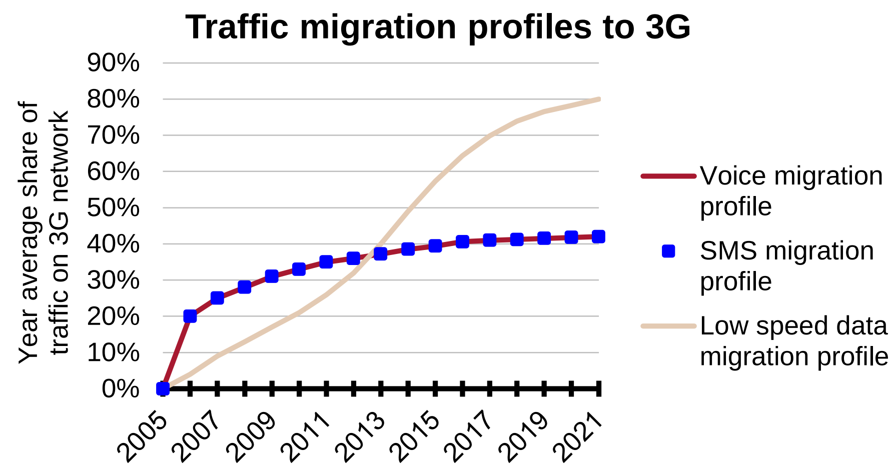


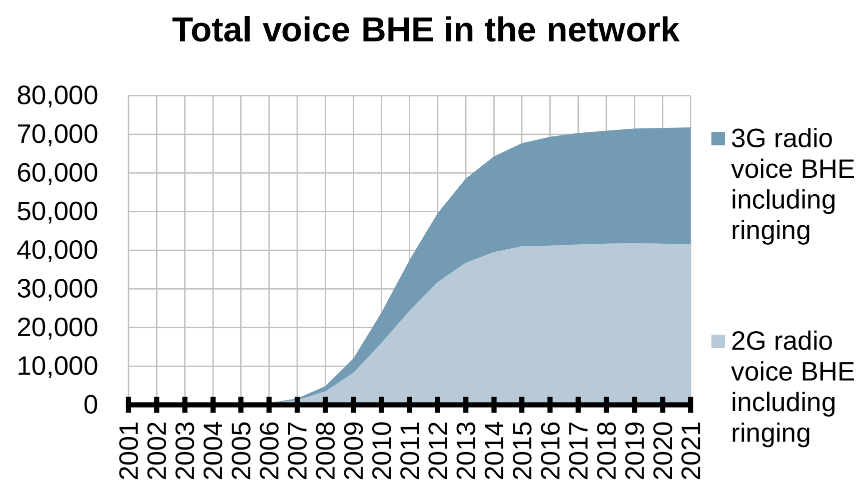
The model considers that future mobile data usage will be mainly transported through new technologies such as LTE, and therefore HSDPA data consumption has been capped at 1.1Gb per subscriber per month

Source: Analysys Mason model

Traffic migration to UMTS determines the evolving voice, SMS and low-speed data load by network

- We apply three traffic migration profiles – used separately to determine *voice*, *SMS* and *low-speed data* traffic on the GSM and UMTS networks:
  - we assume voice and SMS migration to attain 35% by 2011 and 42% by 2021
  - we assume low-speed data migration to attain 80% by 2021
- The migration profile has been approximately based on historical information provided by operators up to 2010 and Analysys Mason estimations
  - Portuguese mobile operators have consistently indicated a slow migration pattern from 2G to 3G in their networks and handset sales
  - migration forecast is based on the projection that 2G and 3G will exist in parallel in Portugal for the foreseeable future – there is no evidence that the operators are rapidly off-loading their 2G networks in preparation for an impending shut-down
  - operators have mentioned the low proportion of subscribers that acquire 3G handsets due to their increased battery consumption and higher costs for a similar voice and SMS service, although data services might change this trend





Source: Analysys Mason model, ANACOM, operator's data

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We obtained population and area statistics for 4261 Portuguese freguesias

- We have divided the Portuguese geography at the freguesia (parish) level
  - this enhances the level of granularity of the data and the model
- We have classified the freguesias into four geotypes based on their population density

Geotype	*Population density (pop/km2)*
Dense urban	> 7400
Urban	> 278, < 7400
Suburban	> 35, < 278
Rural	< 35

- 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 railroads are implicitly included in the above four geotypes

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 on the right:
  - dense urban is characterized as having a high proportion of population in a small area
  - on the opposite, rural is characterized by a small population in a large area
- Traffic is distributed unevenly among geotypes:
  - dense urban and urban areas will likely have a *higher* proportion of traffic than their population proportion
  - suburban and rural areas will likely have a *lower* proportion of traffic than their population proportion
- Different reasons explain why higher density areas carry more traffic in relative terms:
  - easier consumption habits and access to technology in urban areas
  - higher number of medium and big companies in urban areas, which have a high consumption of communication products
  - the fastest networks – e.g. HSPA – are usually first deployed in more dense areas

Comparison area, population and mobile traffic by geotype in Portugal

Concept	*Portugal*
Area	
Dense urban	0.08%
Urban	6.18%
Suburban	33.04%
Rural	60.70%
Population	
Dense urban	8.11%
Urban	54.24%
Suburban	29.82%
Rural	7.83%
Traffic	
Dense urban	13.65%
Urban	57.80%
Suburban	23.28%
Rural	5.27%

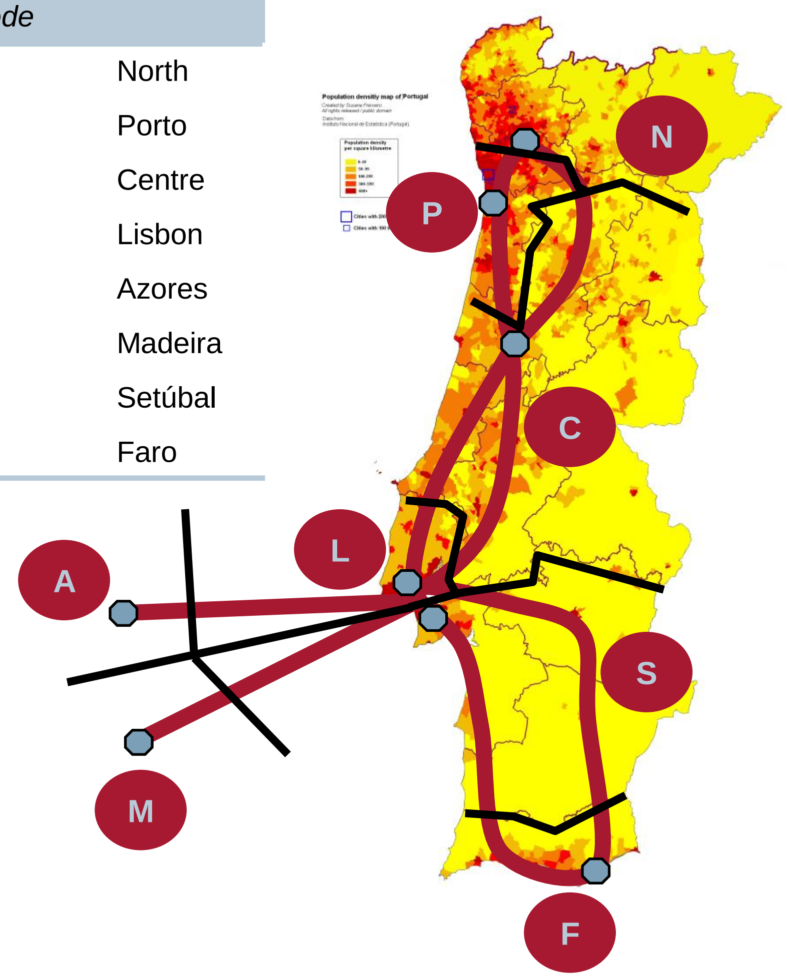
Source: Analysys Mason, MapInfo

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 our 4 switching sites and 8 core transmission sites
- Each of the regions have 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 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	1,100	2.41%
Region M	168	2.36%

Source: Analysys Mason estimation, MapInfo

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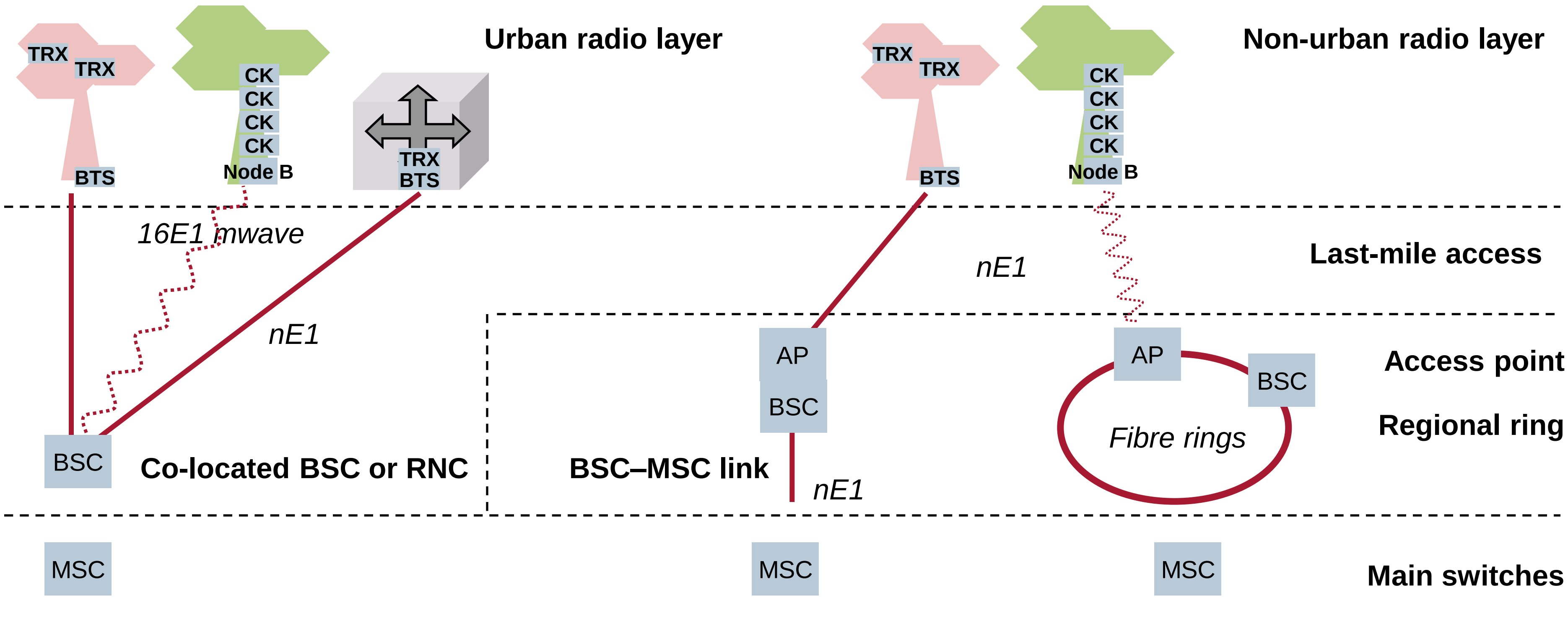
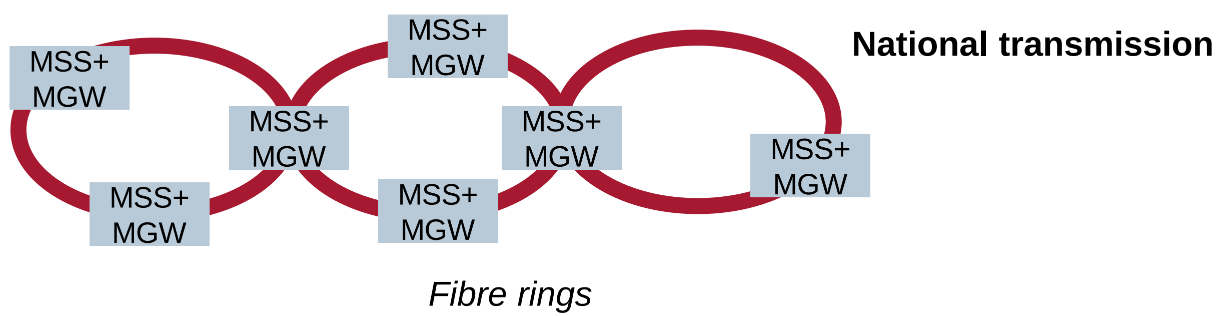
Overview of network architecture



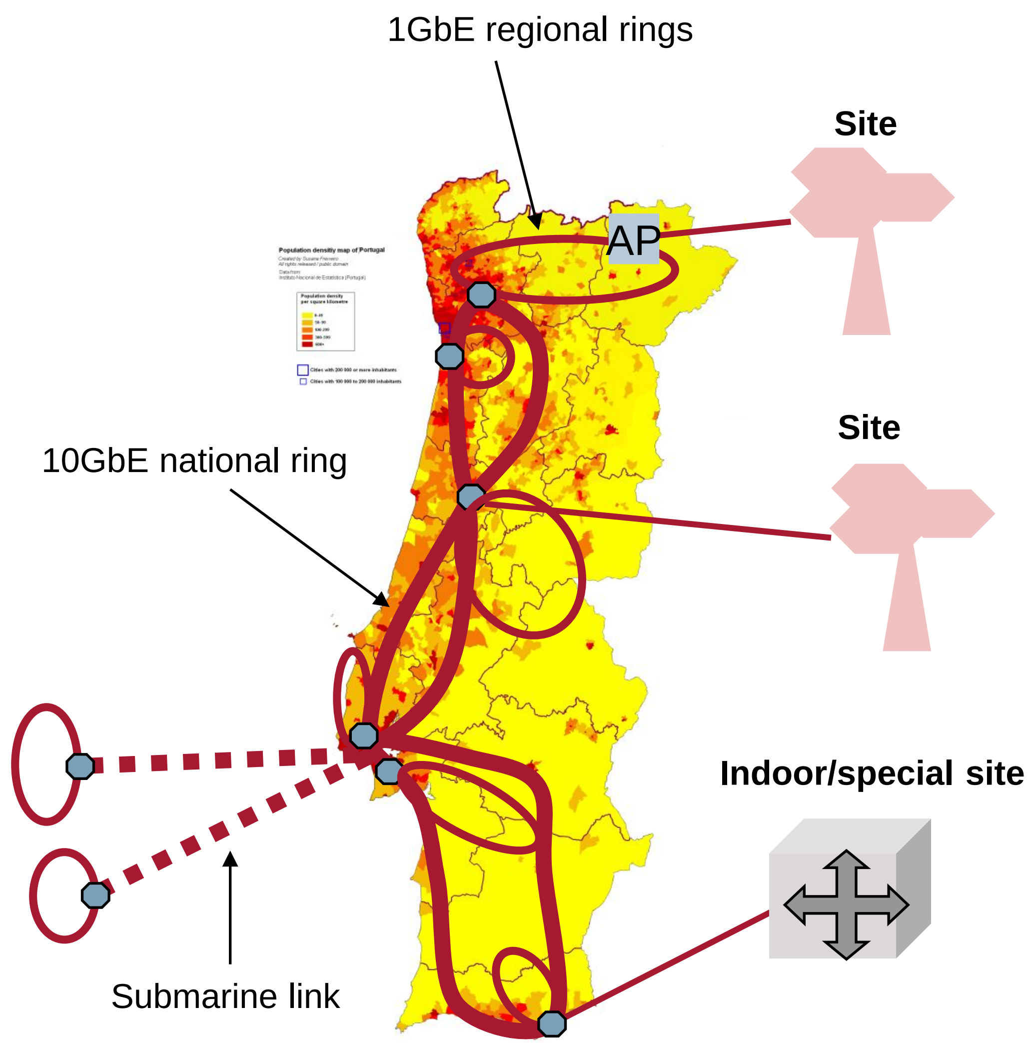
Note: The model has been developed to cope with different options – such as leased lines in the core network, remote BSCs, etc. – which are not systematically used to model the Portuguese hypothetical operator. While we document the full behaviour of the model in this section, we do not explain options that have not been used in the specific case of the Portuguese market.



Source: Analysys Mason

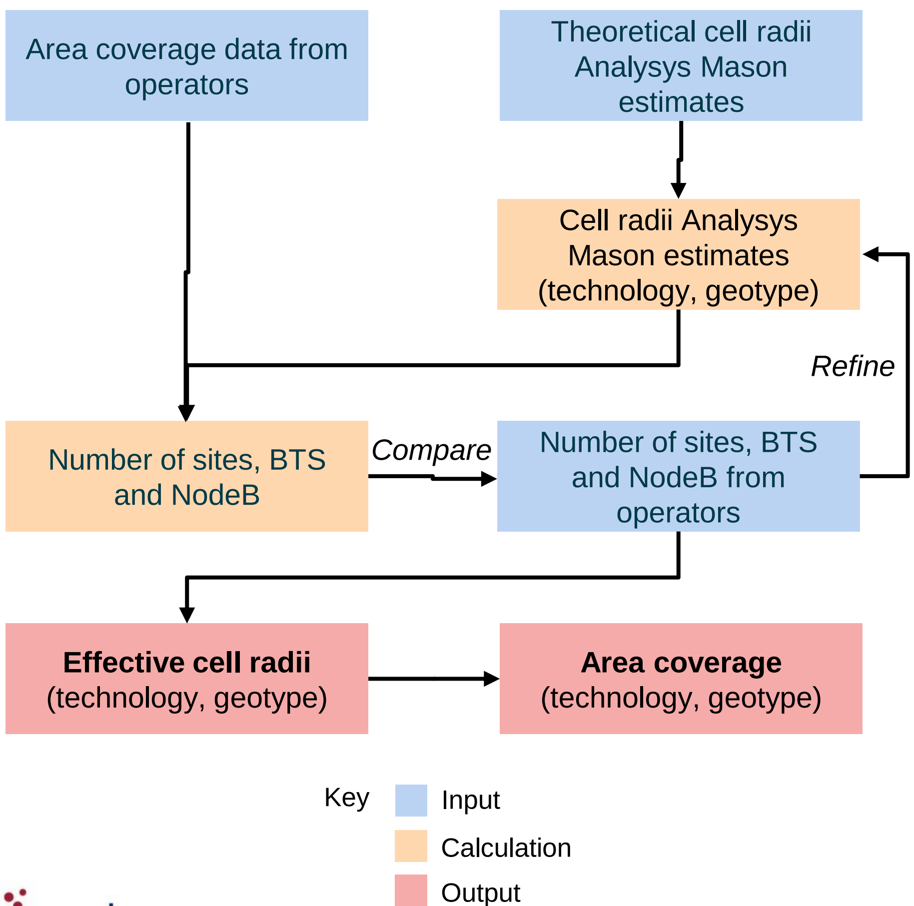
The model deploys an NGN (all-IP) transmission architecture

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



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

Process for calibrating the cell radii and deriving area coverage



- 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 Node B 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 sites locations:
  - effective cell radii are calculated by applying a 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

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 model

Radio network calculations: Theoretical and effective cell radii

- 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 Portugal specificities, and is consistent with radius used in other regulatory models.

