Development of Bottom-up Long-Run Incremental Cost (BU-LRIC) Models

Description of the BU-LRIC Model for Mobile Networks

29 May 2017

Contents

1. Introduction

This report describes the modelling approach, model structure and calculation process followed in the development of the Bottom-up Long-Run Incremental Cost (BU-LRIC) Model for mobile networks ('the model') commissioned by the Caribbean Telecommunications Authority (hereinafter, the ECTEL or the Authority) from Axon Partners Group (hereafter, Axon Consulting).

The model has the following main characteristics:

- It calculates the network cost of the services under the LRIC+ cost standard, which includes common costs
- It is based on engineering models that allow the consideration of a multi-year time frame (2015-2020)[1]

This section presents the main methodological aspects that have been considered in the development of the model and provides an overview of the structure of this document.

1.1. Methodological choices

Methodological choices are determined in the document "*Final Principles Methodologies Guidelines*" (hereinafter, 'the Methodology'), published on ECTEL´s website[2]

The following exhibit contains a summary of the methodological framework that has been established to develop the model:

[1] The model can be extended in future updates up to a total of 25 years
[2] https://www.ectel.int/principles-methodologies-and-guidelines-for-the-determination-of-new-interconnection-rates/

Methodological Issue	Approach Adopted
Cost elements considered	This model considers the following cost elements: ▶ Network CapEx ▶ Network OpEx ▶ Licenses and frequency usage fees ▶ G&A costs ▶ Cost of capital
Treatment of OpEx	OpEx is preferably based on bottom-up calculations. In those specific cases where there is not enough information available, it is obtained as a percentage over CapEx.
Assets valuation method	Use of a static current cost accounting approach, by which all the assets are valued every year based on their price that year. Assets may be substituted for a modern equivalent asset.
Annualisation method	Tilted annuities method is used for all the assets
Cost standard	LRIC+ standard is used to obtain the cost of the services modelled.
Network dimensioning optimisation	Use of a yearly approach, by which the number of assets for a given year is calculated, without taking into consideration the network status in previous years.
Time period	The model includes historical data (since 2015), as well as forecasted data (up to 2020) to represent the future network roll-out.
Operator Modelled	The model considers a hypothetical with a market share between 33% and 50% for each Member State.
List of services considered	Services are broken down according to their type (i.e. voice, data, SMS) and their destination/origin (i.e. on-net, outgoing, incoming). Additionally, the model performs an internal disaggregation of the services as per the technology used for their provision in order to allow a proper modelling of each network considered (GSM, UMTS, LTE).

Methodological Issue	Approach Adopted
Definition of the increments	Increments are defined based on service type, differentiating between voice and data and other services.
Geotypes	Geotypes are based on population centres (considering their population, population density and density of population centres) as well as their orography.
Network topology	The model will use a scorched earth approach to model the access network and a modified scorched node approach to model the core network.
Mobile Access Technologies	The model uses a combination of 2G/3G/4G technologies, according to the availability of each for the operators.
Transmission technologies	Incorporates the following mix of technologies: ▶ Microwaves ▶ Leased lines ▶ Own fibre links
Core Network and Backbone	Considers a 3Gpp legacy core network for the 2G and 3G access technologies and an evolved core network for the 4G access.

Exhibit 1.1: Summary of the methodological framework. [Source: Axon Consulting]

1.2. Structure of the document

The remaining sections of this document describe:

- The modelling approach
- The model structure
- The calculation process

The document is structured as follows:

- General Architecture of the Model: introduces the general structure of the model, from the demand module to the network dimensioning and costing modules
- Model : introduces the main inputs needed for the model

- Dimensioning Drivers: examines the conversion of traffic (at service level) to network parameters (for example, Erlangs and Mbps) facilitating the dimensioning of network resources
- Geographical Analysis: presents the treatment performed to the geographical area of the Sultanate in order to adapt it to the needs of the BULRIC Model
- Dimensioning Module: illustrates the criteria followed in order to design the network and calculate the number of resources required to meet coverage and capacity constraints
- Cost Calculation Module: shows expenditure calculations (CapEx and OpEx) associated to the network resources dimensioned in the dimensioning module
- Depreciation Module: presents the calculation of the depreciation method to distribute CapEx over the years (annualisation)
- Incremental Costs Calculations: includes further explanations about the calculation of costs under LRIC+ standard

Finally, a user manual has been produced and is provided as a separate document.

2. General Architecture of the Model

This chapter of the document introduces the general structure of the model. The following figure shows the function blocks and their interrelationship within the model.