Theoretical cell radius	Outdoor	Actual network
Hexagon per site	900MHz	2100MHz
Dense Urban	0.54	0.25
Urban	2.97	1.41
Suburban	4.45	2.12
Rural	6.24	3.00

- 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 surrounding interfere with transmission of radio signals
- Therefore, we have estimated a scorched-node coverage coefficient (SNOCC) as presented in the following table, which is applied to the theoretical cell radius resulting in an effective cell radii used to determine the effective coverage per site:

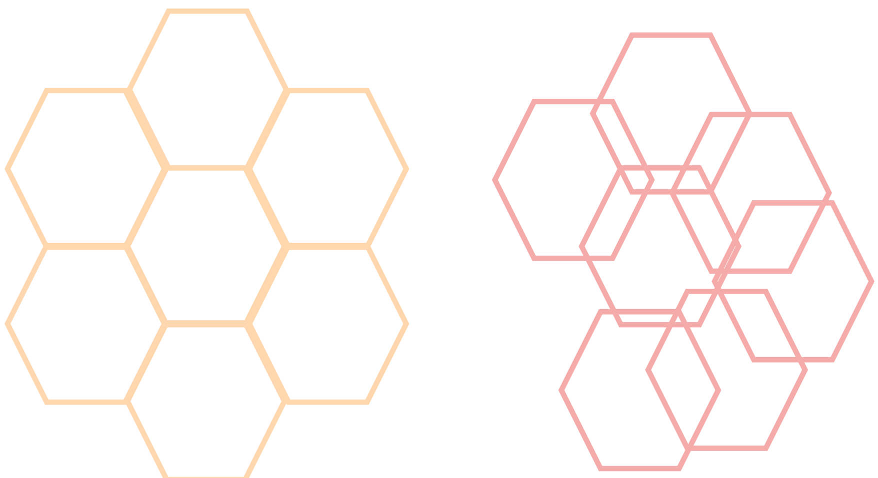
Hypothetical efficient entrant	900MHz	2100MHz
Dense Urban	0.620	1.000
Urban	0.680	1.000
Suburban	0.720	1.000
Rural	0.900	1.000

- The SNOCC is significantly 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, specially in more dense areas where free space– e.g. rooftops – is a scarce resource looked after by many operators
  - it is not necessary to attain perfect 2100MHz overlay coverage when a backdrop 900MHz network is available and co-located sites are predominantly deployed for the 2100MHz overlay

Sheet: NwDes_Inputs, Rows 46–142

Radio network calculations: Application of SNOCC depends on frequencies used for coverage

Coverage models



Optimal locations of BTS

Sub-optimal locations of BTS occurring in reality

- Scorched-node coverage coefficients (SNOCC) are applied to:
  - 900MHz outdoor coverage
  - but not 1800MHz overlays which we model as being deployed to serve high traffic areas
  - nor 2100MHz, that are mainly collocated with 2G coverage sites in Portugal, and thus have an increased effective coverage

Radio network calculations: UMTS network quality

- The UMTS cell radii can be specified according to a number of different quality criteria
- In order to offer a HSDPA service, we assume that operators are deploying a typical "data" quality network – to provide as a minimum, a 64kbit/s uplink path, or sufficient signal strength for HSUPA (if activated):

2100MHz UMTS site radius

Hexagon per site

Based on specific loading and service level criteria

Inputs based on 50% assumed loading	2100MHz
Dense Urban	0.26
Urban	1.43
Suburban	2.14
Rural	3.00

- We assume that UMTS cell radii are planned to accommodate between 50% and 60% radio load depending on geotype:
  - so that cell breathing does not reduce coverage at the edge of cells in the peak hour

Note: the radius in this slide varies slightly to that in slide 36 due to a different cell loading

Sheet: NwDes_Inputs, Rows 48–87

Radio network calculations: UMTS cell breathing

- In order to calculate the effect of cell breathing in the model, we have assigned a traffic load per geotype

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

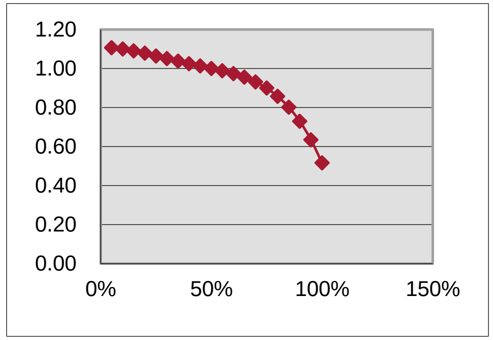
- We estimate the effect of cell breathing in a network without termination traffic as a reduction of 7.5% in traffic load of the network with all traffic considered
  - this corresponds roughly to the proportion of termination traffic vs. (on-net traffic + termination traffic + R99 data in BHE + allowance for HSPA data in the shared carrier)

Geotype	*Traffic load*	*Geotype*	*Traffic load*
Dense urban	55%	Suburban	50%
Urban	50%	Rural	45%

- We have estimated an approximate parameterization 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 will take into account the difference between the cell loading factors between the network *with* and *without* 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

Sheet: NwDes_Inputs, Rows 48–87

Radio network: site deployment characteristics

- The model also contains inputs for the following aspects of radio site deployment:
  - sectorisation of GSM sites – based on actual operators' data
  - sectorisation of UMTS sites – based on actual operators' data
  - primary and secondary spectrum:
    - the modelled operator starts its network deployment with 900MHz frequencies
  - between 95% and 100% of GSM sites depending on geotype are assumed to be suitable for adding a UMTS Node B, which is broadly in line with operators' data
  - the proportion of radio sites which are deployed on an operators' own site (less than 4% based on operators' data), compared to a third-party site. This low % input highlights the large amount of passive site sharing which exists in the actual networks

Average sectorisation per site

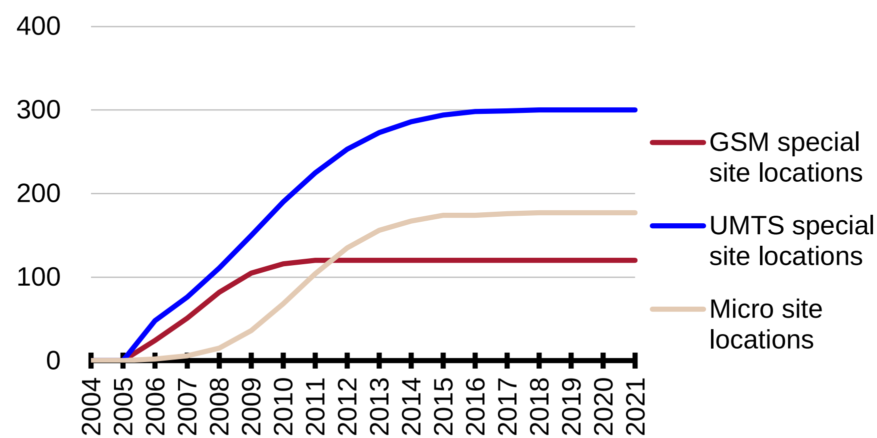
	Dense urban	*Urban*	*Suburban*	*Rural*	*Micro/Indoor*
900MHz	2.57	2.57	2.57	2.57	2.00
1800MHz	2.70	2.70	2.70	2.70	2.00
2100MHz	2.73	2.73	2.73	2.73	2.00

Sheet: NwDes_Inputs, Rows 190–253, 6–43, 265–272, 415–424

Radio network: micro and special sites

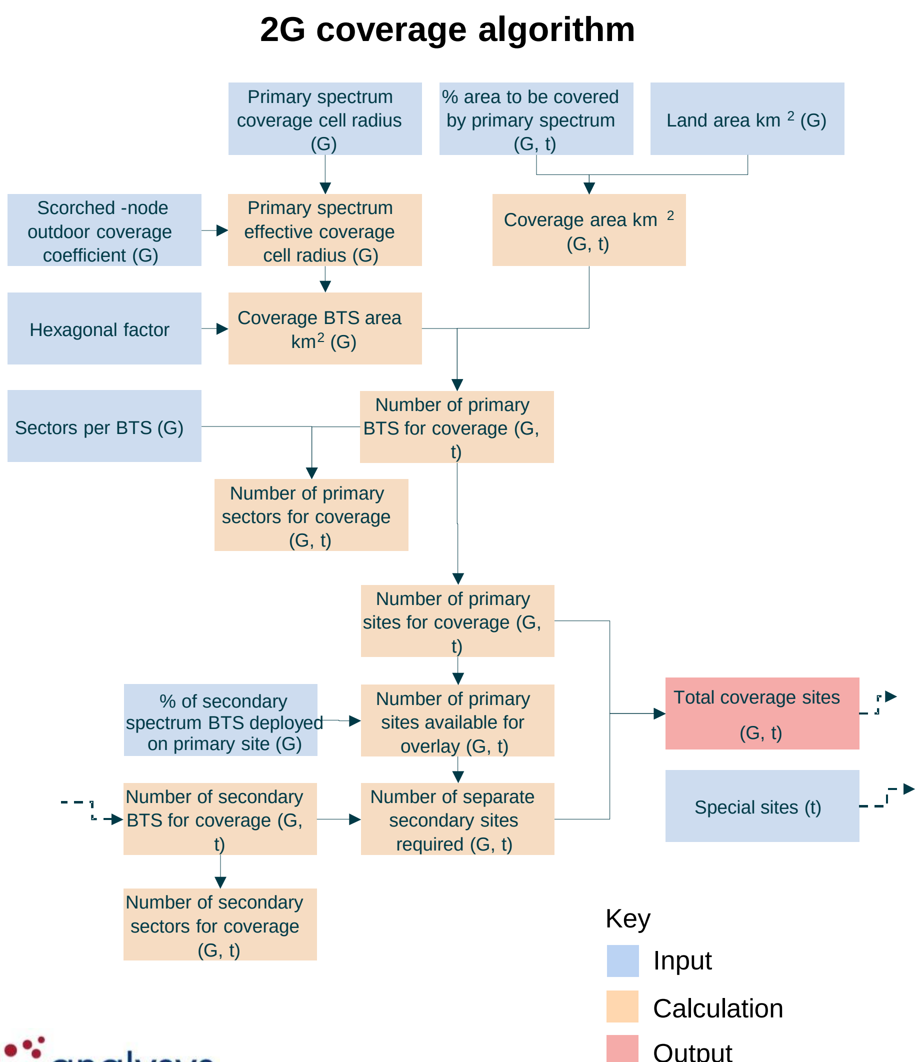
- In addition to outdoor, sectorised macro-sites, we include two types of "indoor" site:
  - **special sites (including distributed antennae)** used to extend coverage in hard-to-reach locations
  - **micro sites** used to provide additional capacity in heavily used locations
- The number of special sites is calibrated against data provided by operators, which has been projected into future periods
- Micro sites for capacity locations convey an assumed proportion of traffic (approx. 5% for GSM and 7% for UMTS) based on operators' data

Evolution of the number of micro and special site locations



Sheet: NwDes_Inputs, Rows 376–412

Radio network: 2G sites deployed for coverage



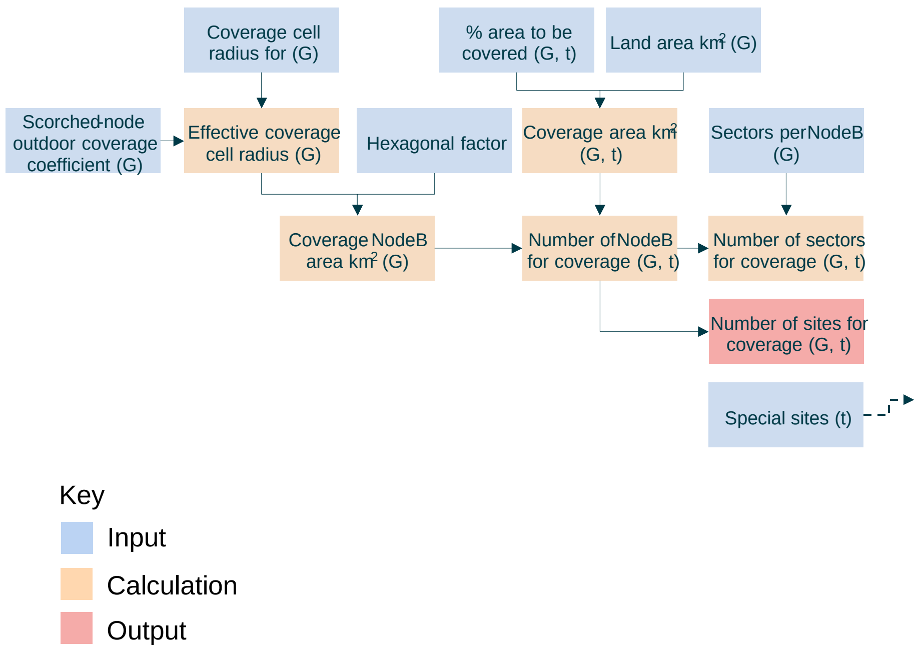
- The coverage networks for each frequency band (primary GSM, secondary GSM) are calculated separately within the model
- The coverage sites for the primary spectrum are calculated first:
  - the area covered by a BTS in a particular geotype is calculated using the effective BTS radius
  - total area 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

Sheet: Nw_Des, Rows 10–122

Note: G indicates varying with geotype, and t varying with time

Radio network: 3G sites deployed for coverage

3G coverage algorithm



- The same methodology is used to derive the initial number of coverage NodeBs required for UMTS
- The model calculates site sharing between GSM and UMTS networks, and any new standalone 3G sites required:
  - the proportion of sites which are available for 3G upgrade is specified by an input for each operator
  - this percentage is multiplied by the number of 2G sites to determine the number of sites available for upgrade
  - 3G sites are then deployed preferentially on these sites first, and thereafter on new, standalone 3G sites
- Special indoor sites are modelled as explicit inputs using operator data

Sheet: Nw_Des, Rows 793-814

Note: G indicates varying with geotype, and t varying with time

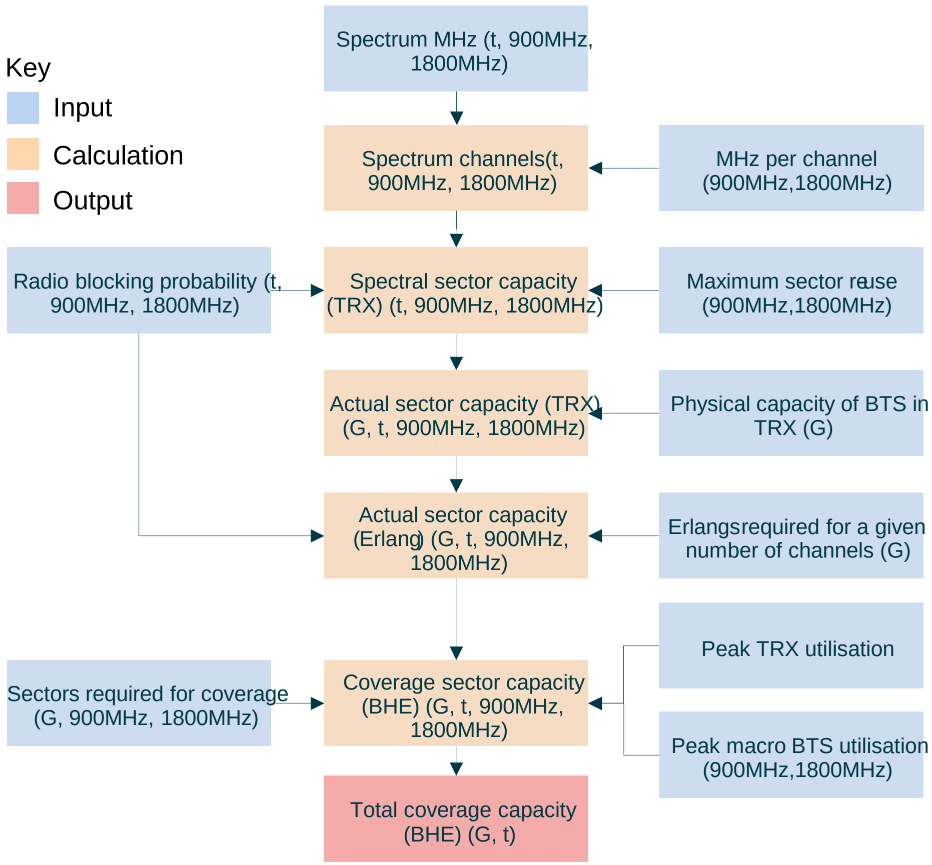
Radio network: GSM capacity calculations

- Further inputs to the radio network bottom-up algorithm include:
  - blocking probability 1%, based on operators' data
  - amount of paired spectrum (8 MHz in the 900Mhz and 6 MHz in the 1800MHz spectrum band, as indicated by ANACOM)
  - maximum reuse factor of 12 (sectors), based on operators' data and Analysys Mason estimates
  - minimum of 1 and maximum of 6 TRX per sector, based on operators' data and Analysys Mason estimates
  - 1.5 reserved GPRS or EDGE channels per sector, based on operators' data
  - 0.7 signalling channels per TRX, based on operators' data and Analysys Mason estimates
  - GPRS/EDGE radio throughput rate of 64kbits/s
- 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

Sheet: NwDes_Inputs, Rows 146, 6–32, 287-308

Radio network: capacity provided by 2G coverage sites

Calculation of the BHE capacity provided by the coverage network



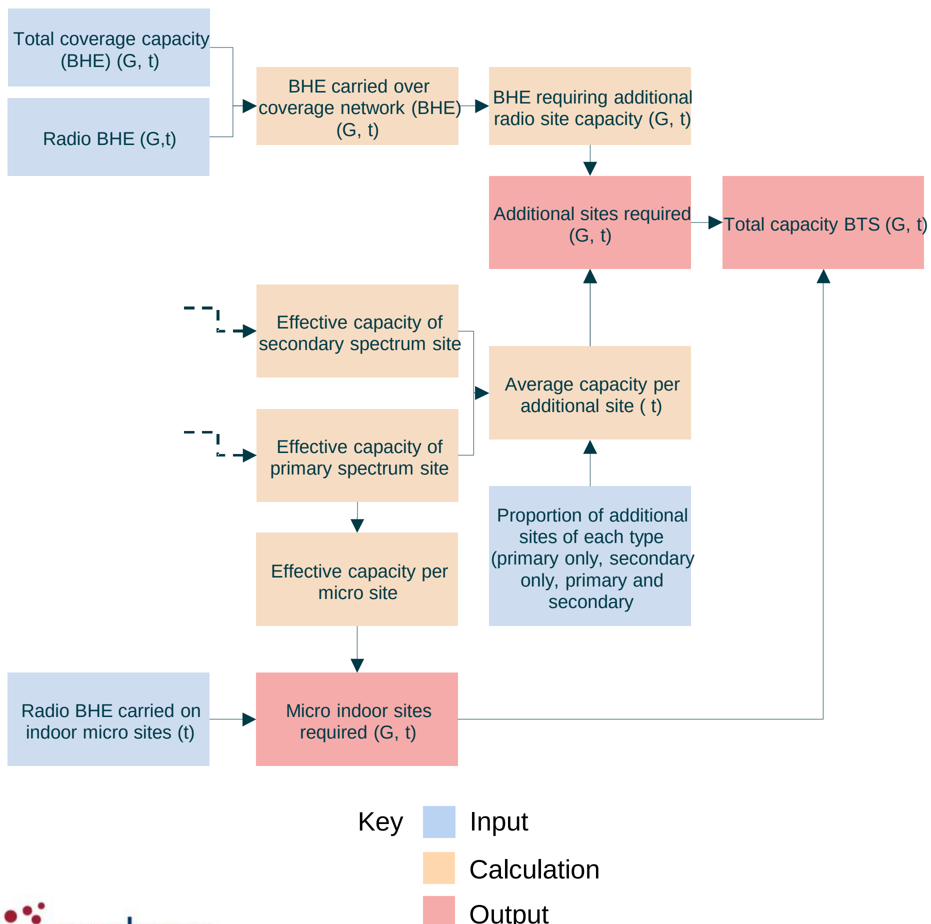
Sheet: Nw_Des, Rows 161–196

- 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 is be *on average* **less than 100%** loaded for the network busy hour
  - we also exclude signalling and reserved GPRS channels from the Erlang capacity

Note: G indicates varying with geotype, and t varying with time

Radio network: additional 2G sites deployed for capacity

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



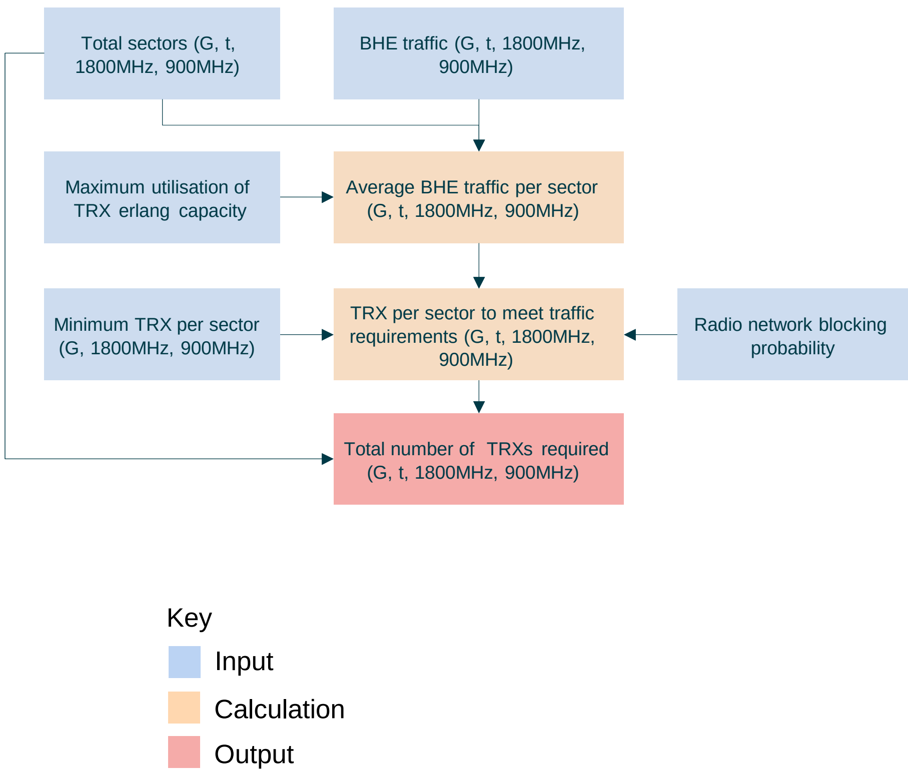
- Additional sites required are calculated to fulfil capacity requirements after the calculation of the capacity of the coverage networks
- Three types of GSM sites are dimensioned according to the spectrum employed: primary-only sites, secondary-only sites and dual sites
  - we currently assume that 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

Sheet: Nw_Des, Rows 198–233

Note: G indicates varying with geotype, and t varying with time

Radio network: TRX requirements

Transceiver deployment



- The number of TRXs required in each sector (on average, by geotype) to meet the demand is calculated:
  - taking into consideration the maximum TRX utilisation percentage
  - converting the Erlang demand per sector into a channel requirement using the Erlang-B table and the assumed blocking probability
  - excluding signalling and GPRS channel reservations
  - assuming a minimum number of 1 TRXs per sector
- The total number of TRXs required is obtained by multiplying the number of sectors and the number of TRXs per sector

Sheet: Nw_Des, Rows 387–527

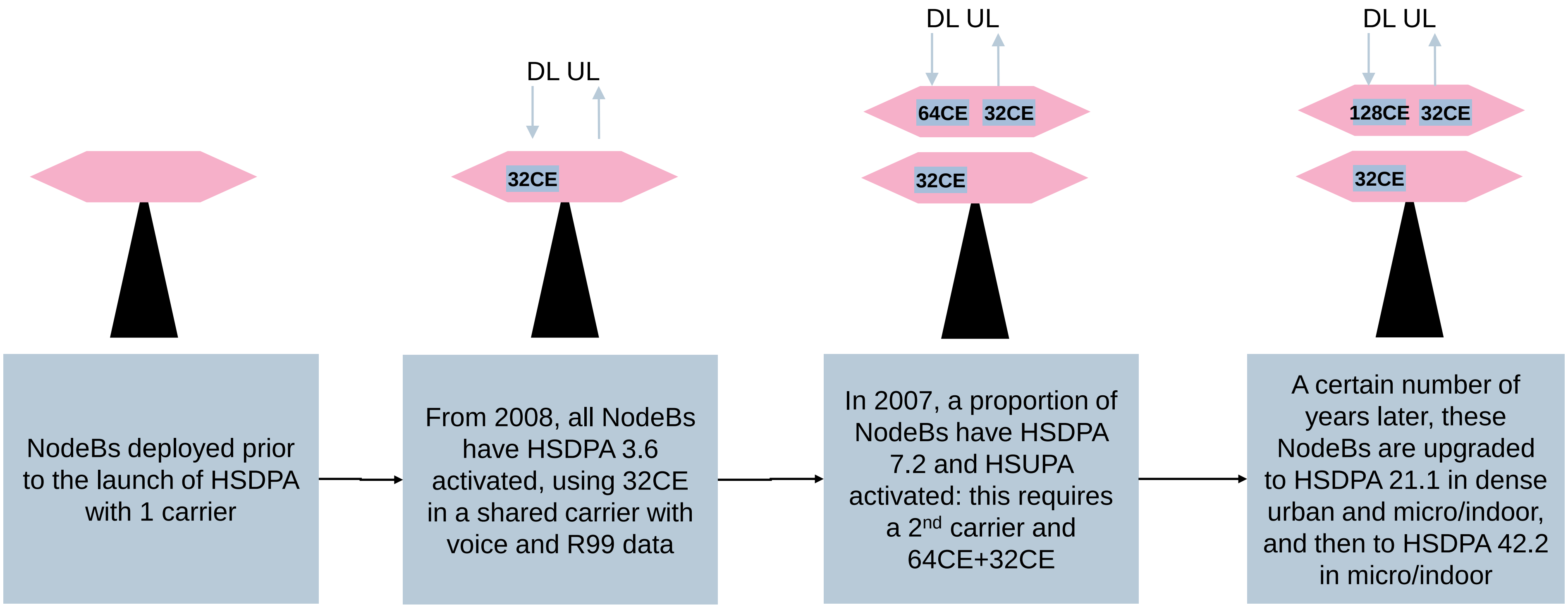
Note: G indicates varying with geotype, and t varying with time