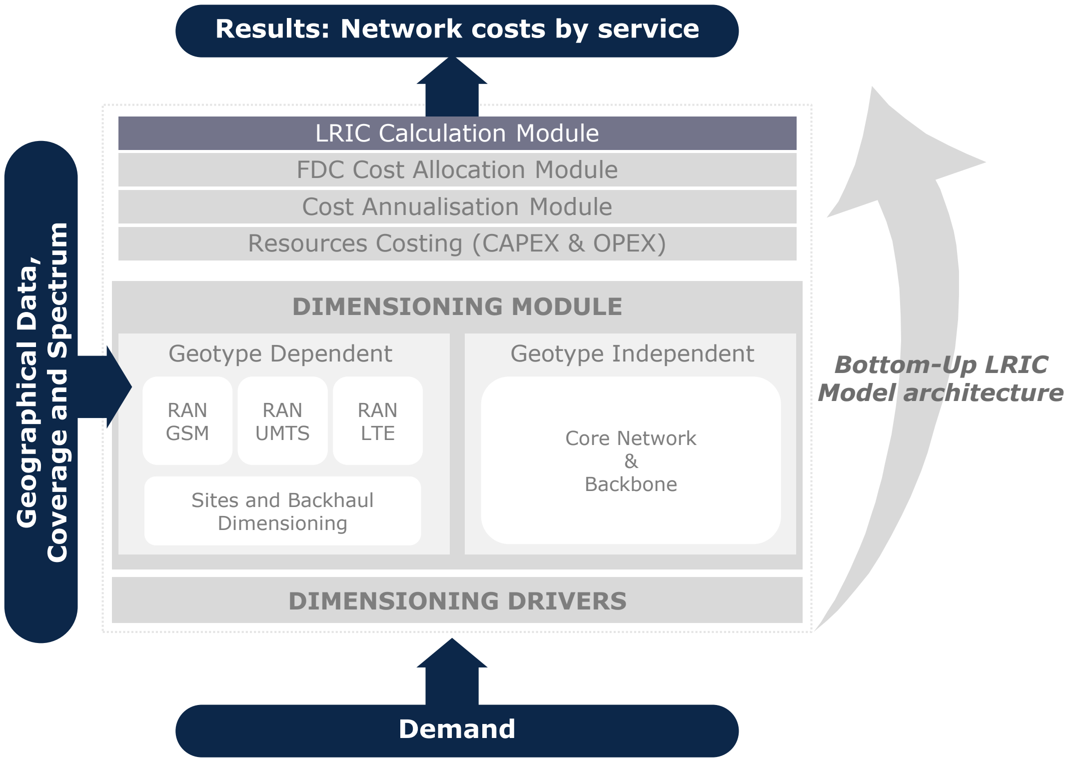

Exhibit 2.1: Structure of the model [Source: Axon Consulting]

Several function blocks can be identified but, as a first classification, the following parts are described below:

- Dimensioning drivers: Converting traffic into dimensioning drivers, later assisting in dimensioning network resources
- Dimensioning module: Computing the number of resources and building the network that can supply the main services provided by the reference operator. It comprises different modules such as GSM, UMTS, LTE, sites, and backhaul, backbone and core network

The estimated traffic for all modelled services is used by the Dimensioning Module.

Additionally, geographical data is introduced in the dimensioning module to take into consideration the relevant geographical aspects of each Member State.

The model recognises that the different parts of the reference operator's network can be geotype-dependent or -independent. For example, the dimensioning process corresponding to GSM, UMTS, LTE, Sites and Backhaul is distinctive and independent for each geotype.

- Dimensioning drivers: Converting traffic into dimensioning drivers, later assisting in dimensioning network resources
- Cost calculation (CapEx and OpEx): calculating cost of resources obtained after network dimensioning, both in terms of CapEx and OpEx
- Annualisation module: allocating CapEx resources costs over time following under the methodology defined, i.e., employing a tilted annuities method.
- Cost imputation to services module: calculating the costs of services by means of resources costs imputation to different services according to a Fully Distributed Cost (FAC) approach
- Incremental costs calculation module: obtaining pure incremental costs related to the different increments (each increment is defined as a group of services) and common costs

The following sections further develop each block of the model:

3. Model Inputs

By definition, the main input for a BU-LRIC model is the demand that should be satisfied by the network to be dimensioned. However, additional data is required. The following list describes the main inputs that are needed for the BULRIC Model:

- Coverage: the coverage achieved (usually measured as a percentage of population covered) has a considerable impact on the results of the model. Therefore, historical and forecast coverage by geotype is input in the model
- Spectrum: the main constraint for the development of mobile networks. It is also important to consider the allocation of spectrum bands to technologies. This input can vary along the time frame considered and can be different for each geotype
- Geographical information: for the dimensioning of the network, certain information about the countries needs to be considered. This information is aggregated into geotypes with homogeneous characteristics (e.g. population density, orography). Additionally, the characterisation of the core network is needed (e.g. core locations, links). Geographical information is produced by using public information (e.g. coordinates and population of the population centres)
- Traffic statistics: for the dimensioning of the network it is necessary to know certain statistics of the network (e.g. concentration of traffic in the busy hour, average call duration)
- Network dimensioning parameters and equipment capacity: dimensioning algorithms need information about the characteristics of the equipment. A number of them are common among manufacturers or are fixed by the technology or the standard

4. Dimensioning Drivers

The rationale of the dimensioning drivers is to express traffic and demand (at service level) in a way that facilitates the dimensioning of network resources.

This section presents the following features of the dimensioning drivers:

- Concept
- Mapping services to drivers
- Conversion factors from services to drivers

4.1. Dimensioning drivers concept

The recognition of dimensioning "drivers" is intended to simplify and increase the transparency of the network dimensioning process.

Dimensioning drivers represent, among others, the following requirements:

- Erlangs
- UMTS bearers CS12,2 (Channel Switched 12,2Kbps is used for voice calls) and CS64 (Channel Switched 64Kbps is used for video calls)
- Mbps for packet switching carriers GPRS / EDGE / UMTS / HSPA (divided into uplink and downlink)
- Mbps for transmission through the core network
- Total number of subscribers for the dimensioning of HLR

The following list contains the drivers used in the BULRIC model:

VARIABLE
DRIV.GSM.VOICE.Channels
DRIV.GSM.GPRS.Download Channels
DRIV.GSM.EDGE.Download Channels
DRIV.GSM.SIGNAL.Channels
DRIV.UMTS.CS.Voice
DRIV.UMTS.CS.VideoCalls
DRIV.UMTS.Data PS.PS64-DL
DRIV.UMTS.Data PS.PS64-UL
DRIV.UMTS.Data PS.PS128-DL
DRIV.UMTS.Data PS.PS128-UL
DRIV.UMTS.Data PS.PS384-DL

VARIABLE
DRIV.UMTS.Data PS.PS384-UL
DRIV.UMTS.Data HSPA-B.HSPA-Best Effort-DL
DRIV.UMTS.Data HSPA-B.HSPA-Best Effort-UL
DRIV.UMTS.Data HSPA-QoS.HSPA-Gold-DL
DRIV.UMTS.Data HSPA-QoS.HSPA-Gold-UL
DRIV.UMTS.Data HSPA-QoS.HSPA-Real Time-DL
DRIV.UMTS.Data HSPA-QoS.HSPA-Real Time-UL
DRIV.UMTS.SIGNAL.SIGNAL
DRIV.LTE.Data LTE-B.Best Effort-DL
DRIV.LTE.Data LTE-B.Best Effort-UL
DRIV.LTE.Data LTE-QoS.Gold-DL
DRIV.LTE.Data LTE-QoS.Gold-UL
DRIV.LTE.Data LTE-QoS.Real Time-DL
DRIV.LTE.Data LTE-QoS.Real Time-UL
DRIV.LTE.SIGNAL.SIGNAL
DRIV.BACKHAUL 2G.VOICE.GSM
DRIV.BACKHAUL 2G.DATA.GPRS/EDGE
DRIV.BACKHAUL 2G.SMS-MMS.GSM
DRIV.BACKHAUL 3G.VOICE.UMTS
DRIV.BACKHAUL 3G.VIDEOCALL.UMTS
DRIV.BACKHAUL 3G.DATA.UMTS/HSPA Best Effort
DRIV.BACKHAUL 3G.DATA.HSPA Gold
DRIV.BACKHAUL 3G.DATA.HSPA Real Time
DRIV.BACKHAUL 3G.DATA.UMTS SMS-MMS
DRIV.BACKHAUL 4G.DATA.LTE Best Effort
DRIV.BACKHAUL 4G.DATA.LTE Gold
DRIV.BACKHAUL 4G.DATA.LTE Real Time
DRIV.BACKHAUL 2G.SIGNAL.GSM
DRIV.BACKHAUL 3G.SIGNAL.UMTS
DRIV.BACKHAUL 4G.SIGNAL.LTE
DRIV.CORE NGN 2G.BHCA.2G
DRIV.CORE NGN 3G.BHCA.3G
DRIV.CORE NGN 4G.BHCA.4G
DRIV.CORE CS_PS.TRAFFIC.CORE VOICE/VIDEO/SMS/MMS
DRIV.CORE CS_PS.TRAFFIC.CORE DATA
DRIV.CORE 2G TRAFFIC.TRAFFIC.CORE 2G TRAFFIC
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VARIABLE
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DRIV.CORE SMS.TRAFFIC.SMS 3G
DRIV.CORE SMS.TRAFFIC.SMS 4G
DRIV.CORE MMS.TRAFFIC.MMS 2G
DRIV.CORE MMS.TRAFFIC.MMS 3G
DRIV.CORE MMS.TRAFFIC.MMS 4G
DRIV.CORE.TRAFFIC.BHCA 2G
DRIV.CORE.TRAFFIC.BHCA 3G
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DRIV.CORE 3G SUBS.TOTAL SUBSCRIBERS.TOTAL 3G SUBSCRIBERS
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DRIV.CORE 2G SUBS SAU.SUBSCRIBERS.SAU 2G
DRIV.CORE 3G SUBS SAU.SUBSCRIBERS.SAU 3G
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DRIV.CORE.SUBSCRIBERS.DATA SAU 4G
DRIV.CORE IX.TRAFFIC.IX CS
DRIV.CORE II.TRAFFIC.IX DATA
DRIV.CORE IX.SIGNAL.IX CS
DRIV.CORE II.SIGNAL.IX DATA
DRIV.CORE 2G MULT IX.TRAFFIC.Multimedia IX 2G
DRIV.CORE 3G MULT IX.TRAFFIC.Multimedia IX 3G
DRIV.CORE 4G MULT IX.TRAFFIC.Multimedia IX 4G
DRIV.CORE ERLANGS.TRAFFIC.CS 2G-3G
DRIV.CORE BILLING.BILLING.EVENTS 2G
DRIV.CORE BILLING.BILLING.EVENTS 3G
DRIV.CORE BILLING.BILLING.EVENTS 4G

Exhibit 4.1: List of Drivers used in the model (Sheet '0D PAR DRIVERS'). [Source: Axon Consulting]

Two steps are required to calculate the drivers:

1. Mapping services to drivers
2. Converting traffic units into the corresponding driver units

These steps are discussed below in more detail.

4.2. **Mapping internal services to drivers**

To obtain drivers it is necessary to indicate which services are related to them. It should be noted that a service is generally assigned to more than one driver, as drivers represent traffic in a particular point of the network.

This operation is performed at the internal service level, with information regarding the technological disaggregation. These services are only defined internally in the model as a disaggregation of the so-called 'external services' (the services whose cost is ultimately calculated in the model that do not differentiate between technology). This disaggregation is based on the data regarding the split of traffic among technologies provided by operators.

For example, voice calls on net should be contained in both the drivers used to dimension radio access and those used for the core network.

The following exhibit shows an excerpt of the mapping of services into drivers:

List of relationships	
SERVICE (Variable Name)	**DRIVER (Variable Name)**
UMTS.Voice.On-net.Retail.On-net	DRIV.UMTS.CS.Voice
UMTS.Voice.On-net.Retail.On-net to voicemail	DRIV.UMTS.CS.Voice
UMTS.Voice.On-net.Retail.On-net to directory assistance	DRIV.UMTS.CS.Voice
UMTS.Voice.On-net.Retail.On-net to customer services	DRIV.UMTS.CS.Voice
UMTS.Voice.On-net.Retail.On-net to emergency services	DRIV.UMTS.CS.Voice
UMTS.Voice.Outgoing.Retail.Off-net to other mobile	DRIV.UMTS.CS.Voice
UMTS.Voice.Outgoing.Retail.Off-net to fixed	DRIV.UMTS.CS.Voice
UMTS.Voice.Outgoing.Retail.Off-net to international	DRIV.UMTS.CS.Voice
UMTS.Voice.Outgoing.Wholesale.MVNO - Origination	DRIV.UMTS.CS.Voice
UMTS.Voice.Incoming.Wholesale.MVNO - Termination	DRIV.UMTS.CS.Voice
UMTS.Voice.Incoming.Wholesale.Incoming from national	DRIV.UMTS.CS.Voice
UMTS.Voice.Incoming.Wholesale.Incoming from international	DRIV.UMTS.CS.Voice

Exhibit 4.2: Except from the Mapping of Services into Drivers. (Sheet '3B MAP SERV2DRIV') [source: Axon Consulting]

4.3. **Conversion factors from services to drivers**

Once services have been mapped to drivers, volumes need to be converted to obtain drivers in proper units.