Radio network: UMTS capacity calculations

- Inputs to the UMTS radio network bottom-up algorithm include:
  - number of paired 5MHz carriers (4 for the Portuguese operators, as indicated by ANACOM)
  - **voice plus low-speed data** traffic dimensioning of channel elements (CE)
    - blocking probability 1%, based on operators' data
    - additional soft-handover Erlangs of 20%, based on Analysys Mason estimates
    - max. of 112 CE per Node B per carrier for R99 traffic, based on operators' data and Analysys Mason estimates
    - Min. deployment of CE per Node B (approx. 48 CE per Node B), based on operators' data
    - 1 carrier for voice, SMS and data (up to HSDPA7.2), based on operators' data and Analysys Mason estimates
    - A channel kit size of 16, based on Analysys Mason estimates
- Additional CE for high-speed data services are also included. We model the following options:
  - HSDPA 1.8 — 32 CE at the Node B — 5+5+5 QPSK
  - HSDPA 3.6 — 32 CE at the Node B — 5+5+5 16QAM
  - HSDPA 7.2 — 64 CE at the Node B — 10+10+10 16QAM
  - HSDPA 21.1 — 128 CE at the Node B — 15+15+15 64 QAM
  - HSDPA 42.2 — 128 CE at the Node B — 15+15+15 64 QAM
  - HSUPA 1.5 — 32 CE at the Node B
- HSDPA or HSUPA service levels are activated, **by year, by geotype** based on operators' deployments:
  - we do not perform a high-speed data dimensioning calculation, but the model does include some checks to show whether the HSDPA volume forecast appears to be exceeding the capabilities of the HSDPA option (in each geotype)

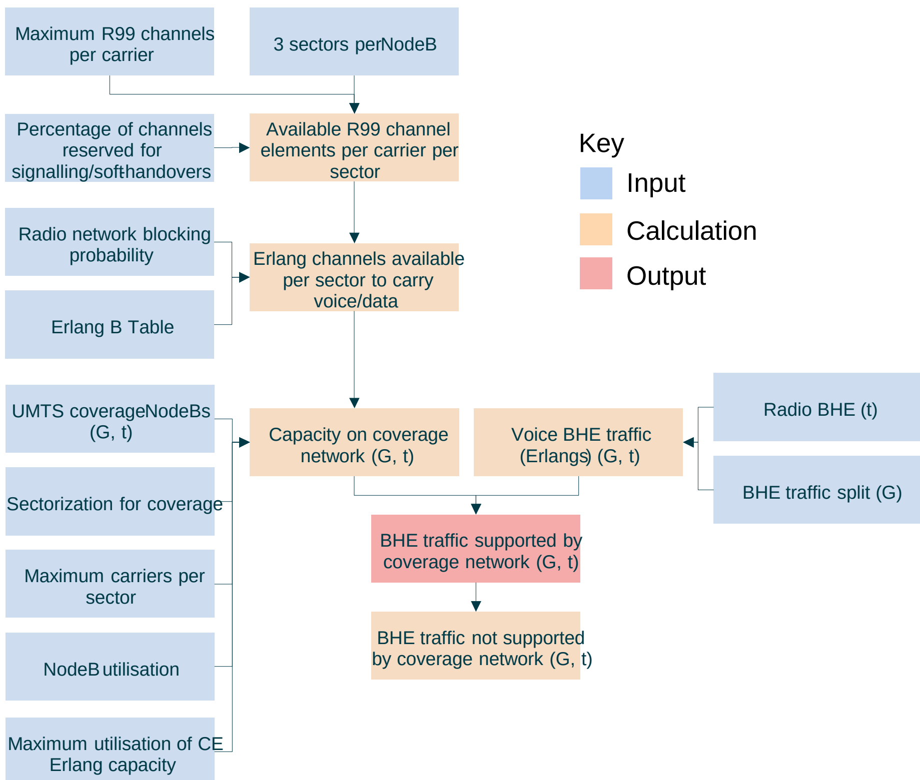
Sheet: NwDes_Inputs, Rows 6–14, 146, 374, 314–321, 325–371

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



Radio network: capacity provided by 3G coverage sites

Calculation of the BHE capacity provided by the UMTS coverage network



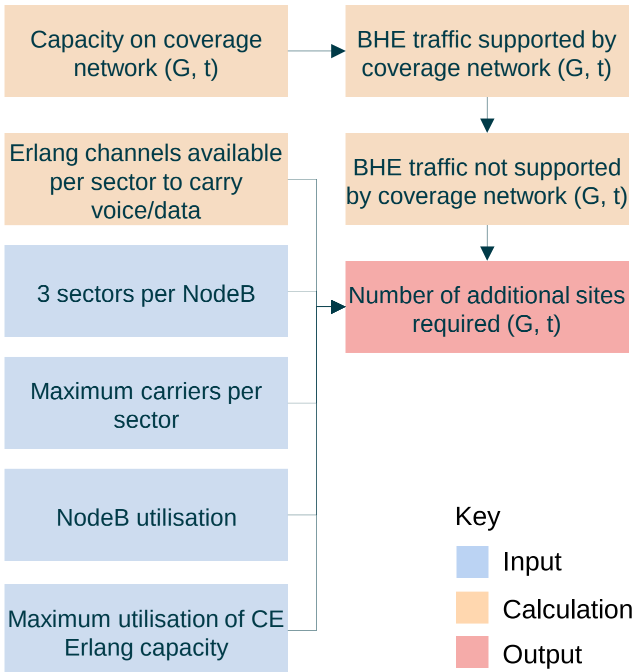
- Calculating the capacity provided by the 3G coverage sites is the first step in the calculation of the capacity requirements
- The model assumes a maximum number of Release 99 channel elements per Node B:
  - the available channel elements per carrier are *pooled* between the three sectors of the Node B 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:
  - a deployment of carriers per sector, subject to the average utilisation factor less than 100%, is assumed on all coverage sites
  - in calculating the effective capacity of each sector in the coverage network, allowance is made for the fact that NodeBs and channel elements is in fact less than 100% utilised on average during the network busy hour
- Special indoor sites are assumed to provide additional capacity as if they were an omni-sector site

Sheet: Nw_Des, Rows 849-870

Note: G indicates varying with geotype, and t varying with time

Radio network: additional 3G sites deployed for capacity

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



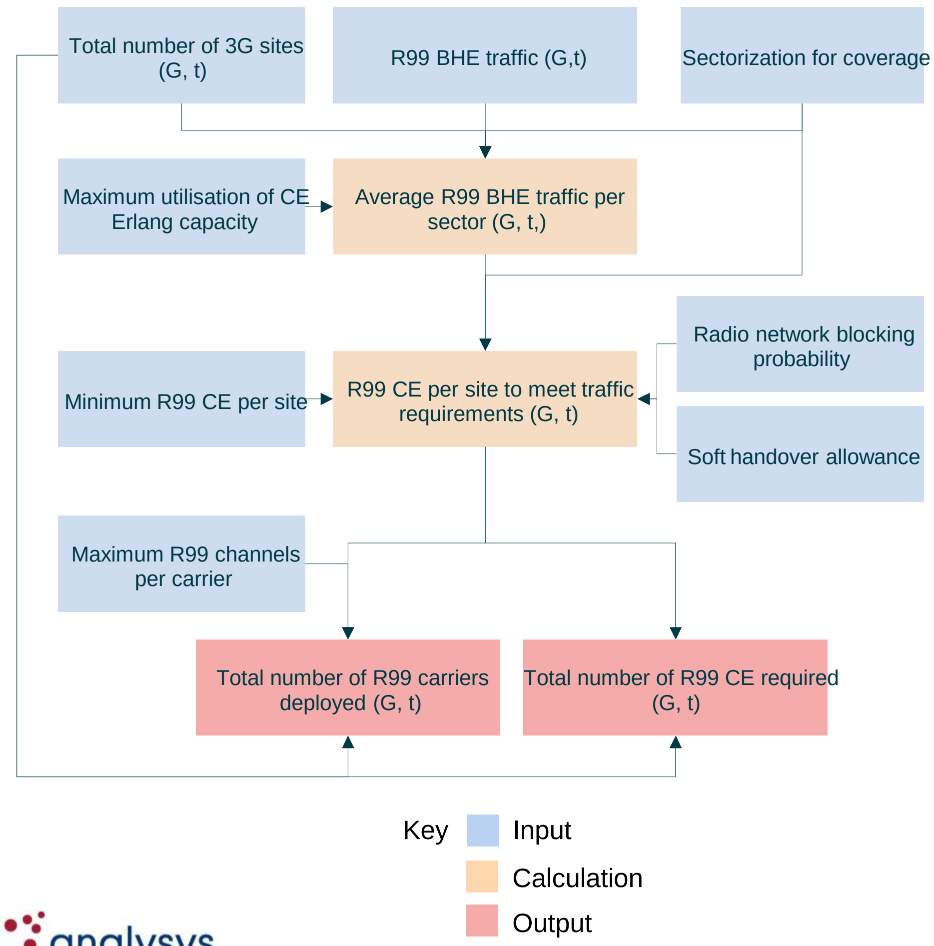
- Additional sites required are calculated to fulfil capacity requirements after the calculation of the capacity of the coverage network
  - BHE that cannot be accommodated by the coverage network by geotype is calculated
  - the calculation of the capacity of the additional sites assumes the deployment of carriers per sector subject to the average utilisation factor
- Micro indoor 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 up to 50%-60% load for cell breathing purposes) therefore additional sites for capacity are only calculated in extremely high traffic situations

Sheet: Nw_Des, Rows 872-877

Note: G indicates varying with geotype, and t varying with time

Radio network: channel element and carrier requirements

R99 channel kit and carrier dimensioning



Sheet: Nw_Des, Rows 917–1151

- 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 channel elements 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 1.8, etc.
  - 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 CEs (R99, HSDPA, HSUPA)

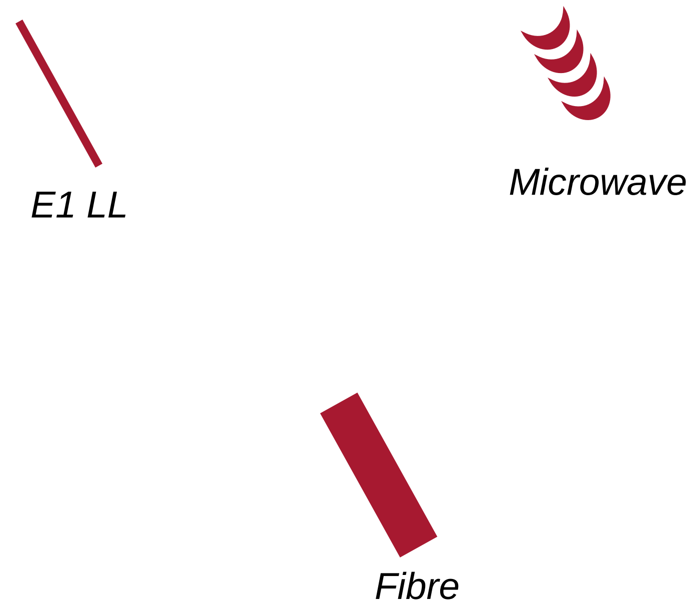
Note: G indicates varying with geotype, and t varying with time

Transmission

- We have split the transmission network into three parts:
  - each part can be built using different transmission technologies
- **Last-mile access (LMA)** network based on leased lines, microwave or fibre:
  - used to collect traffic from BTS/Node B to nearest BSC/RNC or transmission access point
- **Regional backbones** based on self-provided microwave trees or fibre rings:
  - connect suburban and rural geotypes with the seven cities of the urban geotype
  - used to carry backhaul transit i.e. traffic between BSC/RNC and transmission access point
- **National backbone** based on self-provided fibre ring:
  - connects the seven cities of the urban geotype
  - is used to carry inter-switch, interconnect and voicemail traffic
  - can be set to carry BSC-MSC and PCU-SGSN traffic in the situation where a city may not have an MSC or a SGSN

Last-mile access

- Traditional last-mile access:
  - 120 circuits per E1
  - 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 Mbit/s
- Provided by:
  - leased E1s (n per site)
  - microwave links (up to 16 E1)
  - fibre link (n E1s)
- Additional rules:
  - indoor sites always linked with leased E1



Proportions for last-mile access: Distribution of technologies per geotype and 2G/3G

2G last mile technologies	*leased lines*	*microwave*	*fibre*
Dense Urban	15%	10%	75%
Urban	20%	35%	45%
Suburban	20%	60%	20%
Rural	28%	70%	2%
Micro/Indoor	100%	0%	0%

3G last mile technologies	*leased lines*	*microwave*	*fibre*
Dense Urban	15%	10%	75%
Urban	20%	35%	45%
Suburban	20%	60%	20%
Rural	28%	70%	2%
Micro/Indoor	100%	0%	0%

- Last-mile distribution of technologies per geotype have been calculated based on information provided by operators' during the data request and further interviews, and Analysys Mason estimates

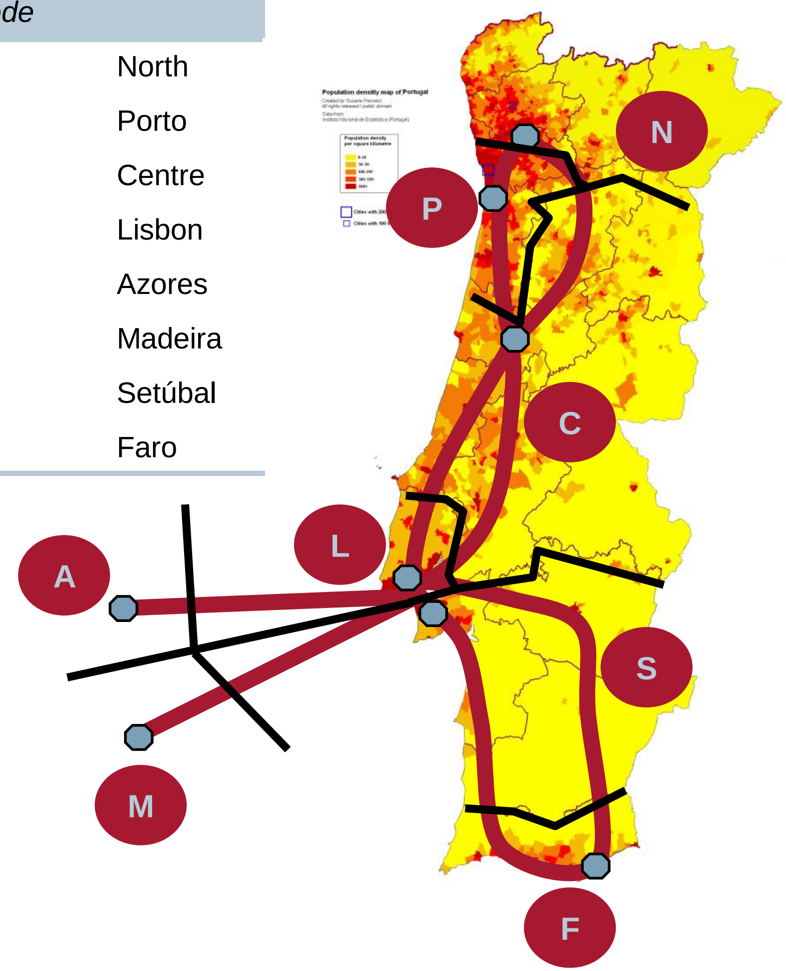
Source: Analysys Mason model, operator's data

National backbone

- The national backbone is self-provided, and is based on fibre and STM-x connections
- It is composed of a network of fibre and transmission sites:
  - the national backbone connects 8 core transmission sites
  - two submarine cable connections are included to account for links between Lisbon and Madeira and Azores
- The assumed lengths of the national backbone are 1472km for the full national backbone, not including the submarine links, based on Analysys Mason estimations

Regional networks for Portugal

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



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/MSC co-located site)
- A proportion of sites are 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 less than 50% - i.e. provision of diverse transmission capacity

Regional backbones – distribution of traffic

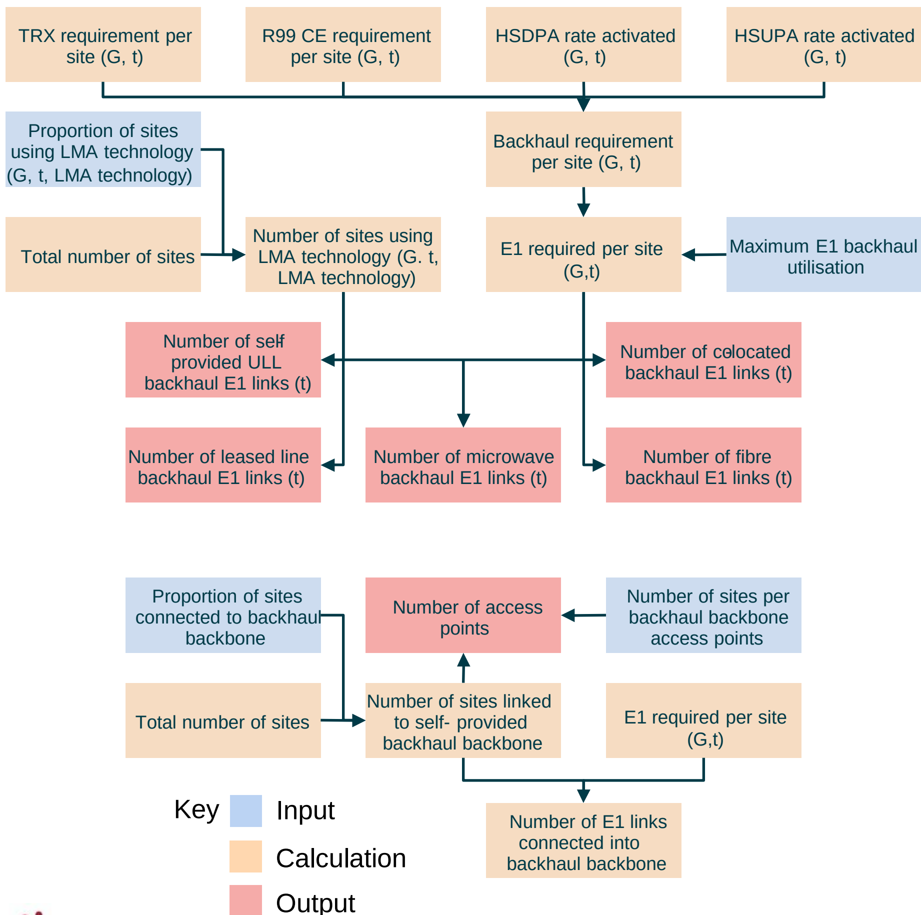
- The length of fibre has been estimated based on road distances between the main points for each region
- Traffic is distributed among the different links based on the following estimates:
  - fibre LMA share of traffic is calculated based on population per geotype per region and a probability of fibre deployment per geotype
  - BSC/RNC-MSC 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-MSC 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	1,100	2.62%	2.41%	2.41%	4.07%
Region Madeira	168	1.94%	2.36%	2.36%	1.31%

Source: MapInfo, Analysys Mason estimations

Dimensioning the backhaul network involves a three-step process…

Backhaul calculation



- First, the backhaul capacity required by site is calculated:
  - TRXs and R99 CEs drive the number of voice and GPRS/EDGE channels requiring backhaul
  - HSDPA/HSUPA backhaul need is directly derived from the active headline rate e.g. 7.2Mbit/s
- 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) is different in each 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 are assumed to require backhaul transit on the regional backbones

Sheet: Nw_Des, Rows 529-673, 1153-1318

Note: G indicates varying with geotype, and t varying with time

…as does dimensioning the 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 and RNC–MSC 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 a 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 Azores and Madeira
  - the number of access points is calculated (directly from a model input for the national backbones 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

Sheet: Nw_Des, Rows 1586–1887

BSCs, PCUs and RNCs

- 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)
    - we have assumed in the model that there are no remote BSCs deployed by the hypothetical efficient operator
- 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 **Node B facing E1 ports** required:
  - all RNCs are assumed to be co-located with main switches
  - RNCs can then be connected to MSCs with either E1 or STM1 ports

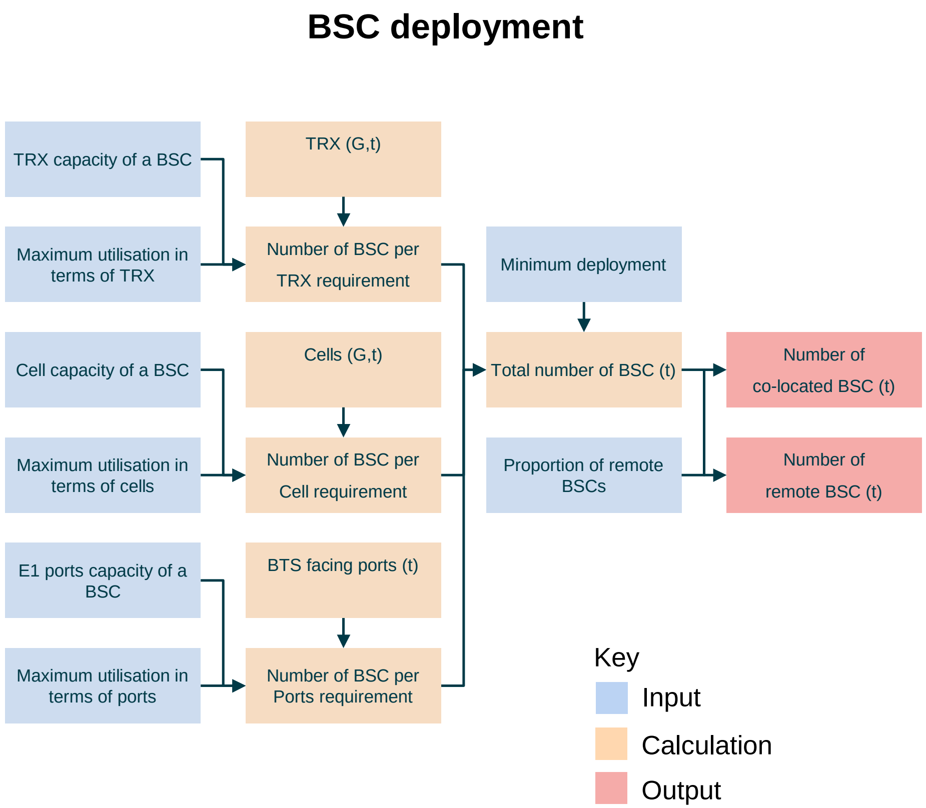
Sheet: Nw_Des, Rows 1891–1972

Capacity measures for BSCs, PCUs and RNCs

Hypothetical efficient operator inputs

Item	*Capacity measures*	*Minimum deployment*	*Source*
BSC capacity in TRX	2000	2	Analysys Mason estimates based on operators’ data
BSC capacity in E1 incoming ports	250		Analysys Mason estimates based on operators’ data
BSC capacity in cells	1000		Operators’ data
PCU per BSC	3		Analysys Mason estimates
RNC capacity in Mbit/s	1600	8	Analysys Mason estimations based on operators’ data
RNC capacity in E1 incoming ports	1200		Operators’ data