For that purpose, a conversion factor that represents the number of driver units generated by each demand service unit has been developed. In general, the calculation of conversion factors consists of six sub-factors, in compliance with the following structure:

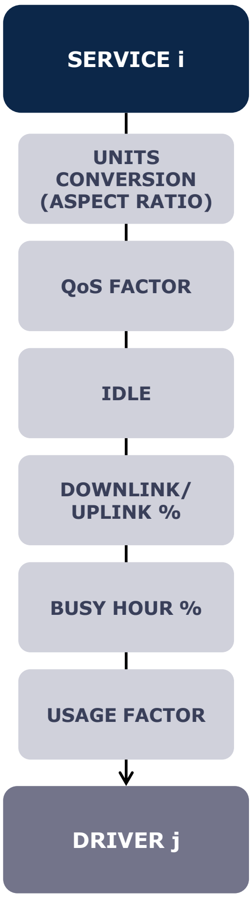

Exhibit 4.3: Conversion process from services to drivers. [Source: Axon Consulting]

The conversion factor thus includes the following items:

1. Units conversion (UC)
2. Qos conversion factors (QoS)
3. Idle Time (IT)
4. Downlink/Uplink Ratio (DLUL)
5. Busy Hour factor (BH)
6. Usage factor (UF)

Conversion factors are obtained from sub-factors in accordance with this formula:

$$FC = UC * QoS * DLUL * BH * UF * (1 + IT)$$

Unit conversion represents the need to adapt services units (e.g. minutes) to those used by the driver (e.g. call attempts).

For example, in the case of converting voice minutes to call attempts the following factor would be applied:

$$UC = \frac{1 + PNR + PNA}{TM}$$

Where PNR is the percentage of non-attended calls, PNA is the percentage where the recipient is not available (device off, out of coverage, etc.), and TM is the average call time in minutes.

The **quality of service** represents the dimensioning factor required to meet all QoS goals in the busy hour.

For circuit-switched and packet-switched services with QoS, it is necessary to apply Erlang tables to reach the adequate dimensioning for a given blocking probability[3].

Idle time represents the difference between the conveyed traffic from the users' viewpoint and the required resource consumption the network needs to face.

For the calculation of idle-time factor the following aspects have been taken into account:

- Time required to set up the connection, which is not considered as time of service.

  It represents waiting time until the recipient picks up the phone to accept the call. During that time an actual resources assignation is produced. For the calculation of the factor this formula is used:

  $$Connection\ Time\ Percentage = ART/ACD$$

  Where ART it is the average ringing time and ACD the average duration time of the call.

- Missed calls: Non-attended calls, for general recipient unavailability.

  This factor even takes into consideration communications to notify the impossibility of completing the call.
  This is the formula used:

  $$\%\ of\ not\ attended\ calls = \frac{\frac{PNRC}{1-PNRC-PO} * ART + \frac{PO}{1-PNRC-PO} * AT}{ACD}$$

  Where PNRC represents the percentage of non answered calls, PO is the percentage of calls where the recipient is busy, ART is the average ringing time and AT is the duration time of the message indicating the failure to establish the call.

[3] For the access drivers, QoS is directly considered during the dimensioning process, making direct use of Erlang tables.

- Inefficiencies in resource usage: this factor, which is very common in data communications, represents the time a user is assigned a channel even if it is neither receiving, nor transmitting data (due to burstiness of data traffic). Although the technologies under consideration have systems for resources reassignment, a share of network capacity will be lost. This inefficiency factor is highly dependent on the technology used and the features of the typology of data traffic. To obtain the parameter the following formula is employed:

$$\% \text{ of employed traffic} = \text{Bmax} * \frac{(\text{ts} + \text{tc})}{Bav * ts} - 1$$

  Where Bmax it is the maximum bit rate assigned to the user, ts the average time of assigned slot, tc the resources reconfiguration time and Bav the average bit rate employed by the user. These parameters may vary in relation to the technologies used.

The **downlink/uplink ratio** applies to data transmission services and represents the percentage of the service's total traffic carried in each direction, that is, the percentage of data sent or received by the user.

It should be pointed out, that, for dimensioning purposes, it is necessary to know the amount of data transmitted in one direction (the more dominant for GSM) or in both (for UMTS dimensioning is done separately to satisfy both uplink and downlink demand).

Busy hour factor represents the percentage of traffic that is carried in one busy hour over the total yearly traffic.

Usage factor represents the number of times a service makes use of a specific resource. For example, when obtaining drivers used for access network dimensioning, it is necessary to ensure that on-net services will use two radio accesses (one for the caller and one for the receiver). On the contrary, off-net and termination services will use just one radio access.

However, when obtaining drivers for core dimensioning, it is necessary to consider that, for example, not all GSM calls will make use of MSC-MSC transmission, since a percentage will be made within the same MSC and therefore won't be passed on through main core rings.

Usage factor then reflects the average effect of "routing" of different services through network topology.

5. Geographical Analysis

5.1. Introduction

The design of mobile access networks is highly dependent on the geographical characteristics of the zone to be covered, as well as on the demand.

The main purpose of this analysis is to aggregate the areas with similar characteristics (e.g. population density, orography) into geotypes. Geotypes will be used for the dimensioning of access and backhaul networks, which is detailed in section 6.

As defined in the methodology, the modelling approach depends on the network segment as follows:

- Access network: based on a scorched earth approach. This requires an analysis of the population centres in order to model a network from scratch.
- Core network: based on a scorched node approach. In this case, an understanding the networks deployed by the operators is necessary.

5.2. Geographical analysis for access network

The steps below have been followed in the geographical analysis for the access network (including radio access nodes and backhaul transmission):

1. Break down of the country into samples
2. Assignment of population centres to samples
3. Orography recognition
4. Aggregation of samples into geotypes, considering roads as a sample-independent geotype

These steps followed for each Member State.

5.2.1. Break down the country into samples

The first step consists of the division of the total area of the country into samples. Each sample represents a square containing a number of population centres (e.g. cities, villages).