Four requirements are used to drive the number of BSC units

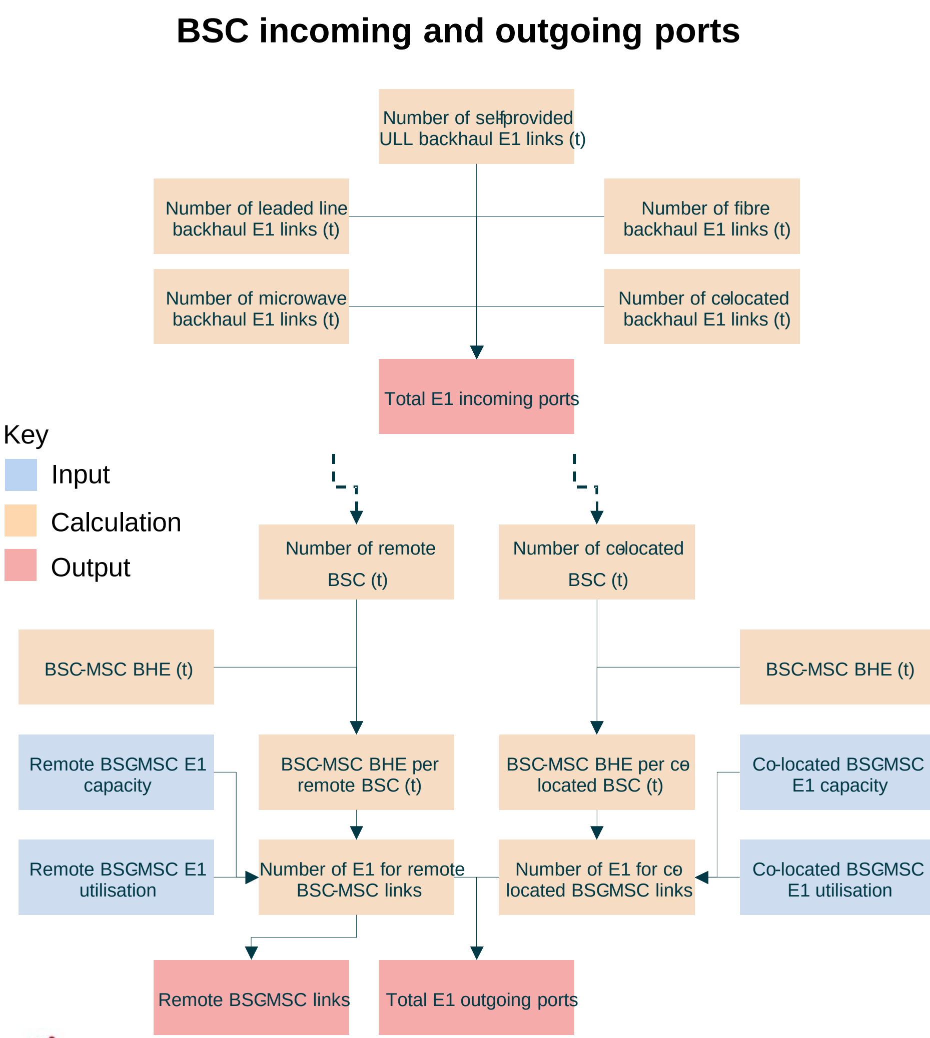


- BSC unit deployment is driven by four requirements:
  - maximum number of TRXs controlled, assuming a maximum utilisation
  - maximum number of cells controlled, assuming a maximum utilisation
  - maximum number of E1 ports connected, assuming a maximum utilisation
  - minimum number of two BSCs deployed 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)
  - this proportion is set to zero for the modelled operator by default and is assumed to be constant over time

Sheet: Nw_Des, Rows 676–729

Note: G indicates varying with geotype, and t varying with time

BSC incoming and outgoing ports and outgoing transmission requirements are dimensioned



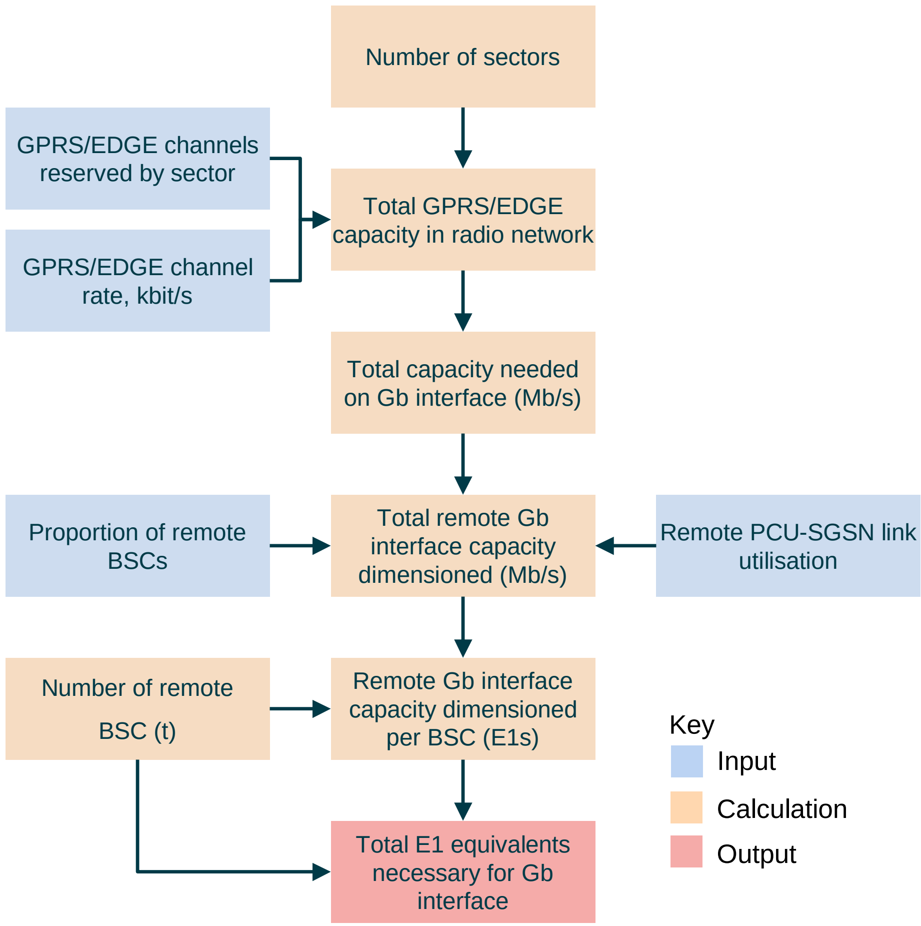
- BSC incoming ports (ports facing BTS) are directly derived from the number of backhaul E1 links, all technologies included
- Remote BSC–MSC traffic is first calculated as a proportion of total BSC–MSC traffic (based on the proportion of remote BSCs) and then dimensioned taking into account the capacity 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 STM1 equivalents depending on the capacity needed

Sheet: Nw_Des, Rows 731–739, 757-787

Note: G indicates varying with geotype, and t varying with time

PCU-SGSN links are dimensioned and added to the BSC-MSC links

PCU-SGSN links (Gb interface)



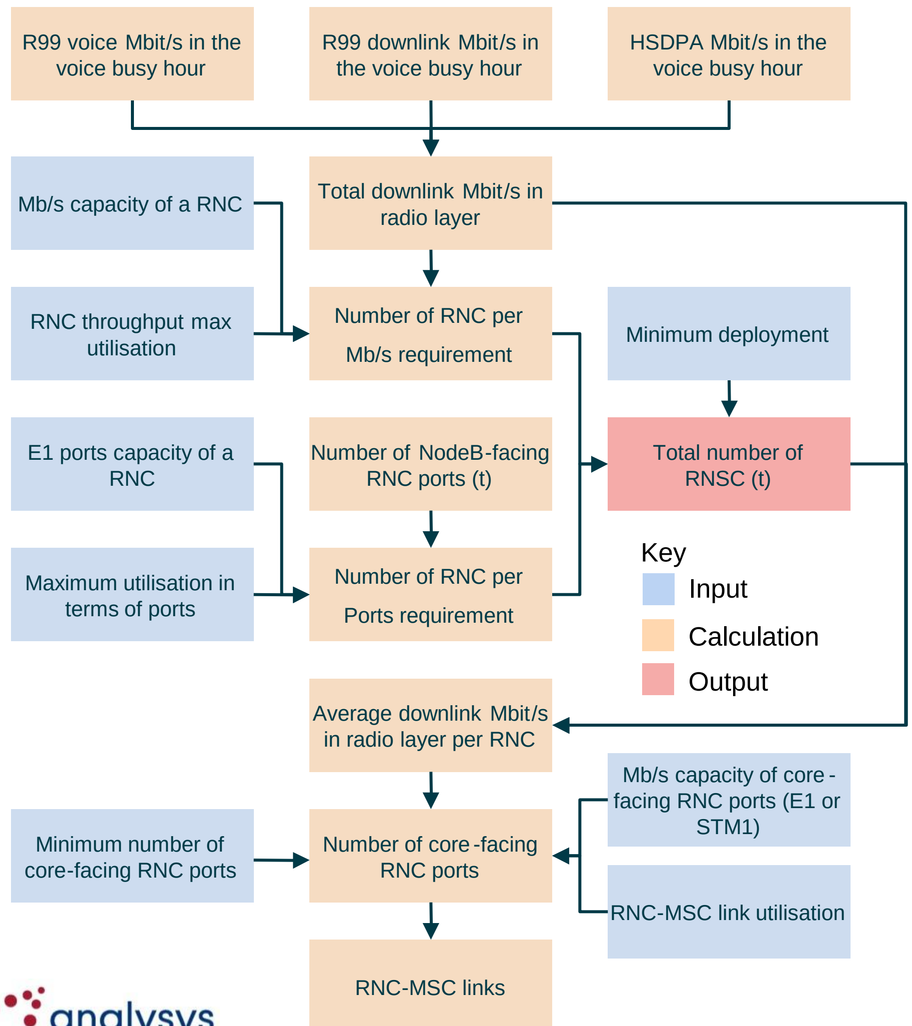
- First, the Gb interface (PCU-SGSN links) is dimensioned in order not to be the network bottleneck
  - capacity needed on the Gb interface is assumed to be equal to the capacity that would be needed if all GPRS/EDGE channels reserved were simultaneously active on all sectors in the network
- Second, 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 equivalent taking into account the utilisation of remote PCU-SGSN links
- Finally Gb links are added to the BSC-MSC links for the purpose of expressing either in E1 or STM1 equivalents depending on the capacity needed

Sheet: Nw_Des, Rows 744–755

Note: G indicates varying with geotype, and t varying with time

Three requirements are used to drive the number of RNC units

RNC deployment and port dimensioning



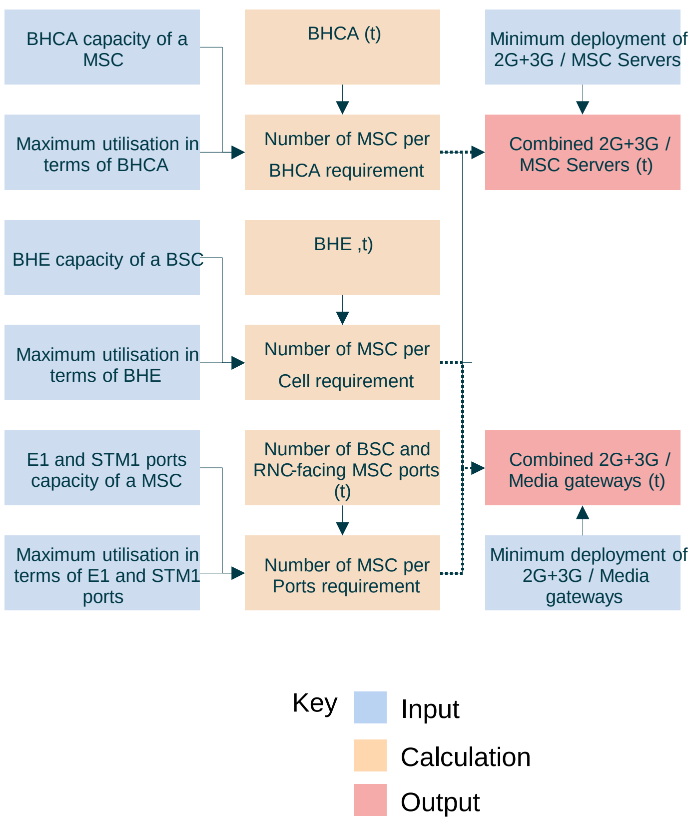
Sheet: Nw_Des, Rows 1320–1368

- RNC units 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 STM1 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

Note: G indicates varying with geotype, and t varying with time

Four requirements are used to drive the number of MSC units

MSC deployment



- 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

Sheet: Nw_Des, Rows 1424–1472

Note: G indicates varying with geotype, and t varying with time

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 interconnect 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 MSC (not shown here)

# MSC	0
# MSC locations	0
# MSC per location	0.0
# Inter-switch logical routes	0
# Inter-switch logical routes (remote)	0
# Inter-switch logical routes (coloc)	0
# POIs	0
# Interconnect logical routes	0
# VMS sites	0
# VMS logical routes	0
# VMS logical routes (remote)	0
% incoming traffic on inter-switch logical routes: INCLUDES inter-MSC	0%
% outgoing traffic on inter-switch logical routes: INCLUDES inter-MSC	0%
% on-net traffic on inter-switch logical routes: INCLUDES inter-MSC	0%
% GPRS traffic on inter-switch logical routes: INCLUDES inter-MSC	0%
% international traffic on inter-switch logical routes: INCLUDES inter-M	0%

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, how many routes of different types, 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

Sheet: Nw_Des, Rows 1474–1505

MSC incoming/outgoing ports and outgoing transmission requirements are dimensioned

- The combined MSC servers have a capacity of 300,000 BHCA for MSCS, or 25 STM1 for MGW (from Analysys Mason estimates based on operators' 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 – interconnect 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 STM1 equivalents
- 25% additional MGWs has been taken into account for redundancy and/or resiliency

Sheet: Nw_Des, Rows 1507–1584

A number of other network elements are modelled using simple drivers of deployment

Item	*Deployment rule*
SMSC HW	BH SMS/s
SMSC SW	BH SMS/s
MMSC	BH MMS/s
GGSN	PDP contexts (calculated from a proportion of the subscriber base)
SGSN	SAU (calculated from a proportion of the subscriber base)
VMS	Subscribers
HLR, EIR, AUC	Subscribers
VAS, WAP, IN	Subscribers
Wholesale billing	CDRs per day
NMS	Per “functional unit” of the network: a NMS sub-system is deployed for each major unit of the network (e.g. 2G radio, 3G radio, LL, Mwave, MSC, backup, etc.)

Sheet: Nw_Des, Rows 1891–1972

Capacity measures for network servers

Hypothetical efficient operator inputs

Item	*Capacity measures*	*Minimum deployment*	*Source*
SMSC HW	4500 BH SMS/s	2	Operators' data
SMSC SW	1500 BH SMS/s	2	Operators' data
MMSC	50 BH MMS/s	1	Operators' data
GGSN	675 000 PDP contexts	1	Operators' data
SGSN	4 000 000 SAU	1	Operators' data
VMS	2 000 000 subscribers	2	Operators' data
HLR, EIR, AUC	6 000 000 subscribers	2	Operators' data
VAS, WAP, IN	2 000 000 subscribers	1	Analysys Mason estimates
Wholesale billing	12 000 000 CDRs per day	1	Analysys Mason estimates

Sheet: NwDes_Inputs, Rows 801–880

Spectrum inputs must be set in the model

GSM	*UMTS*

• The modelled operator has both 900MHz and 1800MHz spectrum in the same quantities as existing mobile operators in the Portuguese market
  ◗ 8MHz of 900MHz spectrum
  ◗ 6MHz of 1800MHz spectrum
	• The modelled operator has 2100MHz spectrum in the same quantities as existing mobile operators in the Portuguese market
	  ◗ 20MHz of 2100MHz spectrum

- This analysis does not take into account results from the spectrum auction that happened in November 2011 that occurred after the publication of the mobile termination prices consultation

Sheet: NwDes_Inputs, Rows 6-32

Licence payments are an important input to the model

GSM

- 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 assume that the spectrum assignment is automatically renewed at no cost every 15 years
  - assignments in 2004, 2019 and 2034

UMTS

- We assume that the operator re-purchases its original spectrum allocation for the same fee as the original licence (PTE 20,000 million) adjusted for inflation:
  - the same value is applied in **real terms**, meaning that the actual nominal payment increases with inflation
- In the model, we assume that the operator re-purchases its 2100MHz 3G licences every 15 years at the same price, adjusted for inflation
  - purchases in 2004, 2019 and 2034

Yearly fees

- The model calculates yearly fees modelling two different methods (pre- and post-2009), as well as the migration between both:
  - 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 a yearly fee of EUR120k per MHz of spectrum and a cost per reserved mobile number

Sheet: NwDes_Inputs, Rows 884-993

Business overheads are modelled using simple expenditure inputs

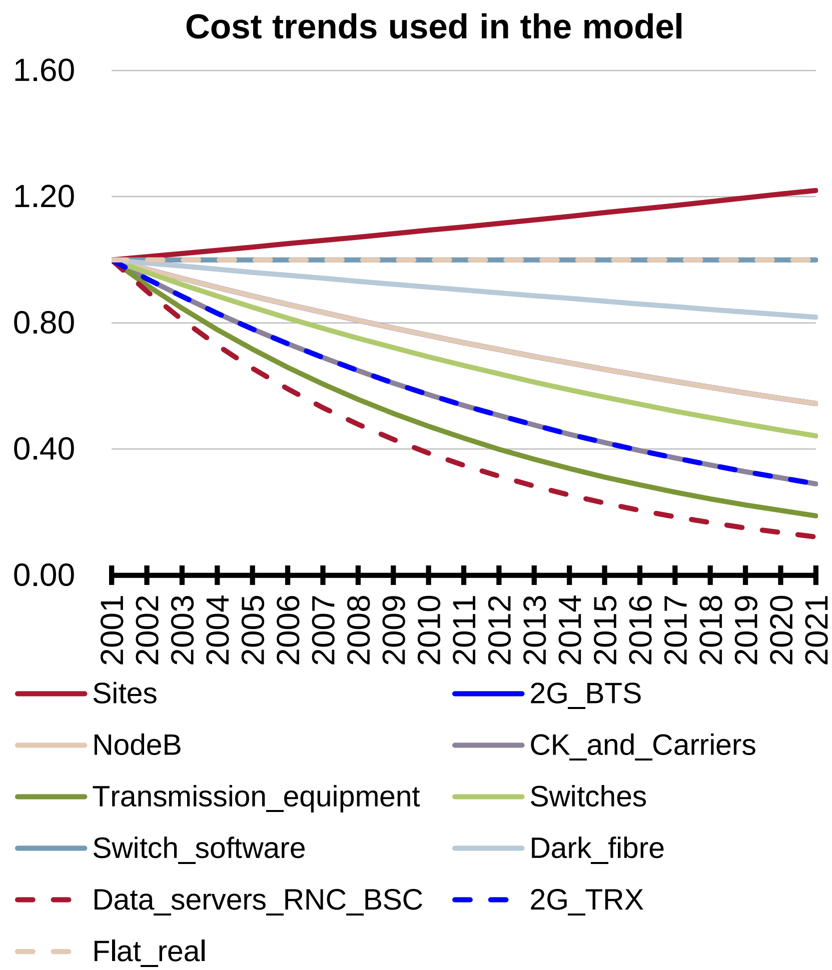
- We have included business overheads expenditures
  - the modelled operator accounts for this expenditure in terms of capital or operating expenditure
  - we assume that this expenditure (in real terms) is incurred each year of operation
- The business overheads have been calculated during the calibration process based on the level of overheads and costs experienced by real mobile operators
  - we have modelled a business overhead of EUR2.5 million in capex and EUR10 million in opex

Sheet: Asset_input, Rows 112–113 and NwDes_Inputs, Rows 997-1005

Contents

The model contains a 2008 input price and an assumed price trend

- There is a capital and operating expenditure input for each modelled network element
- For 2G and 3G network elements, we 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 exception is site acquisition, preparation and maintenance, which increases due to labour costs and increasing difficulty in finding sites



Sheets: Asset_input, CostTrends

Source: Analysys Mason estimations

CAGR of capital network equipment prices are generally downwards: -1% to -10% per annum

- We assume positive real-terms price trends for radio sites and switch sites (shared by the 2G and 3G networks)
- Other network elements – dedicated to 2G or 3G – are assumed to have negative price trends, except software and spectrum fees which is modelled with a 0% real-terms trend

Real terms price trend	*CAGR 1999-2048*	*Real terms price trend*	*CAGR 1999-2048*
Sites	1.0%	Switches	-4.0%
2G BTS	-3.0%	Switch software	0.0%
NodeB	-3.0%	Dark fibre	-1.0%
CK and Carriers	-6.0%	Data servers RNC BSC	-10.0%
Transmission equipment	-8.0%	2G TRX	-6.0%

- Price trends are based on recent regulatory models developed by Analysys Mason
  - price trends will be similar across European geographies, due to the global nature of hardware providers

Source: Analysys Mason estimations

Direct equipment prices have been obtained from submitted operator data or Analysys Mason estimates…

Direct costs used for radio/regional network

VALUES HAVE BEEN MODIFIED TO PROTECT CONFIDENTIAL DATA

Asset name	Capex	Opex
Own macro site location (acquisition, ancill, tower)	147,400	7,910
Third party macro site location (acquisition, ancill)	93,800	6,780
Third party indoor site location (acquisition, ancill)	134,000	7,910
BTS 1-sector	26,800	3,390
BTS 2-sector	40,200	3,390
BTS 3-sector	53,600	3,390
TRX	2,680	113
Node B 3-sector (excluding carrier equipment)	53,600	4,520
Node B R99+1.8/3.6/7.2 carriers (excluding channel kit)	13,400	1,130
Node B Release 99 channel kit (16 CE)	2,680	23
Micro BTS	26,800	3,390
Indoor special BTS+distributed antenna	26,800	3,390
Indoor special NodeB+distributed antenna	67,000	5,650
Site upgrade - 2G site upgrade facilities for 3G	80,400	
Fibre LMA	74,136	1,344
Leased E1 LMA Dense Urban	1,980	2,998
Leased E1 LMA Urban	1,980	3,222
Leased E1 LMA Suburban	1,980	3,707
Leased E1 LMA Rural	1,980	4,358
Leased E1 LMA Indoor	1,980	2,998
Self provided ULL E1	1,980	3,390
Microwave link (up to 32 Mb/s)	5,360	3,390
Microwave E1 activated	402	
Leased E1 - Remote BSC/PCU to MSC/SGSN	2,654	6,329
Leased STM1 - Remote BSC/PCU to MSC/SGSN	4,644	69,022
Leased E1 - MSC to MSC/VMS	2,654	19,939
Leased STM1 - MSC to MSC/VMS	4,644	252,988
Regional backbone access points STM1	14,740	1,695
Regional backbone access points STM4	40,200	2,825
Regional backbone access points STM16	67,000	6,780
Regional backbone access points STM64	134,000	10,170
Regional backbone distance (km)	1,675	2,260

Capex baseline input	Opex baseline input
Based on Portuguese operators data and benchmarks (own macro site location; third party macro and indoor site locations)	
Based on Portuguese operators data and benchmarks (BTS 1-, 2- and 3-sector; TRX)	
Based on Portuguese operators data and benchmarks (Node B items)	
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 (Fibre LMA)	
Connection prices from PT 2Mbit/s price list (Leased E1 LMA)	Rental prices based on estimated distances of operator sites and PT price list
Connection prices from PT price list (Leased E1/STM1 links)	Based on distance estimations and PT price list
Based on Portuguese operators data and benchmarks (regional backbone access points)	
Estimates based on fibre provider (regional backbone distance)	Estimates based on fibre provider

Source: Analysys Mason model, operators' data

Note: Indirect network cost mark-up already included

… and have been adapted in the calibration to reflect realistic capex and opex based on existing operators

Direct costs used for core/national network

VALUES HAVE BEEN MODIFIED TO PROTECT CONFIDENTIAL DATA

Asset name	Capex	Opex
National backbone access points STM1	14,740	1,695
National backbone access points STM4	29,480	3,390
National backbone access points STM16	58,960	6,780
National backbone access points STM64	117,920	13,560
National backbone distance (km)	1,675	2,260
BSC base unit	938,000	3,390
Remote BSC sites	536,000	
BSC E1 ports (facing BTS)	1,340	226
BSC E1 ports (facing MSC)	1,340	226
RNC base unit	1,340,000	339,000
RNC E1 ports (facing Node B)	1,340	226
RNC E1 ports (facing core)	1,340	339
RNC STM1 ports (facing core)	1,340	113
Regional backbone access points 1GbE	90,450	11,441
Regional backbone distance 1GbE (km)	1,675	2,260
National backbone access points 10GbE	134,670	17,035
National backbone access distance 10GbE (km)	1,675	2,260
National backbone access submarine STM-4 connection	90,450	71,233
Main switching sites	26,800,000	226,000
2G MSC	1,340,000	565,000
2G MSC software	402,000	0
MSC E1 ports (facing BSC and RNC)	2,680	678
MSC STM1 ports (facing BSC and RNC)	13,400	3,390
MSC E1 ports (facing other MSC)	1,340	678
MSC STM1 ports (facing other MSC)	13,400	3,390
MSC E1 ports (facing POI)	2,680	678
MSC E1 ports (facing VMS, etc.)	1,340	678
2G/3G MSC combined	1,340,000	565,000
2G/3G MSC combined software	402,000	0
MGW	1,072,000	226,000
MSC remote BSC facing E1 transcoders 16-64kbit/s	13,400	3,390

Rows	*Capex baseline input*	*Opex baseline input*
National backbone access points STM1 – National backbone distance (km)	Same as for regional links	Same as for regional links
BSC base unit – BSC E1 ports (facing BTS)	Based on Portuguese operators data and benchmarks	Based on Portuguese operators data and benchmarks
RNC base unit – RNC STM1 ports (facing core)	Based on Portuguese operators data and benchmarks	Based on Portuguese operators data and benchmarks
Regional backbone access points 1GbE – National backbone access distance 10GbE (km)	Analysys Mason estimates for IP equipment	Analysys Mason estimates for IP equipment
National backbone access submarine STM-4 connection	Analysys Mason estimates for IP equipment	Estimate based on benchmark of trans-Atlantic routes
Main switching sites – 2G MSC software	Approx. operator data	Approx. operator data
MSC ports	Based on benchmarks	Approx. operator data
2G/3G MSC combined – MGW	Approx. operator data	Approx. operator data
MSC remote BSC facing E1 transcoders 16-64kbit/s	Based on benchmarks	Approx. operator data

Source: Analysys Mason model, operators' data

Note: Indirect network cost mark-up already included

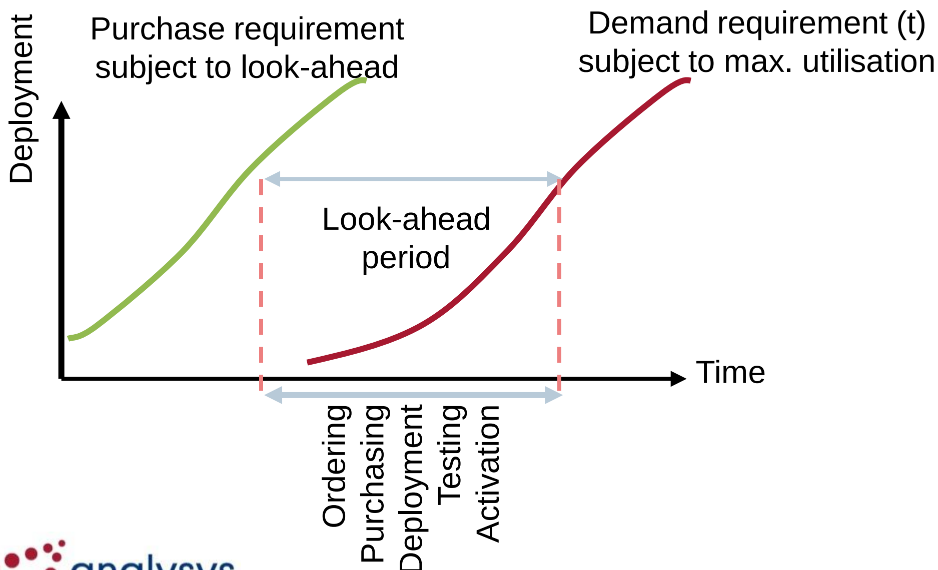
Indirect expenditures are estimated for the hypothetical efficient operator

- Indirect network costs are distributed among capex and opex as a mark-up
  - we apply this mark-up to all capex and opex costs per unit
  - the resulting costs per unit are then used for the calculation of total costs and termination costs
- Mark-up values have been estimated based on the analysis of operators' data and during 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

Asset purchase is according to *1.* deployment lead times, and *2.* replacement lifetimes

- Model calculates active network assets at mid-year
- Capital expenditure on assets occurs 1–18 months in advance of activation:
  - depending on lead times and size of network assets
- Operating expenditures incurred once activated
- Replacement lifetime (3–20 years) determines when asset is replaced at current cost

Lead-time expenditure profile



Sheet: NwDeploy

Lifetime	*Network elements*
20	Own macro site
	Switching sites
15	Third-party macro and indoor sites
10	Fibre rings
	Node B and equipment
	BTS equipment
	Leased lines, microwave equipment, access points and transmission links
8	MSC, HLR
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 estimations

Purchasing, replacement and capex planning periods

Planning periods	*Network elements*
18 months	Switching sites
12 months	Access points and transmission links
	Fibre rings
9 months	Own macro site
	Third-party macro sites
	BSC, RNC equipment
	MSC, MGW
	Billing
6 months	Third-party indoor sites
	IN, VMS, HLR, AUC, EIR, GPRS, VAS
3 months	BTS equipment
	Node B equipment
	Microwave equipment,
	BSC, MSC ports
	SMSC, MMSC
1 month	TRX, NodeB carriers, NodeB channel kits, leased lines

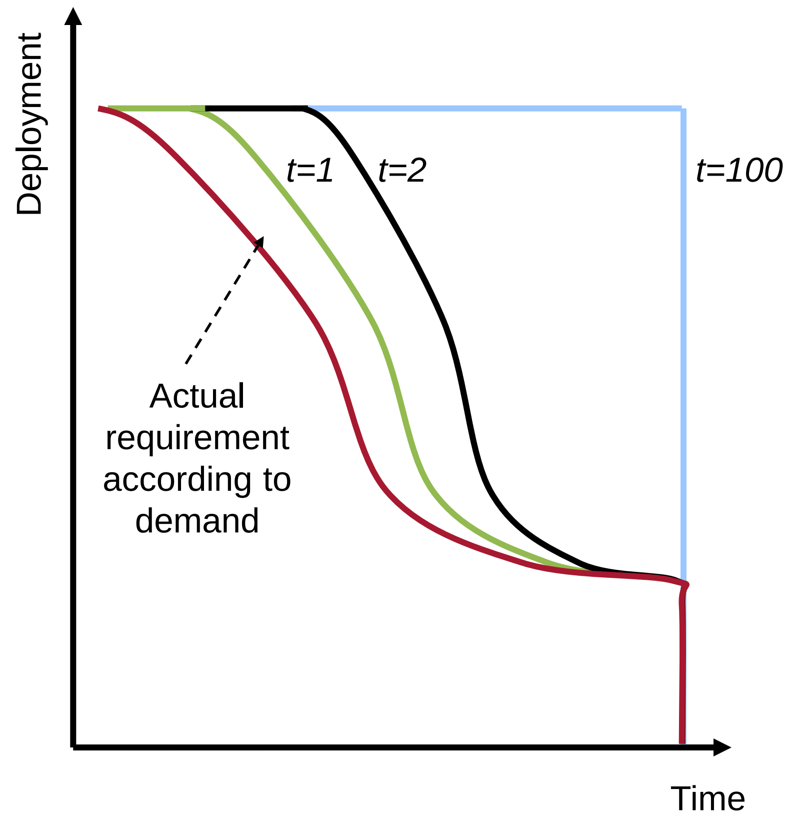
Note: The planning period is the period of time elapsed between the first deployment expenditure activities for a network element and the time where the network element becomes operational

Source: Analysys Mason estimations

Network elements are removed from the network 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 cost-less with zero scrap value

Retirement options



Sheet: NwDeploy

Source: Analysys Mason model

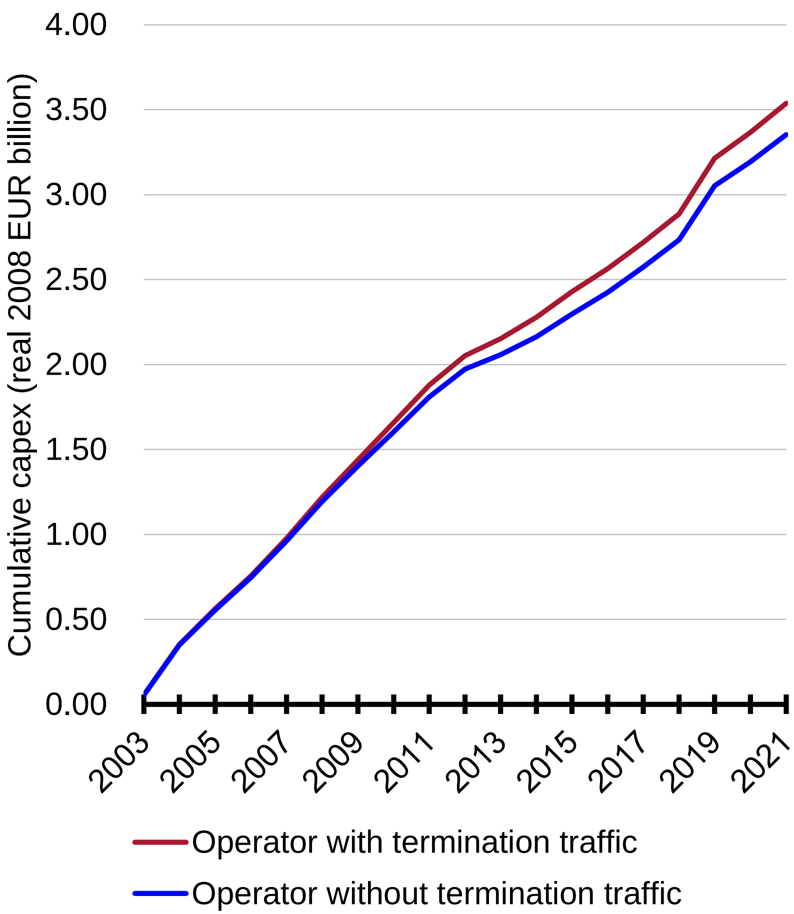
Retirement algorithm

Retirement period	*Network elements*
Retained in network until shutdown date, if any	Owned, third-party macro and indoor sites
	BTS equipment
	NodeB equipment, carriers
	2G/3G MSC combined, MGW
Retired from network 2 years after demand decline	BSC, RNC equipment
	Switching sites
	GPRS
Retired from network 1 year after demand decline	TRX, NodeB channel kits, leased lines
	Access points and transmission links
	BSC, MSC ports
	2G MSC
	IN, VMS, HLR, AUC, EIR, VAS, SMSC, MMSC, Billing
Retired from network immediately after demand decline	NodeB or 2G MSC software
	Licence fees

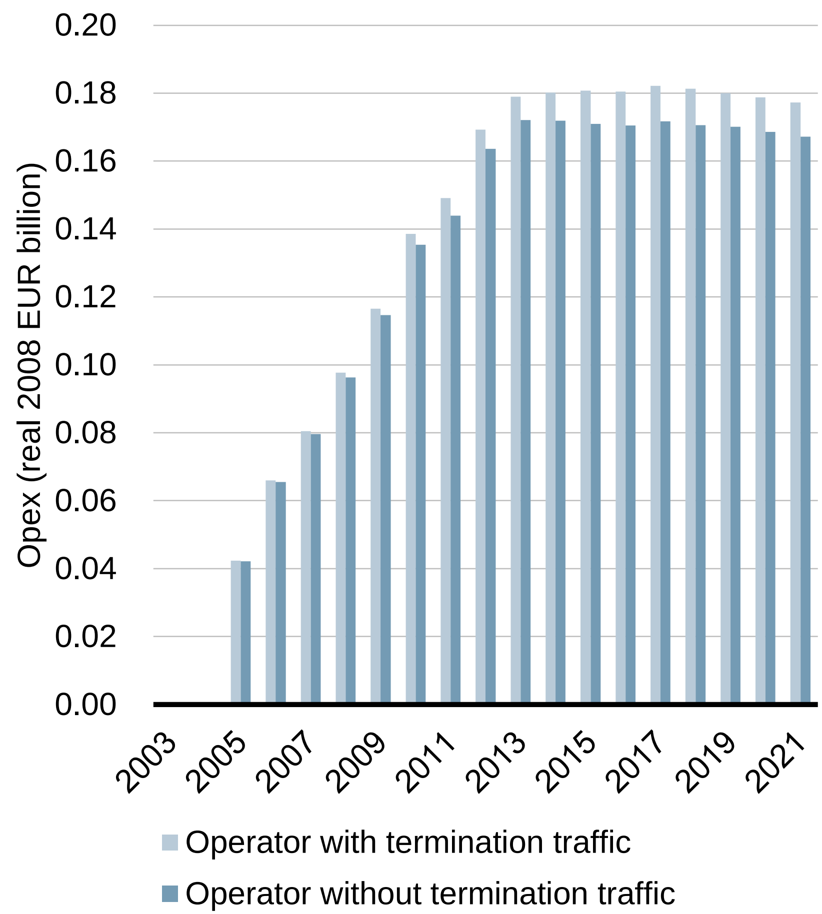
Source: Analysys Mason estimations

Expenditures from the model show a cumulative capex of EUR7.6bn for 2001-2050 and a peak annual opex of EUR181m

Cumulative capex of modelled operator (2003–2021)



Opex of modelled operator (2003–2021)



Source: Analysys Mason model

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

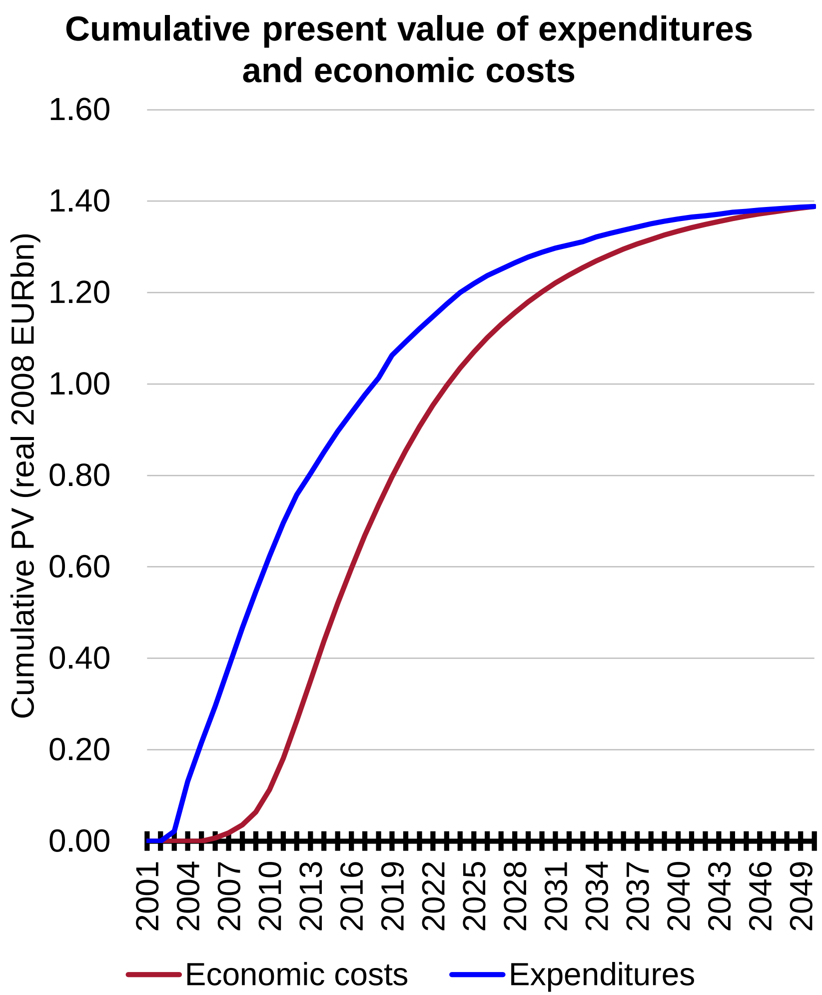
- **Level of economic costs determined by:**
  - total expenditure divided by output, in the form of a net present value calculation

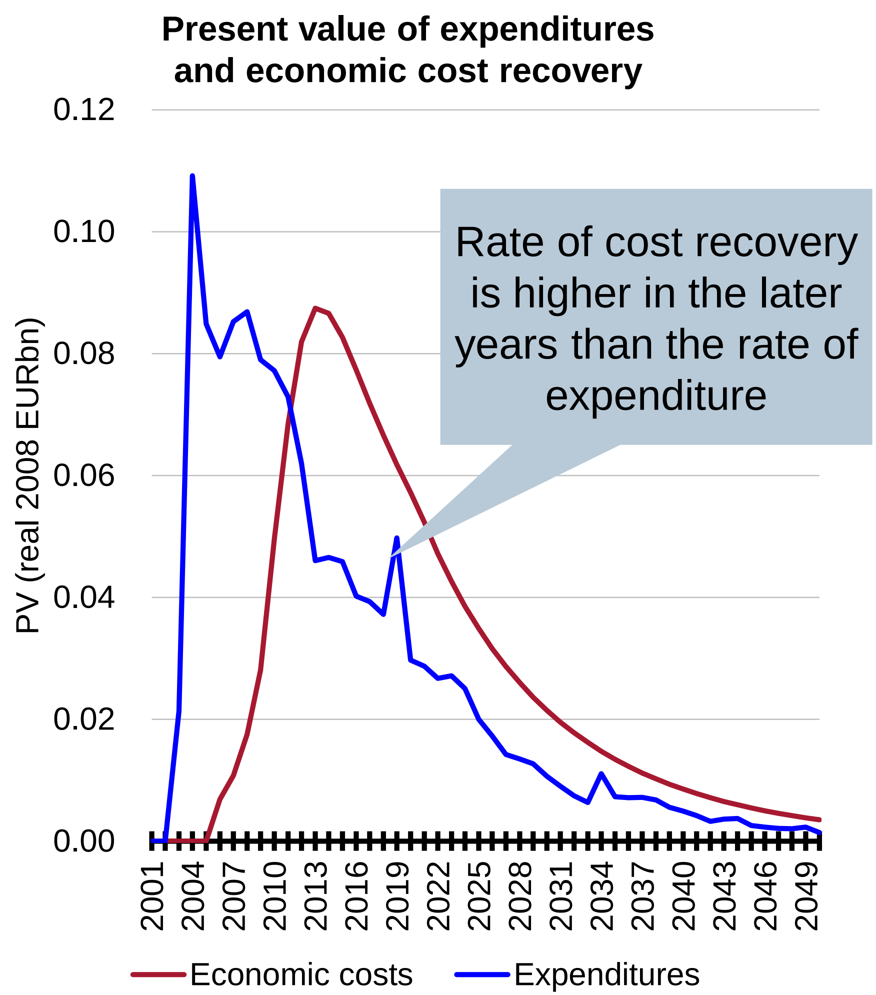
$$\frac{\text{PV (expenditures)}}{\text{PV (network element output)}}$$