The following exhibit shows an example of the grid used for breaking down the member states into samples (each small square is a sample):

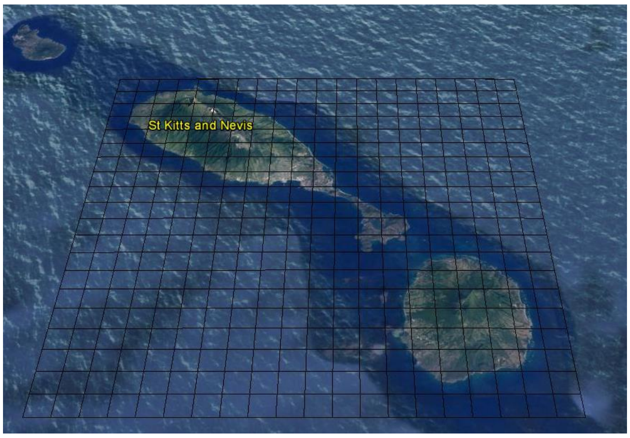

Exhibit 5.1: Illustrative example of grid applied to an area of a member state. [Source: Axon Consulting]

5.2.2. Assigning population centres to samples

Once the grid is defined, the population centres[4] are assigned to the sample in which they are located. The following exhibit illustrates the process of allocation:

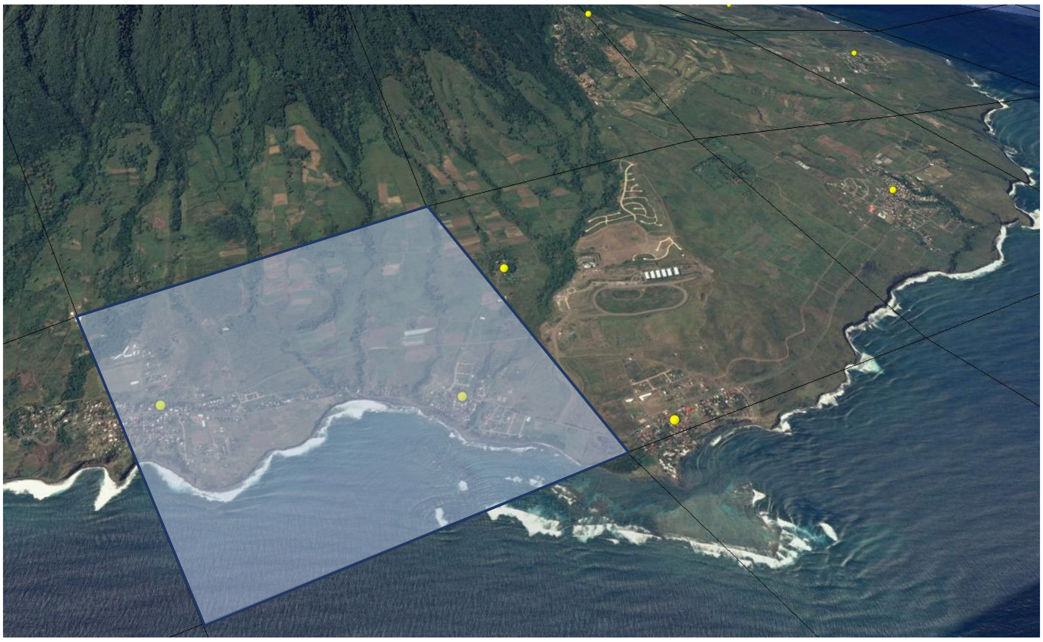

Exhibit 5.2: Illustrative example of aggregation of population centres (yellow circles) into samples (blue square) [Source: Axon Consulting]

This process has been followed for all the population centres existing in the countries analysed.

[4] Population centre names, coordinates and population have been extracted from www.geonames.org

The result of this step is the number of population centres and the population contained in each sample. This information will be used later on to define the geotypes.

5.2.3. **Orography recognition**

The orography is one of the most limiting geographical characteristics of mobile networks. It is relevant because it has a direct effect on the area covered by one base station and, therefore, to the number of sites needed. For instance, radio coverage is lower in highly mountainous areas than in flat ones.

For the recognition of the orography characteristics of the samples, several measures of elevation have been made in different points of each sample.

The following figures provide an example of the orography measurement followed.