- **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% in the year

Sheet: EconDep

The model accumulates cost recovery to achieve full cost recovery over the lifetime of the business





Source: Analysys Mason model

WACC

- We have used a WACC estimated by Analysys Mason as a separate exercise on mobile cost of capital:
  - 9.2% in pre-tax real terms
- This estimation follows a similar methodology to that proposed by PwC for its calculation of the WACC of Portugal Telecom in 2009 and 2011
  - we have adapted the methodology to reflect an improved choice of benchmarked operators and available data

Parameter of WACC calculation	*Value*	*Source*
Cost of debt	**4.4%**	
Cost of debt (post-tax)	6.1%	Benchmark of debt premiums of European regulators
Nominal tax rate	29.0%	ANACOM
Cost of equity	**9.7%**	
Risk free rate	4.8%	Based on 10 years' Portuguese bonds (2009-2010)
Equity Risk Premium	6.0%	Benchmark of ERP from ANACOM's decisions and other sources
Beta	0.81	Based on Beta from Mobistar, Telenor ASA, TeliaSonera AB, Vodafone Group and Mobile Telesystems OJSC
Pre Tax nominal WACC	**11.1%**	
Inflation	1.7%	Euromonitor, average for 2011-2021
Pre Tax real WACC	**9.2%**	

Sheet: DiscFacs

The LRAIC for each service is calculated according to 2G routeing factors…

- 2G routeing factors are summarised below:

Network element	*Subscribers*	*2G on-net voice min*	*2G out voice minute*	*2G in voice minute*	*2G SMS*	*Packet data Mbytes*
Radio equipment		2 + 2RT	1 + RT	1+RT	~0.001	5.47
Backhaul		2 + 2RT	1 + RT	1+RT	~0.001	5.47
BSC		2 + 2RT	1 + RT	1+RT	~0.001	5.47
MSC	1 per sub	7 per BHCA	2 per BHCA	5 per BHCA	1 per BHSMS	
National transmission	x% MSC-MSC	~0.58	~0.68	~0.77		
	y% MSC-VMS	1		1		
	z% backhaul	2 + 2 RT	1 + RT	1+RT	~0.0021	5.47

RT = ring time per conveyed minute

Sheet: RouFacs

…3G routeing factors…

- 3G routeing factors are summarised below:

Network element	*Subscribers*	*3G on-net voice min*	*3G out voice minute*	*3G in voice minute*	*3G SMS*	*R99 Mbytes*	*HSDPA Mbytes*
Radio equipment		2 + 2RT + SH	1 + RT + SH	1 + RT + SH	~0.0003	8.79	1.30
Backhaul		2 + 2RT + SH	1 + RT + SH	1 + RT + SH	~0.0003	8.79	9.76
RNC		2 + 2RT + SH	1 + RT + SH	1 + RT + SH	~0.0003	8.79	9.76
MSC	1 per Sub	7 per BHCA	2 per BHCA	5 per BHCA	1 per BHSMS		
National transmission	x% MSC-MSC	~0.58	~0.69	~0.77			
	y% MSC-VMS	1		1			
	z% backhaul	2 + 2 RT + SH	1 + RT + SH	1+RT + SH	~0.0003	8.79	

RT = ring time per conveyed minute; SH = an additional 20% soft-handover Erlangs for circuit-switched 3G traffic

…and routeing factors for the various other network elements

Network element	*On-net voice min*	*Out voice minute*	*In voice minute*	*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 on & out		
GPRS					1	
Wholesale billing		1	1	in, out		
NMS	1	1	1	1	1	1
VAS	1	1		on, out	1	
Business overheads	1	1	1	1	1	1
Licence fees	as 2G or 3G radio assets					

Sheet: RouFacs

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

Routeing factor component	*Method of derivation*
Ringing time per minute	1/ (avg. call duration × call attempts per successful call × 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	[(**A** × **B**) / **C**] × [(**D** × **E**) / **F**] **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 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

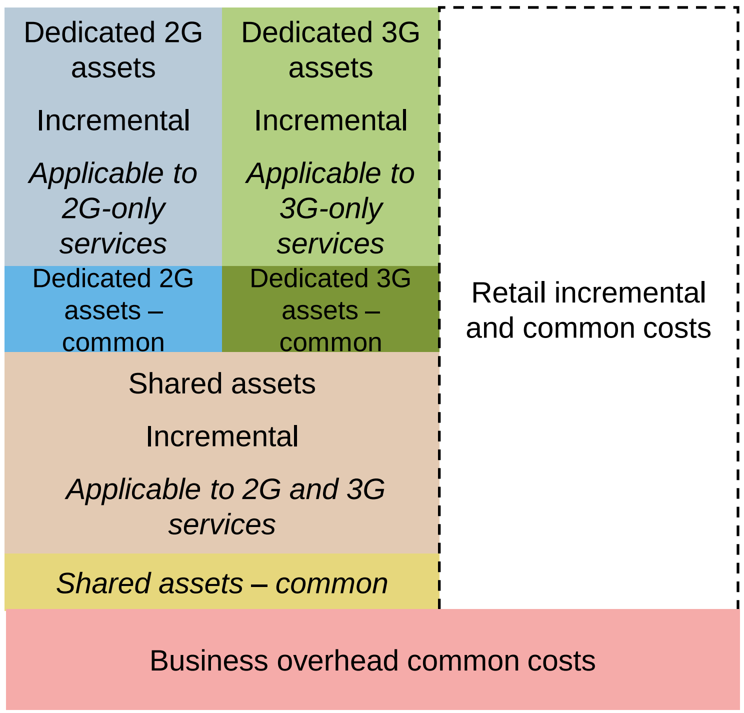
…as are conversion factors between data and voice traffic

Routeing factor component		*Value*	*Method of derivation*
Conversion factor (SMS per minute)	2G SMS	**0.0009**	Bits per SMS (320) / SDCCH channel rate in bits per minute (368,160)
	UMTS SMS	**0.0003**	Bits per SMS (320) / radio channel rate in bits per minute (960,000)
Conversion factor (Mbytes per minute)	GPRS	**5.4738**	Minutes to transfer 1MB of data (7.29) × proportion in downlink (75%)
	R99	**7.3212**	Minutes to transfer 1MB of data (9.66) × proportion in downlink (75%)
	HSDPA1.8	**2.7766**	1MB of raw data at the air interface in bits [8,000,000/(1-14.63%) ●] / 60 × HSDPA rate per CE in bits/s (1,800,000/32)
	HSDPA3.6/7.2	**1.3883**	0.5 × factor for HSDPA1.8 (due to faster coding rate)
	HSDPA21.1/42.2	**0.9475**	1MB of raw data at the air interface in bits [8,000,000/(1-14.63%) ●] / 60 × HSDPA rate per CE in bits/s (21,100,000/128)
	HSUPA	**3.3320**	1MB of raw data at the air interface in bits [8,000,000/(1-14.63%) ●] / 60 × HSUPA rate per CE in bits/s (1,500,000/32)

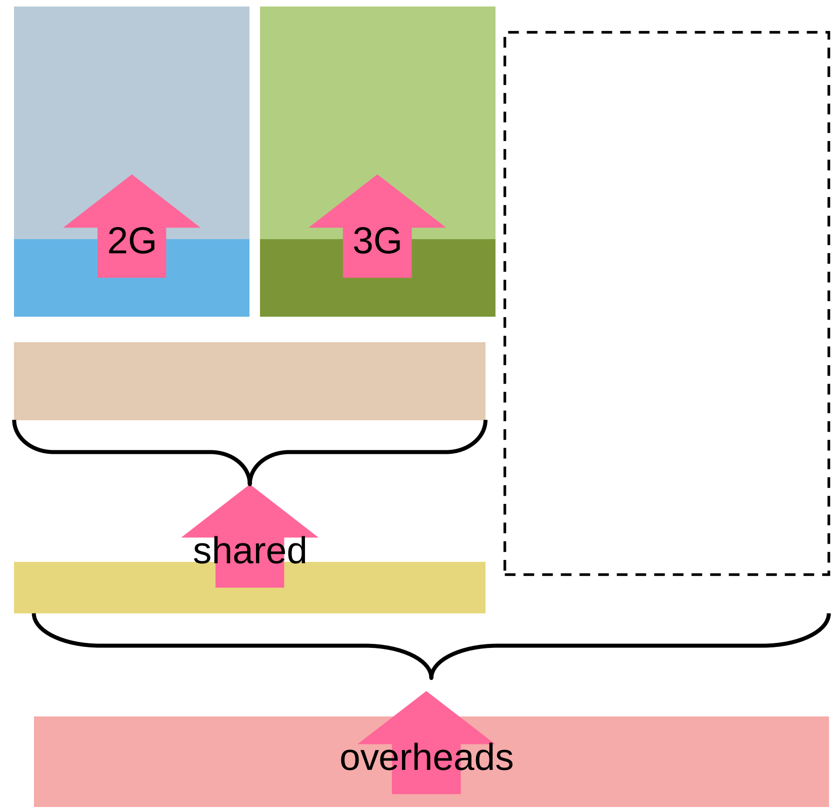
● *This factor is an IP overhead*

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

Incremental and common cost components



Mark-up sequence



- 2G common costs: licence fee
- 3G 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

Contents

We have calibrated our results against ANACOM's data and operators' data

- The calibration process of the hypothetical operator has two distinct processes
  - **network calibration** of the main network elements
  - **economic calibration** of the cumulative capex and opex of the mobile operator
  - as we have not modelled any existing operator, there has been no reconciliation of the model with any single mobile operator. However, we have used the data from the operators to improve our calibration results

Common calibration

- Results for the model were compared against 2009 and historical data provided by ANACOM and the operators during a data request process that happened in 2010
- For the calibration, an operator with a constant 99.0% GSM coverage and a 82.6% UMTS coverage was considered
  - this corresponds to the estimated market coverage for GSM and UMTS in 2009

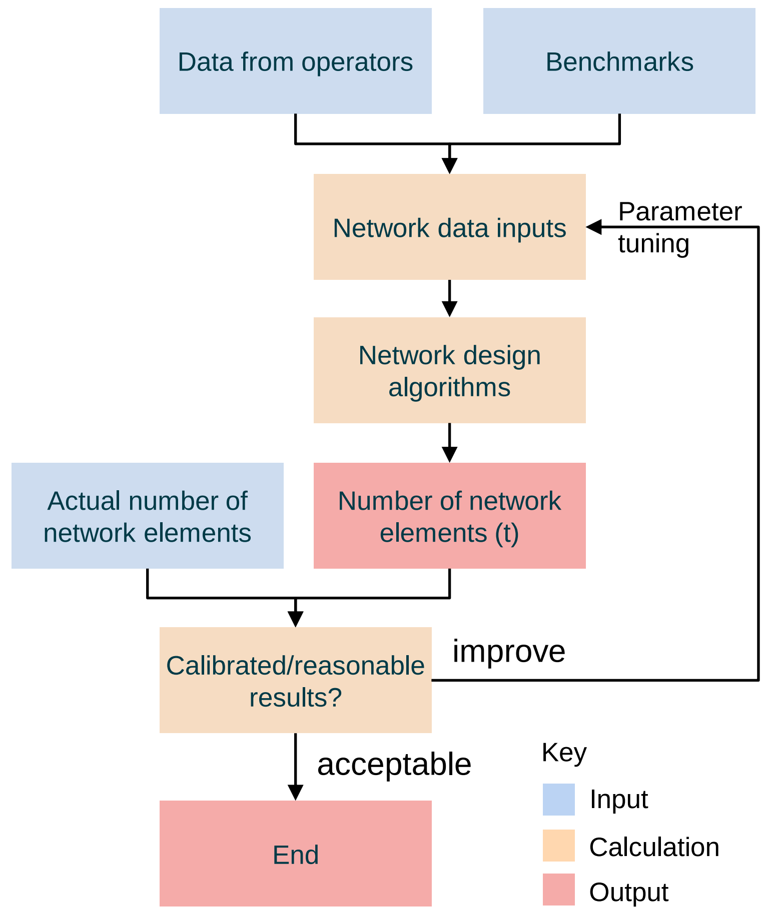
Network calibration

- The calibration process involved comparing each of the three existing operators data with results from scaling the operator in the model with a market share percentage
  - we introduced the approximate market share of each operator in the model, and compared the model results with the operators' real data
- We have considered the following network elements in the calibration :
  - Sites
  - BTS
  - TRX
  - NodeB
  - CK
  - Carriers
  - BSC
  - RNC
  - Switching sites
  - MSC
  - MGW

The network calibration process considers 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 e.g.:
  - many network design aspects are not explicitly modelled (or would be overly complex to do so in 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 perfect, for example:
  - equipment capacities, for instance, have increased over time resulting in the network design algorithms forecasting fewer, higher-capacity units than actual numbers

Scorched-node calibration process



Note: The example numbers provided in the graph are illustrative

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

GRAPH REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION

Source: Analysys Mason

… while a modern core network in the model results in lower numbers of elements compared to real operators

GRAPH REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION

Source: Analysys Mason

We have performed an economic calibration based on capex and opex comparison with existing operators' data

Economic calibration

- The model has been calibrated with top-down accounting data provided by the three mobile operators
- An operator with a constant market share of 33.3%, representing an average operator in a 3-operators' market has been considered for this calibration test
- Initially, the bottom-up model was populated with "bottom-up" 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 to investigate the discrepancy
- Opex model results were compared to an average opex of the three main operators
- Capex model results were compared to an average capex of the three main operators
  - we have considered cumulative capex covering the years 2001-2009 to reflect total investments
- We have considered three main cost groups:
  - *Transmission*: backhaul and core transmission
  - *Core network:* core platforms and switching
  - *Radio access network:* 2G and 3G networks
- Indirect network costs have been equally distributed among cost centres
  - the indirect mark-up resulting from indirect network costs over considered costs have been calculated for the three operators for opex and capex
  - the mark-up has been applied to each unit cost of the modelled operator
- The calibration took into account the increased efficiency of the hypothetical operator (modern switching network, etc.) as a result of modern technology available at the moment of its network deployment
- We have excluded the cost of licenses and business overheads in this test, which are added separately

A more effective and modern deployment has resulted in a lower cumulative capex for the modelled operator

Cumulative capex comparison, 2001-2009

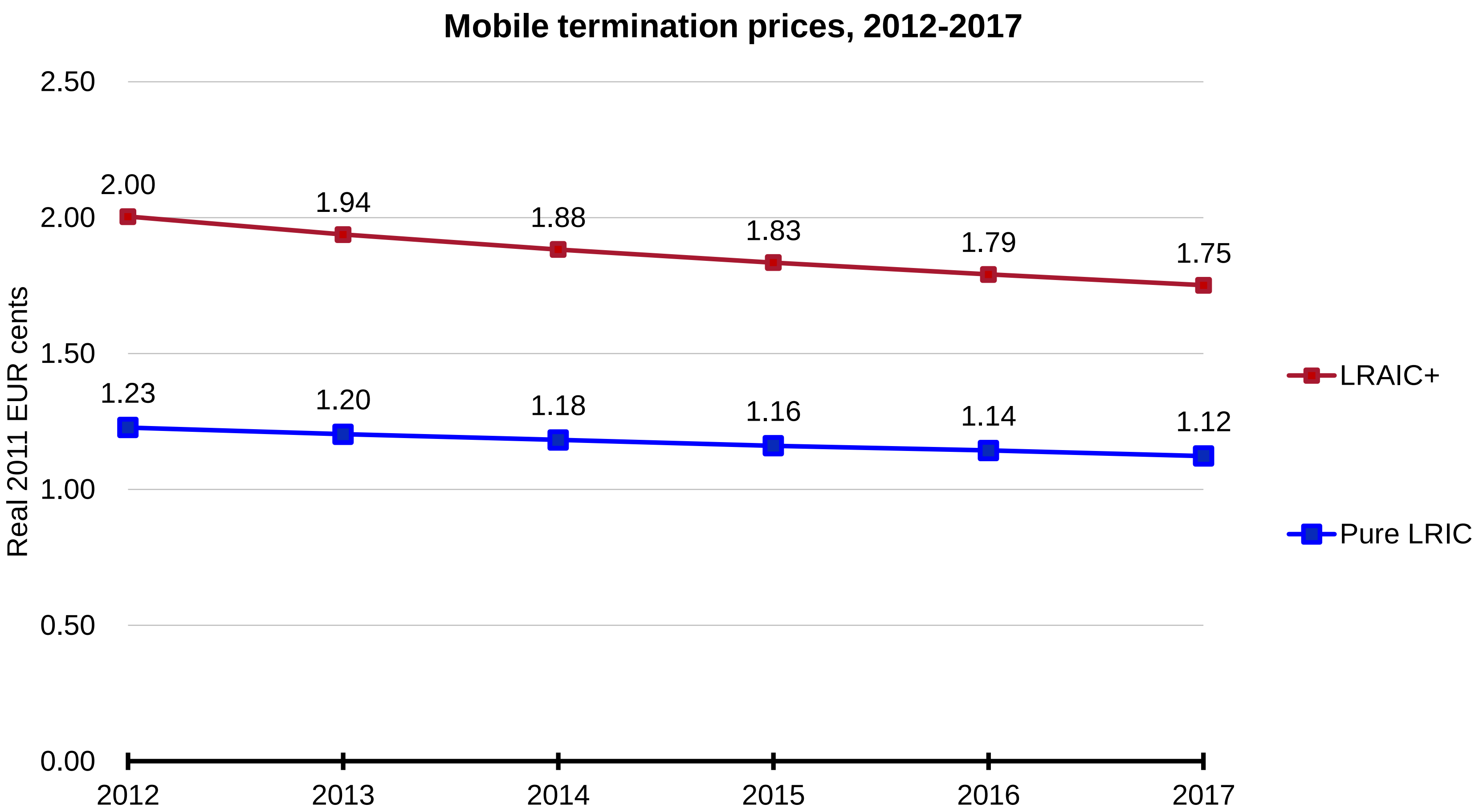
Opex comparison, 2009

GRAPH REMOVED TO PROTECT CONFIDENTIAL OPERATOR INFORMATION

Source: Analysys Mason, operators

Contents

In 2016, the unit cost of mobile termination reaches EUR1.79 cents, or EUR1.14 cents on a Pure LRIC basis

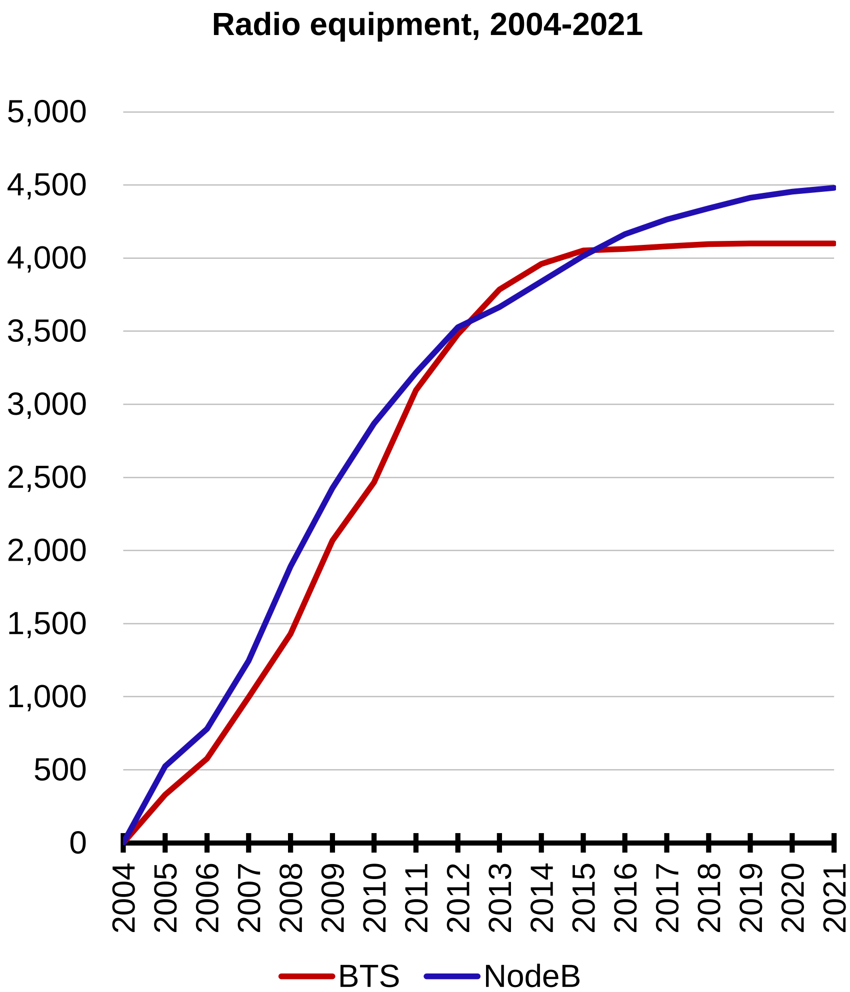


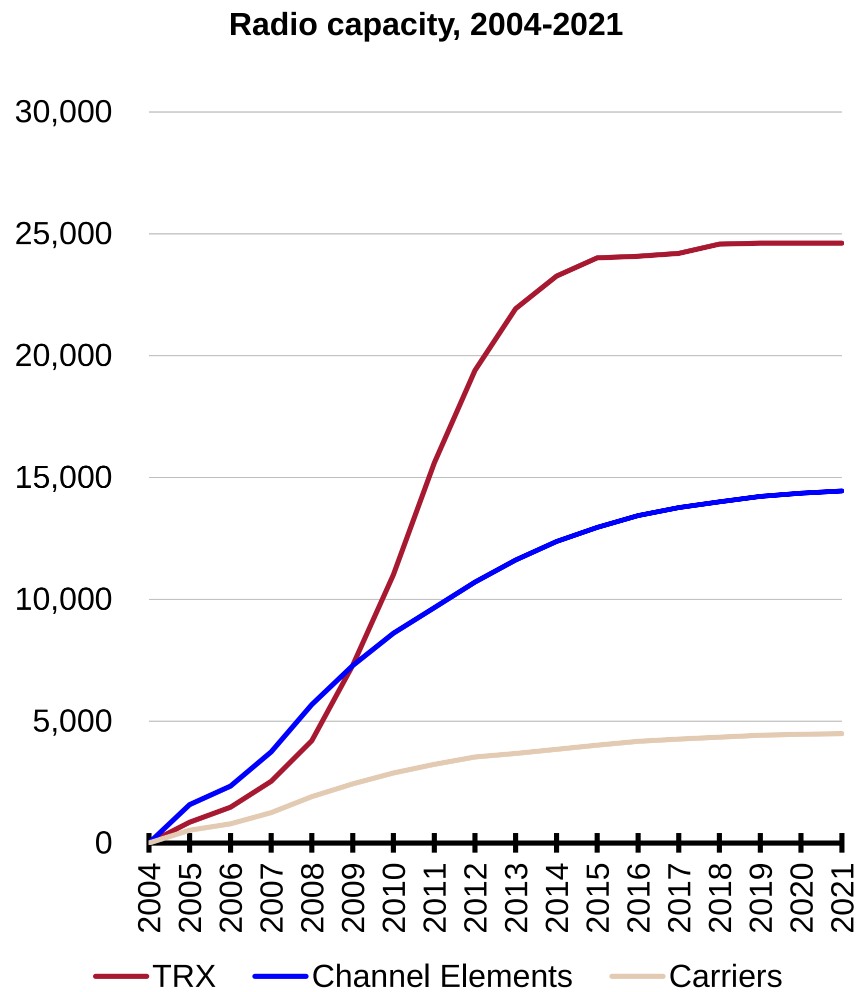
Unit cost results from the model are presented in real 2011 EUR currency terms.