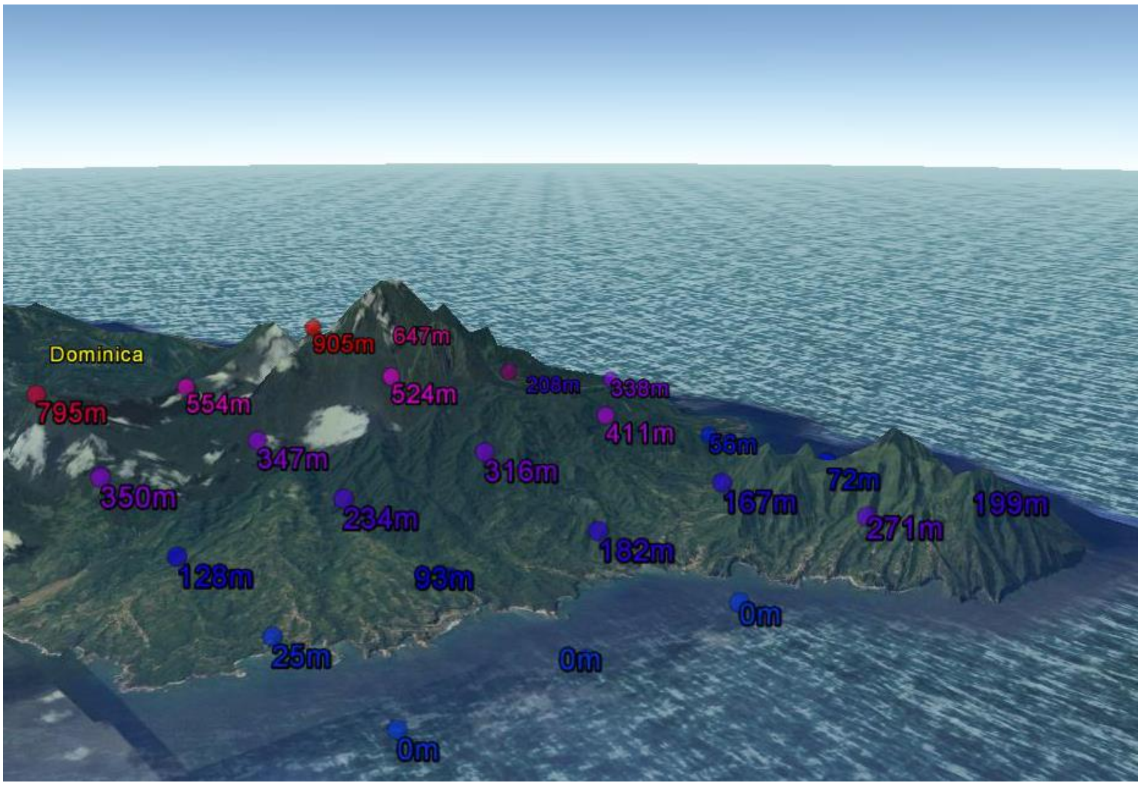

Exhibit 5.3: Illustrative example of orography measurement process [Source: Axon Consulting]

Once the measures are obtained, the difference between the highest and lowest elevation points surrounding the population centres will represent its orography (the higher the difference, the more mountainous the sample). The difference is called "delta".

5.2.4. **Aggregation of samples into geotypes**

Once the information of all the samples has been obtained (i.e. population centres, population), samples with the same characteristics are aggregated into geotypes. For the definition of geotypes the following parameters have been used:

- Population
- Population density
- Population centres per km^2
- Elevation delta

In the figure below a schematic representation of the variables used to organise the classification of samples into geotypes is provided:

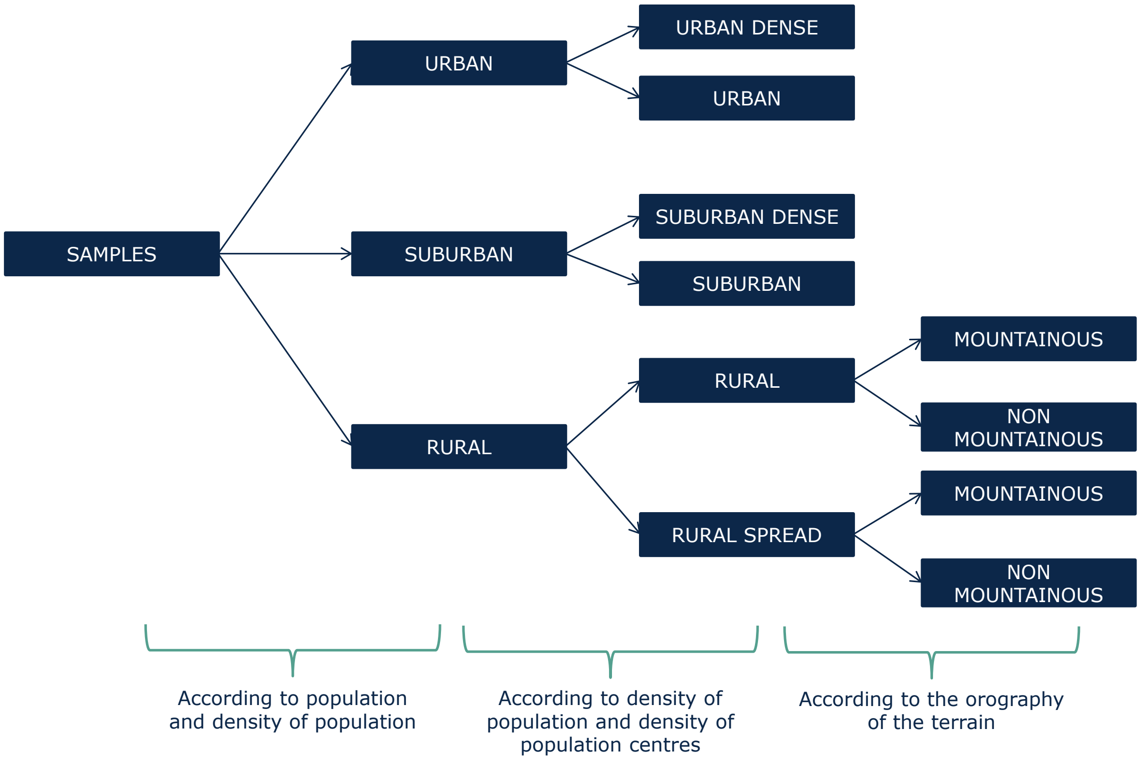

Exhibit 5.4: Classification of samples into geotypes. [Source: Axon Consulting]

The exhibit below describes the specific criteria that have been used to identify each geotype:

GEOTYPE	Description
URBAN_DENSE	▶ Samples with a population higher than 3000 Inhab and a density of population higher than 900 Inhab/km2
URBAN	▶ Samples with either a population higher than 3000 Inhab or a density of population ranging from 750 to 900 Inhab/km2
SUBURBAN_DENSE	▶ This geotype contains samples with a population between 1500 and 3000 and a population density higher than 600 Inhab/km2
SUBURBAN	▶ This geotype contains samples with a population between 1500 and 3000 and a population density from 375 to 600 Inhab/km2
RURAL-NON MOUNTAINOUS	▶ Samples with more than 0.3 pop centres per km^2, with less than 1500 Inhab and with an elevation delta of less than 100 metres
RURAL-MOUNTAINOUS	▶ Samples with more than 0.3 pop centres per km^2, with less than 1500 Inhab and with an elevation delta of more than 100 metres
RURAL_SPREAD-NON MOUNTAINOUS	▶ Samples with less than 0.3 pop centres per km^2, with less than 1500 Inhab and with an elevation delta of less than 100 metres
RURAL_SPREAD-MOUNTAINOUS	▶ Samples with less than 0.3 pop centres per km^2, with less than 1500 Inhab and with an elevation delta of more than 100 metres

Exhibit 5.5: Description of the geotypes identified [Source: Axon Consulting]

After taking these considerations into account, the population centres of all the countries have been aggregated into geotypes; see Annex A.

5.3. **Geographical analysis for core network**

The analysis geographical analysis for the core network involves defining where core nodes are located, where traffic is aggregated and the characteristics of the links that make up the backbone.

In order to do so, we have analysed the information provided by the operators to define the core and backbone networks that would be installed by the reference operator. The core network defined for each member state is summarised in Annex A.

6. Dimensioning Module

The dimensioning module aims to design the network and dimension the network resources required to serve the reference operator's traffic. This section presents this module's characteristics:

- Considerations on network node configuration
- Considerations on spectrum
- Radio access dimensioning GSM/GPRS/EDGE
- Radio access dimensioning UMTS/HSPA
- Radio access dimensioning LTE
- Radio site dimensioning
- Backhaul network dimensioning
- Core network dimensioning

6.1. Considerations on network nodes configuration

From a general point of view, a mobile network can be seen as a combination of:

- A set of nodes of different type and functionalities
- A set of links connecting them

The exercise of network configuration design entails a decision on the dimensioning algorithms. As stated in the methodology, a scorched earth approach was selected as the methodology in order to dimension the access network of the reference operator and a modified scorched node approach was selected to model the core network. The use of this method is defined below for both access and core networks:

- Access network: The implementation of a scorched earth approach for the access network comprises the steps described below:
    1. The model will estimate the number of radio sites required per technology and geotype to meet the coverage target.
    2. The model will calculate the radio equipment required per technology and geotype, to meet capacity requirements.
- Core network: in this case, the position is more relevant (especially for the dimensioning of the backbone links) and may depend on political, economic,

demographic and geographic issues. Therefore, the number and location of the core nodes will be based on the operators' existing nodes.

6.2. Considerations on spectrum

An important feature of the model is the configuration of the available spectrum for radio access networks. The amount of available spectrum (bandwidth in MHz) for the reference operator and the portion assigned to each different technology is composed of a series of entry values for each available band, technology and geotype.

The following parameters need to be taken into account when introducing available spectrum in the model: technology modularity and minimum band required for each technology.

- Modularity: An integer number of spectrum modules need to be assigned to each technology. In practice, available modules are:
  - GSM: 0,2 MHz
  - UMTS: 5 MHz
  - LTE allows several bands: 1,4, 3, 5, 10, 15 and 20 MHz
- Minimum bandwidth: This represents the minimum spectrum required to build a coverage network. In case of UMTS, the minimum spectrum is equal to the minimum module (5 MHz). Nevertheless, for GSM the frequency reuse factor also needs to be considered (commonly 12 if using tri-sectorial cells). Therefore, for GSM the minimum spectrum that can be assigned is 12*0.2 MHz = 2.4 MHz.

6.3. Radio access dimensioning GSM/GPRS/EDGE

6.3.1. Presentation of the algorithm for radio network dimensioning GSM/GPRS/EDGE

The dimensioning algorithm for GSM (including GPRS and EDGE) is organised into six steps, as shown in the chart below. Like in other dimensioning modules, this algorithm runs separately for each of the geotypes considered.

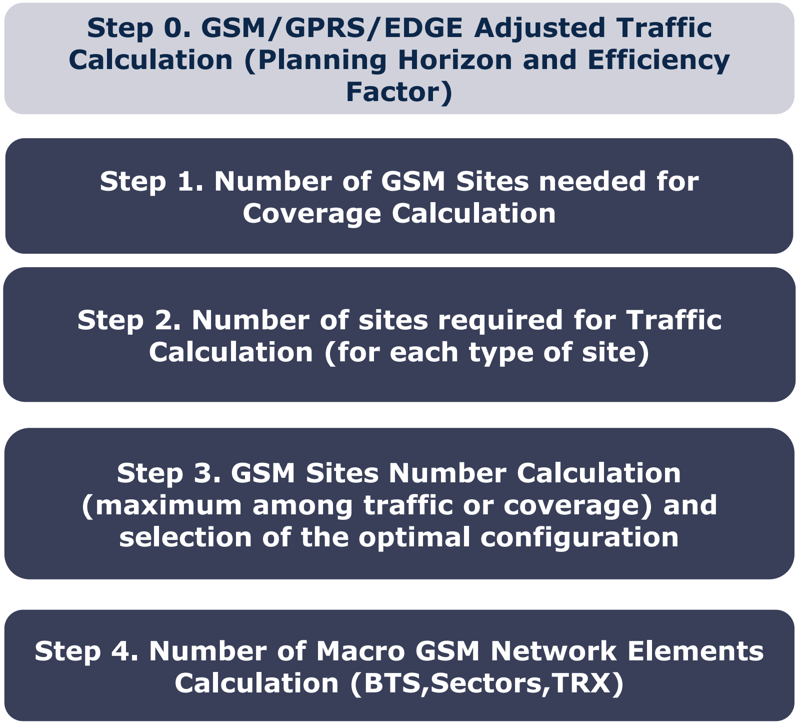

Exhibit 6.1: Steps for Radio Dimensioning GSM / GPRS / EDGE. [Source: Axon Consulting]

The dimensioning algorithm for GSM radio access network is implemented in the '6A CALC DIM GSM' sheet of the model. Each step is explained in further detail in the following subsections.

6.3.2. Step 0. Calculation of adjusted traffic (planning horizon and network efficiency factor)

A preliminary step to dimensioning GSM/GPRS/EDGE networks is the calculation of traffic to be used in the traffic dependent part of the network. In the calculation of this traffic, denominated "adjusted traffic", two factors are involved:

1. The effect of the planning horizon: when the network is being designed, forecast demand is taken into account to avoid necessary upgrades in the short term.
2. The overcapacity needed for security reasons.

The GSM radio network dimensioning based on traffic is done using the drivers listed below:

- DRIV.GSM.VOICE.Channels
- DRIV.GSM.GPRS.Download Channels
- DRIV.GSM.EDGE.Download Channels
- DRIV.GSM.SIGNAL.Channels

Drivers are broken down by voice, signalling and data, distinguishing between GPRS and EDGE. All drivers are measured in dimensioning channels.