This means that inflation for future years will need to be added (using forecast or actual inflation)

Source: Analysys Mason model

BTS and NodeB grow based on geographic coverage and capacity requirements

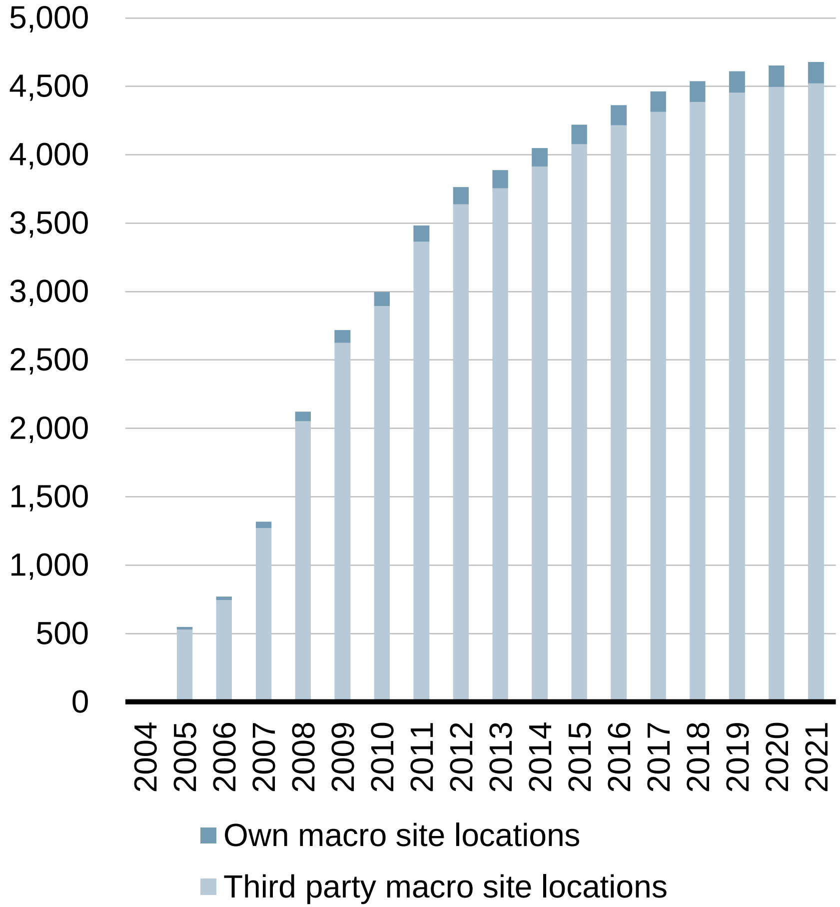




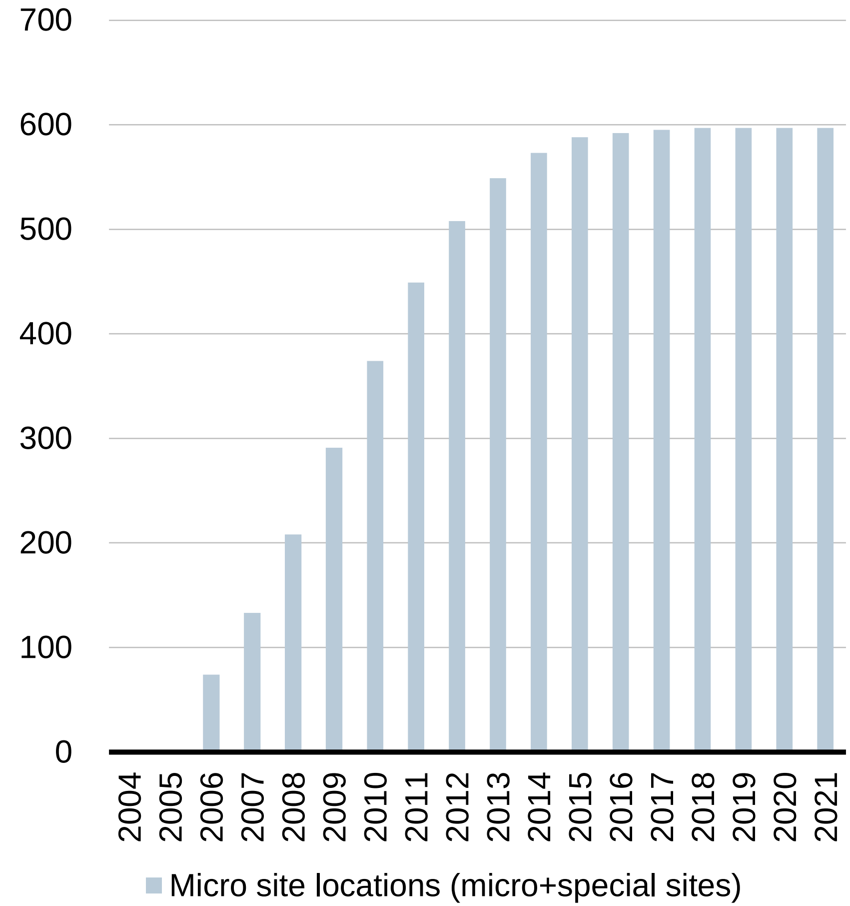
Source: Analysys Mason model

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

Macro site locations, 2004-2021

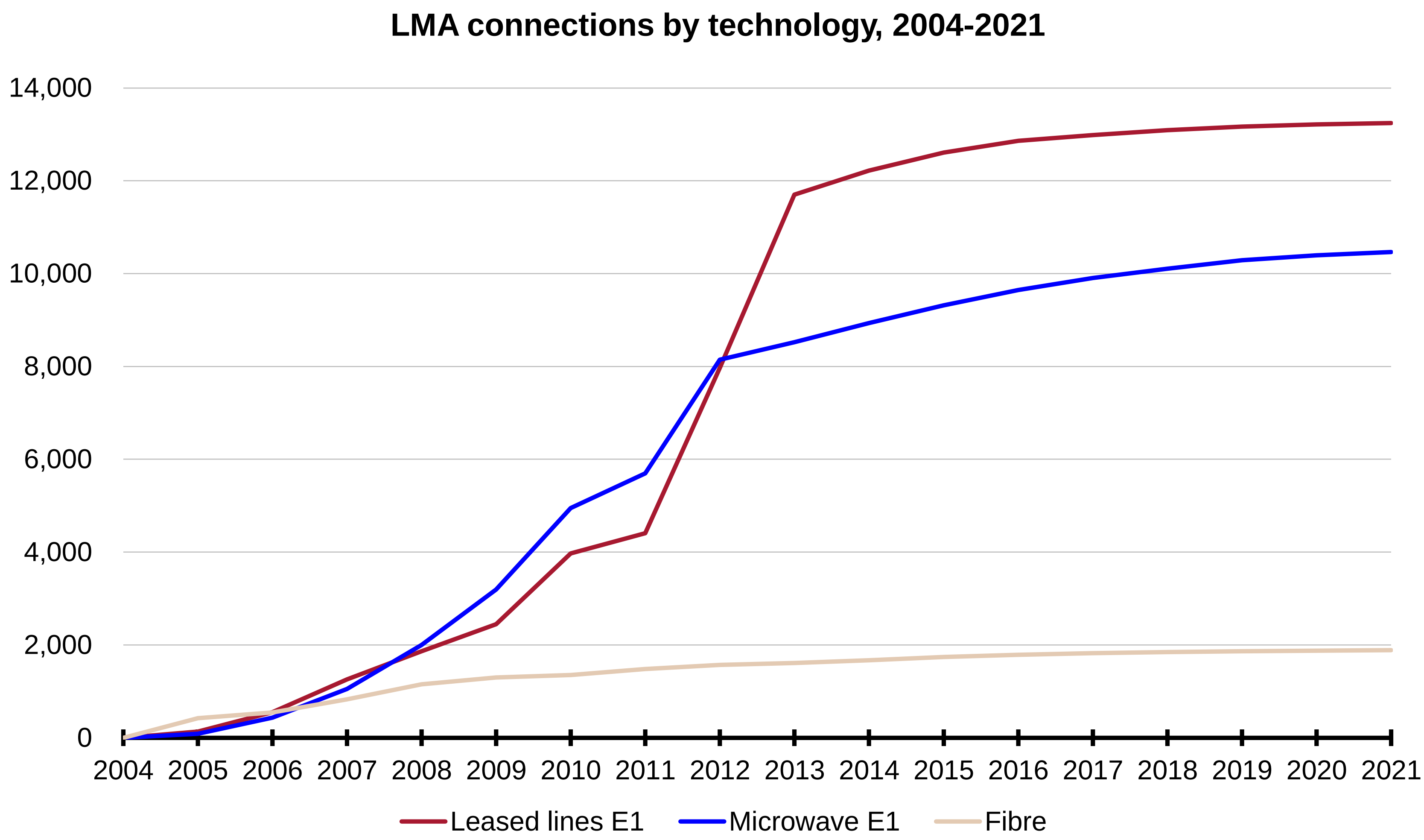


Micro+special site locations, 2004-2021



Source: Analysys Mason model

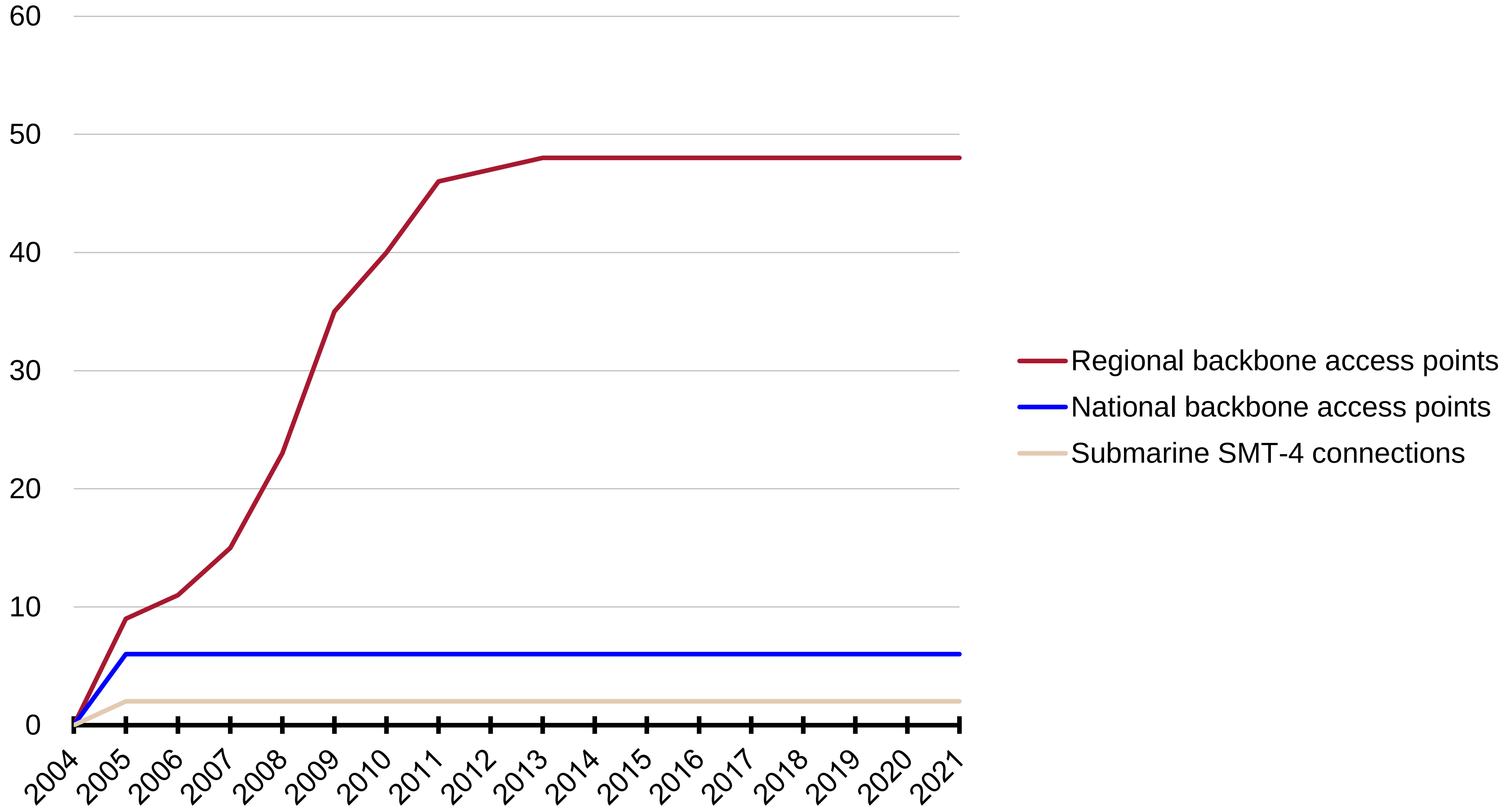
Last-mile access capacity increases steeply during HSPA roll-out



Source: Analysys Mason model

The national backbone is deployed from the launch of the operator, while the regional backbone develops gradually

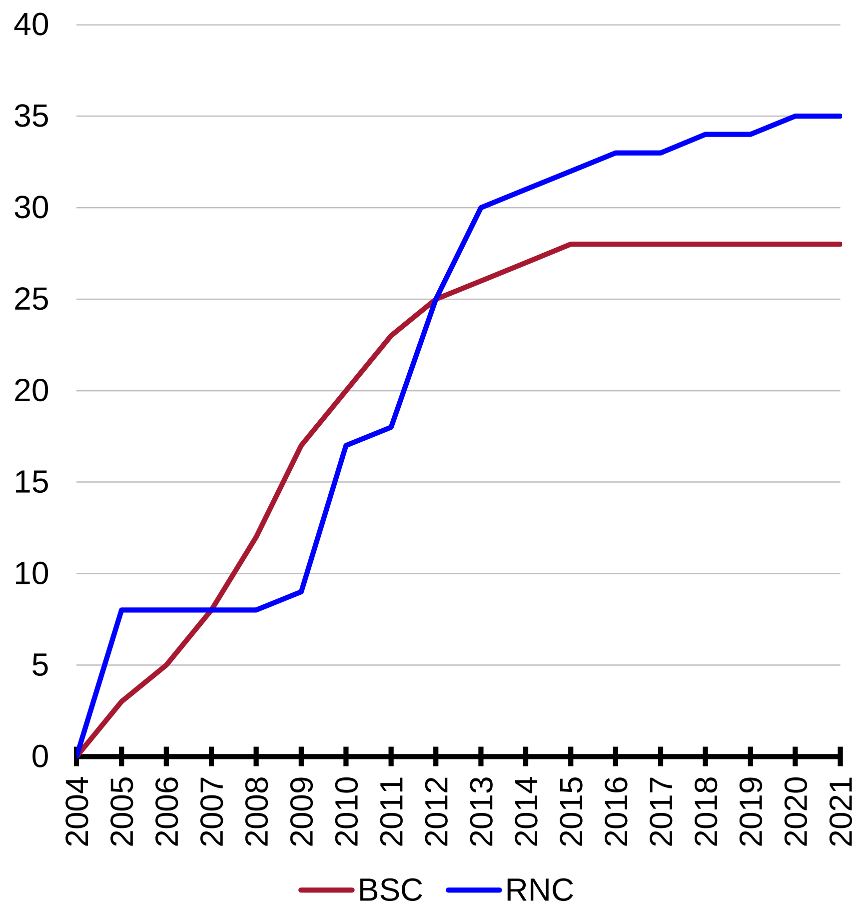
Regional and national backbone network, 2004-2021



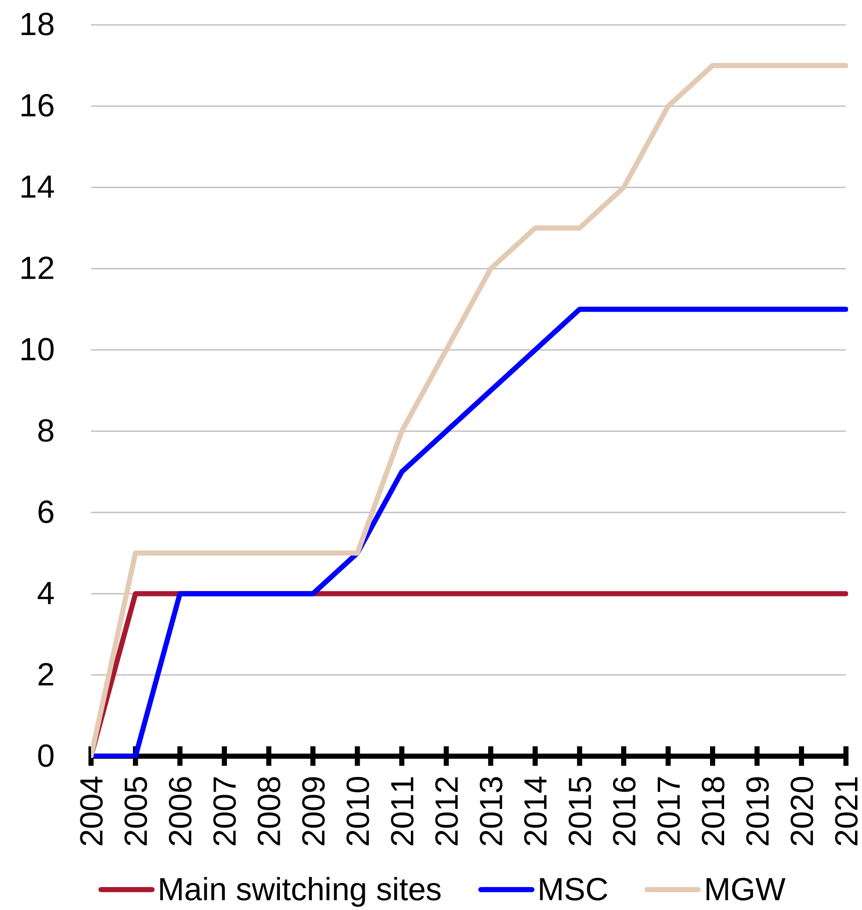
Source: Analysys Mason model

BSC, RNC and switching elements grow based on network load, while switching sites remain constant at 4

BSC and RNC, 2004-2021



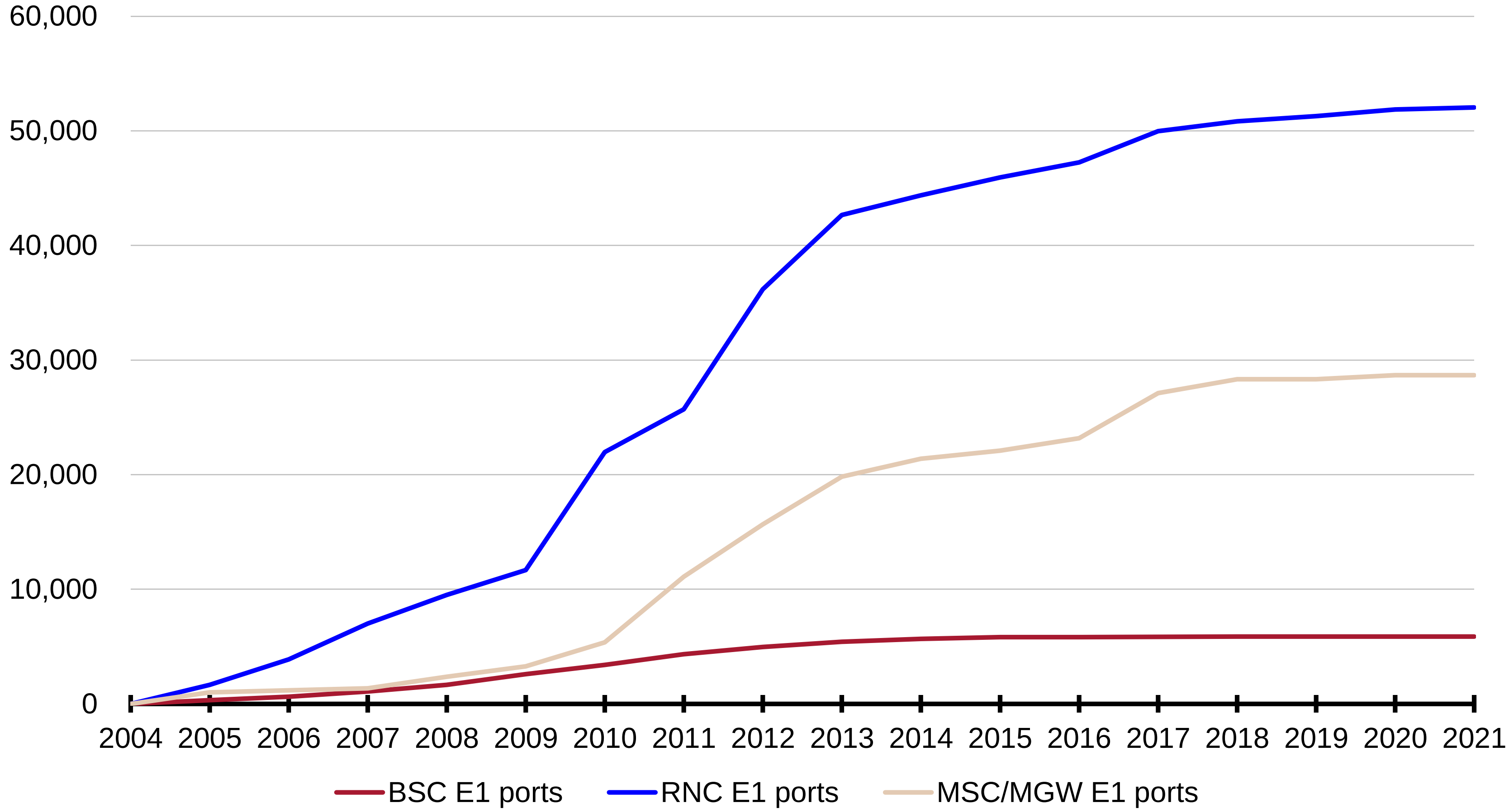
Main switching sites and MSC/MGW, 2004-2021



Source: Analysys Mason model

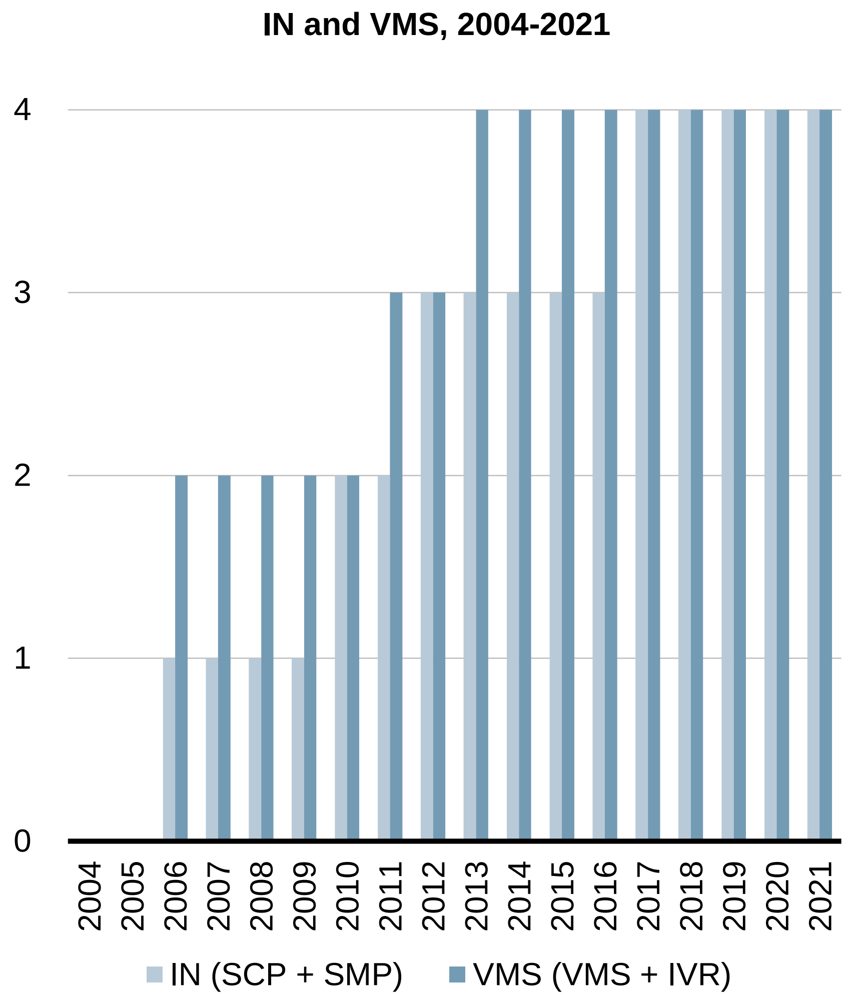
RNC ports experience a stronger growth than BSCs due to increasing data traffic

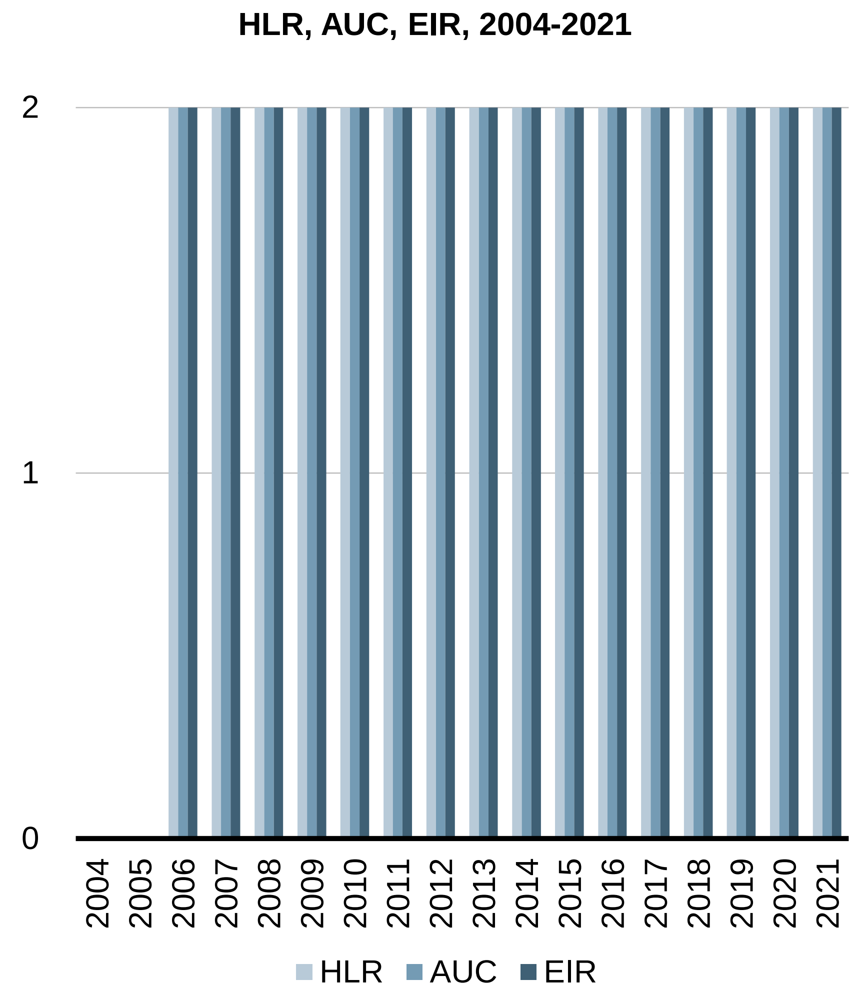
BSC, MSC and switching E1 ports, 2004-2021



Source: Analysys Mason model

Other network elements [1/2]

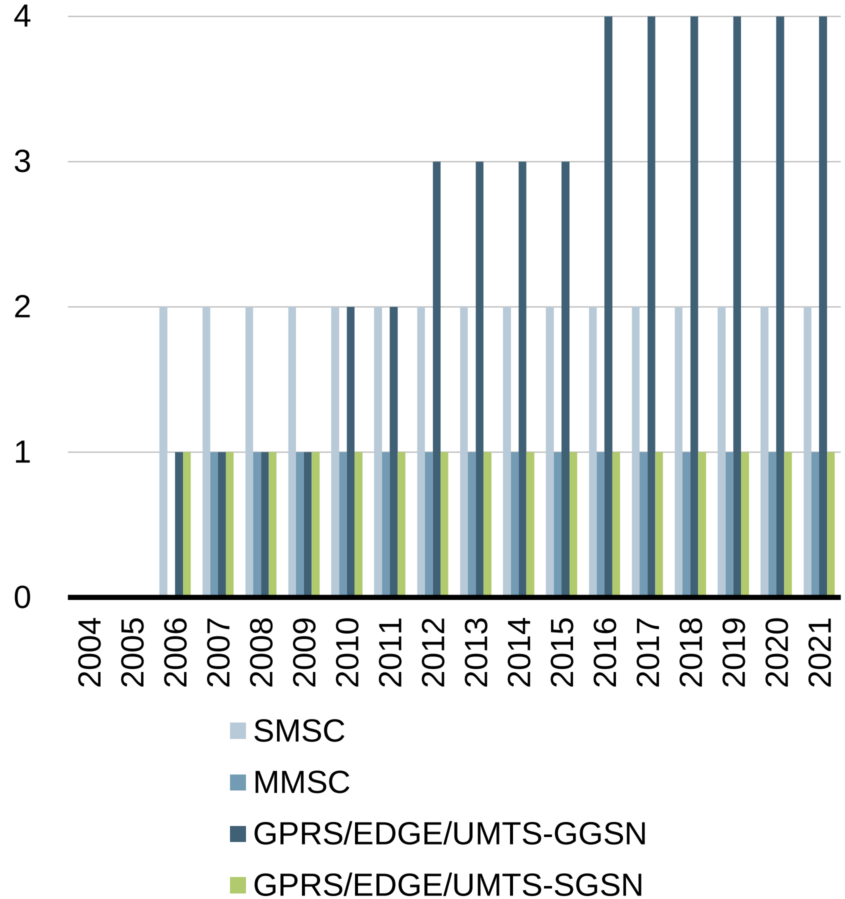




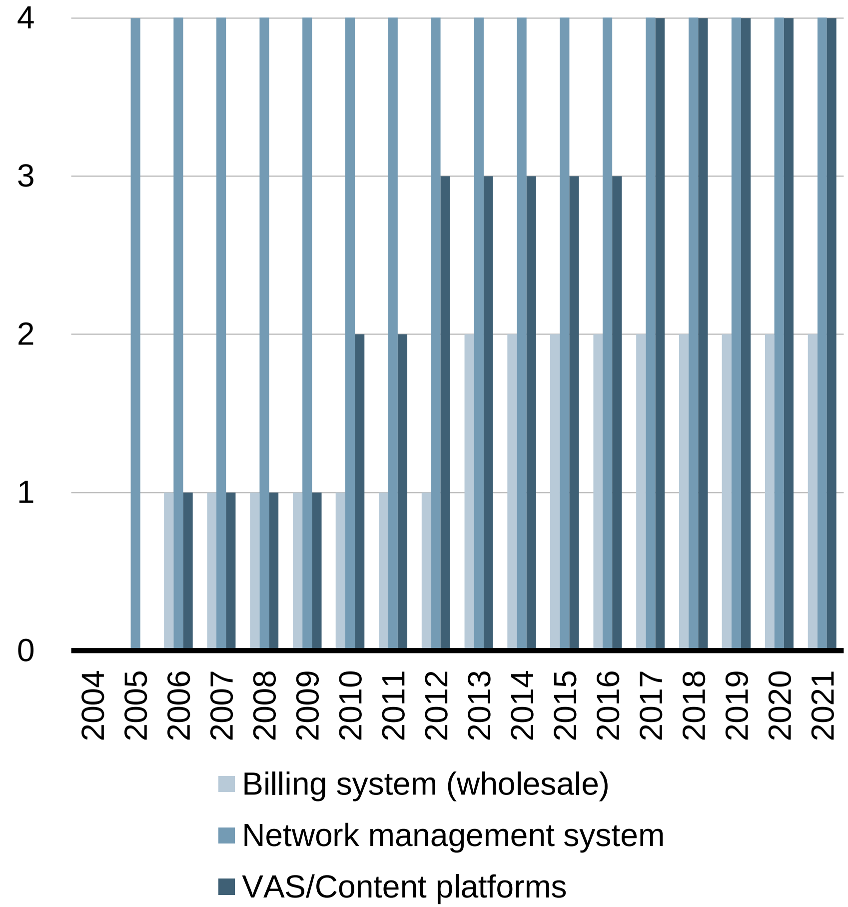
Source: Analysys Mason model

Other network elements [2/2]

SMSC, MMSC, GGSN and SGSN, 2004-2021



Billing system, network managements system and VAS/content platforms, 2004-2021



Source: Analysys Mason model

Annexes

Acronyms used throughout the document [1/3]

Acronym	Meaning
2G	Second generation of mobile telephony
3G	Third generation of mobile telephony
ANACOM	Portuguese Telecommunication Authority
AUC	Authentication centre
BH	Busy-hour
BHE	Busy-hour Erlangs
BSC	Base station controller
BTS	Base transmitter station or base station
CCH	Control channel
CE	Channel element
CK	Channel kit
CPU	Central processing unit
DCS	Digital cellular system
E1	2Mbit/s unit of capacity

Acronym	Meaning
EC	European Commission
ED	Economic depreciation
EGSM	Extended GSM
EIR	Equipment identity register
EPMU	Equi-proportional mark-up
FAC	Fully-allocated cost
F-M	Fixed to mobile
GGSN	Gateway GPRS serving node
GPRS	General packet radio system
GSM	Global system for mobile communications
GSN	GPRS serving node
HCA	Historical cost accounting
HLR	Home location register
HSDPA	High speed downlink packet access

Acronyms used throughout the document [2/3]

Acronym	*Meaning*
HSPA	High speed packet access
HSUPA	High speed uplink packet access
IN	Intelligent network
IP	Internet Protocol
LRAIC	Long-run average incremental cost
LRIC	Long-run incremental cost
LTE	Long-term evolution
MEA	Modern equivalent asset
MGW	Media gateway
TCH	Traffic channel
TDD	Time division duplex
TRX	Transceiver unit
TSC	Transit switching centre
M-F	Mobile to fixed

Acronym	*Meaning*
M-M	Mobile to mobile
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
NMS	Network management system
NodeB	Denotes UMTS equivalent of a BTS
NR	National roaming
OLO	Other licensed operator
PCU	Packet control unit

Acronyms used throughout the document [3/3]

Acronym	*Meaning*
PDP	Packet data protocol
PoI	Point of interconnect
PS	Packet switch
PV	Present value
QAM	Quadrature amplitude modulation
R99	Release-99
RNC	Radio network controller
SDCCH	Stand-alone dedicated control channel
SGSN	Subscriber GPRS serving node

Acronym	*Meaning*
SMS	Short message service
SMSC	SMS centre
SNOCC	Scorched-node coverage coefficient
SP	Service provider
STM	Synchronous transport module
UMTS	Universal mobile telecommunications systems
VLR	Visitor location register
VMS	Voicemail system
WACC	Weighted average cost of capital

Annexes

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 HSUPA 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 • 2G to 3G migration profiles for voice, SMS and low-speed data • average call durations, call attempts per call and ring time • PDP context activity proportion.

Description of sheets that compose 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 • coverage proportions • cell and site deployment proportions • radio capacities • HSPA activations • soft-handover factor • indoor/special sites and micro traffic proportion • switch capacity parameters • transmission capacity parameters • transmission proportions • business overhead capex-opex ratio • licence fees.
Operator.NwDes	Summarizes 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, shared) and category • network element lifetime, planning period, retirement delay • direct capex and opex per network element • indirect capex and opex multipliers/discounts.

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

Excel sheet	*Description*
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 rollout profile of GSM and UMTS networks.
DemCalc	Calculates the demand on the network: • radio BHE (total, 2G, 3G) • MSC BHCA (total, 2G, 3G) • SMS in the busy hour (BHSMS, and SMS/s) • data kbit/s, equivalent erlangs, BHMbit/s • wholesale billing system.
SubsCalc	Calculates the low-speed data user proportion of voice subscribers and active PDP contexts and SAU, as well as the MMS in the BH.
Nw_Des	Calculates network requirement for each part of the mobile network according to detailed network design algorithm, demand drivers and network design inputs, including: • 2G and 3G radio network • radio sites • main switching • transmission • other network elements.
Full_nw	Collates number of network elements required in each year according to demand drivers and network design rules.

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

Acronym	*Meaning*
NwDeploy	Calculates a smoothed number of network elements, and switches network element requirementsas 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.
CostTrends	Defines the capex and opex cost trends, and calculates 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 with number of network elements purchased in each year.
UnitOpExp	Calculates opex per network element according to base price and opex trend, including allowance for working capital
TotOpex	Calculates total operating expenditures by multiplying unit opex with number of network elements operated in each year

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

Acronym	*Meaning*
EconDep	Calculates annualised costs over time, in total and per unit output, according to PV of expenditures and PV of (*production output* x *price index*)
Common	Define 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 of 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

Annexes

The sources for the model inputs are mainly based on ANACOM, operators' data and Analysys Mason estimation

- We present the sources of the main inputs to the model in this annex
- The main sources for the model inputs include:
  - ANACOM statistics on the Portuguese market data and regulation – e.g. on spectrum yearly costs
  - operators' data whenever available, which can be used as an average, or as an indicator from which an Analysys Mason estimate is produced
  - Analysys Mason estimate, based on our broad experience in many costing models from different geographies, and from 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 easy reference in the model whenever possible

List of model inputs [1/10]

Model sheet	*Model inputs*	*Source*
Operator_Demand	Population	Euromonitor, ITU, EIU
	Mobile penetration	ANACOM, ITU, forecast Analysys Mason estimates
	Subscribers	ANACOM, forecast Analysys Mason estimates
	Traffic mobile on-net	ANACOM, forecast Analysys Mason estimates
	Outgoing traffic mobile to fixed	ANACOM, forecast Analysys Mason estimates
	Outgoing traffic mobile to off-net	ANACOM
	Outgoing traffic mobile to international	ANACOM
	Incoming traffic fixed to mobile	ANACOM
	Incoming traffic off-net to mobile	ANACOM
	Incoming traffic international to mobile	ANACOM
	Roaming in origination	ANACOM
	Roaming in termination	ANACOM
	SMS	ANACOM, forecast Analysys Mason estimates
	MMS	ANACOM, forecast Analysys Mason estimates
	Low-speed data volumes	Analysys Mason
	High-speed data subscribers	ANACOM, forecast Analysys Mason estimates

Source: Analysys Mason model

List of model inputs [2/10]

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
	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
Load_inputs	Busy days per year	Analysys Mason estimates
	Voice traffic profile	Analysys Mason estimates based on Portuguese data provided by operators

Source: Analysys Mason model

List of model inputs [3/10]

Model sheet	*Model inputs*	*Source*
Load_inputs	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
	Voice migration profile	Analysys Mason estimates based on operators' data and interviews
	SMS migration profile	Analysys Mason estimates based on operators' data and interviews
	Data migration profile	Analysys Mason estimates based on operators' data and interviews
	Average call durations	Analysys Mason estimates and Analysys Mason estimates based on Portuguese data provided by operators
	Call attempts per successful call	Analysys Mason estimates and Analysys Mason estimates based on Portuguese data provided by operators
	Ring time per call	Analysys Mason estimates
	Subscriber loading proportions	Analysys Mason estimates

Source: Analysys Mason model

List of model inputs [4/10]

Model sheet	*Model inputs*	*Source*
NwDes_Inputs	Spectrum, paired	Operators’ data
	900MHz channels	Operators’ data
	1800MHz channels	Operators’ data
	Primary GSM spectrum	Operators’ data
	2100MHz UMTS site radius	Analysys Mason estimates
	Cell loading radius effect (cell breathing)	Analysys Mason estimates based on Portuguese data provided by operators
	Selected loading per geotype	Analysys Mason estimates
	900MHz theoretical cell radius per geotype	Analysys Mason estimates and calibration
	1800MHz radii ratio to 900Mhz	Analysys Mason estimates and calibration process
	2100MHz radii ratio to 1800Mhz	Analysys Mason estimates and calibration process
	SNOCC	Analysys Mason estimates and calibration process
	Air interface blocking probability	Operators’ data average
	Population coverage for 900MHz, 1800MHz and UMTS	Analysys Mason estimates based on Portuguese data provided by operators
	Traffic proportions per geotype (if 100% covered)	Estimates based on Analysys Mason’s French MLRIC model
	Average sectorisation per macro site and geotype for 900MHz, 1800MHz and 2100MHz	Operators’ data average

Source: Analysys Mason model

List of model inputs [5/10]

Model sheet	*Model inputs*	*Source*
NwDes_Inputs	Deployment of secondary spectrum coverage sites on primary spectrum coverage sites	Analysys Mason estimates based on Portuguese data provided by operators
	Deployment of UMTS sites on GSM sites	Analysys Mason estimates based on Portuguese data provided by operators
	Deployment of sites for capacity, by spectrum type	Analysys Mason estimates based on Portuguese data provided by operators
	GSM sectoral spectrum re-use limit	Analysys Mason estimates / 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
	HS data activation per speed and geotype	Analysys Mason estimates based on Portuguese data
	UMTS R99 soft-handover	Analysys Mason estimates / technical standard
	GSM, number of special sites	Analysys Mason estimates based on Portuguese data provided by operators

Source: Analysys Mason model

List of model inputs [6/10]

Model sheet	*Model inputs*	*Source*
NwDes_Inputs	UMTS, number of special sites	Analysys Mason estimates based on Portuguese data provided by operators
	GSM, proportion of traffic carried on micro sites	Analysys Mason estimates based on Portuguese data provided by operators
	UMTS, proportion of traffic carried on micro sites	Analysys Mason estimates based on Portuguese data provided by operators
	Radio site deployment types	Analysys Mason estimates based on rounded average Portuguese data provided by operators
	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
	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

Source: Analysys Mason model

List of model inputs [7/10]

Model sheet	*Model inputs*	*Source*
NwDes_Inputs	Incremental interconnect logical routes per MSC (IN+OUT)	Analysys Mason estimates
	Network blocking probability	Analysys Mason estimates
	MSC local traffic multiplier	Analysys Mason estimates
	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 based on Portuguese population distribution
	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

Source: Analysys Mason model

List of model inputs [8/10]

Model sheet	*Model inputs*	*Source*
NwDes_Inputs	2G and 3G backhaul technologies per geotype	Analysys Mason estimates based on operators' data and interviews
	Leased line prices	ANACOM and Analysys Mason estimates
	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 characteristics	Analysys Mason estimates based on Portuguese data provided by operators
	Wholesale billing system	Analysys Mason estimates based on Portuguese data provided by operators

Source: Analysys Mason model

List of model inputs [9/10]

Model sheet	*Model inputs*	*Source*
NwDes_Inputs	Initial spectrum payments	ANACOM and Analysys Mason estimations
	Spectrum yearly fees	ANACOM and Analysys Mason estimations
	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	MapInfo data
	Geotype per freguesia	Analysys Mason estimates based on density analysis of freguesias
SubsCalc	Mobile data user proportion - low-speed	Analysys Mason estimates
	Mobile data user proportion - high-speed	Analysys Mason estimates
	MMS per mobile data user (low-speed) per year	ANACOM, forecast Analysys Mason estimates
Nw_Des	RNC minimum number of ports	Analysys Mason estimates

Source: Analysys Mason model

List of model inputs [10/10]

Model sheet	*Model inputs*	*Source*
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
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

Source: Analysys Mason model

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