These drivers are calculated based on traffic demand. Please note the following:

- As it has been stated previously, for mapping voice traffic on Erlangs, a percentage of "idle" or inactive traffic was added to represent unbilled time, but during which the network is used (e.g. time until the recipient picks up the phone, calls not answered). A factor is applied to this "increased" traffic to calculate the number of channels required (according to the Erlang B formula) for a given blocking probability.
- Regarding data services, an "idle" occupancy rate of the channel is taken into consideration to model the time during which the user is assigned a channel but is neither transmitting nor receiving any data. The system has automatic mechanisms to detect and remove resources when not in use, but this is not an instantaneous process. Therefore, this parameter reflects the delay between the moment the user stops sending or receiving data and the moment the system reallocates the unoccupied resources.
- Signalling drivers are those that consider the time required for transmission of SMS (and requests for using the channel), transmissions to coordinate call establishment, frames for periodic location update and handover processes depending on the number of active users.

For all drivers outlined above, the busy hour percentage and the factor of use of radio access service apply depending on whether the services are on-net (using the radio network at both ends of the communication) or off-net (using a single communication endpoint).

6.3.3. Step 1. Calculation of number of sites required for coverage

The calculation of equipment requirements for coverage is worked out for each geotype.

The model is able to calculate the minimum number of sites required for coverage for both GSM 700-900MHz and 1800-2600MHz bands.

The site coverage radius is adjusted depending on geotype class by defining a percentage over the maximum radius, which is a function of the propagation conditions for each class of geotype.

The diagram below illustrates the calculation of the minimum number of sites associated with GSM coverage.

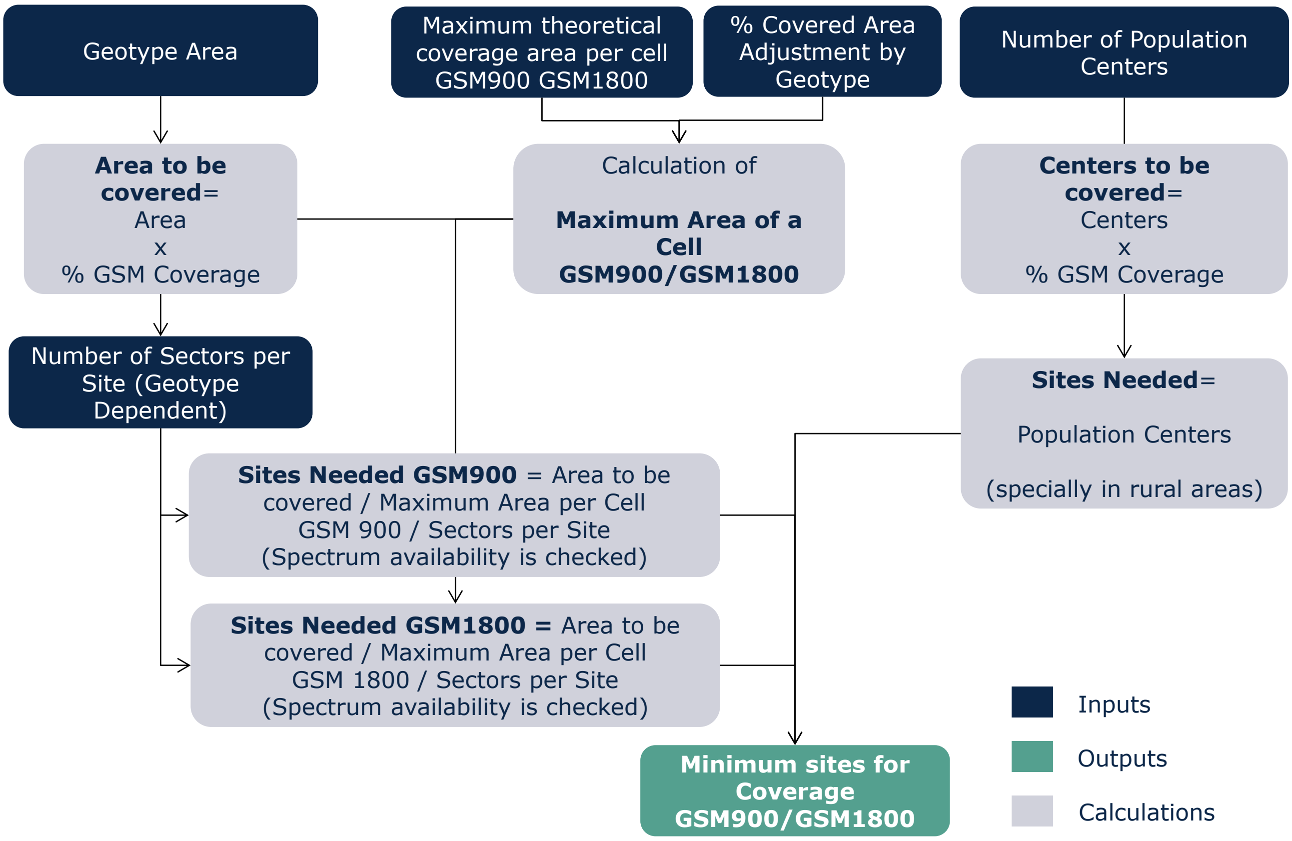

Exhibit 6.2: Algorithm for calculating number of sites for GSM coverage (step 1). [Source: Axon Consulting]

The maximum coverage area per cell is calculated according to the formula:

$$MaximumCellArea = \frac{3 \times \sqrt{3}}{2} \times (MaxRadius \times RadiusReductionFactor)^2$$

Where MaxRadius represents the maximum coverage radius (different for GSM700-900 and GSM1800-2600), RadiusReductionFactor is a reduction factor of the maximum coverage radius depending on geotype, and the constant factor corresponds to the area of a hexagon.

The number of required sites to cover the geotype in a band is obtained by dividing the area to be covered by the Area per site (Maximum Cell Area multiplied by the number of sectors).

Additionally, it is common in spread areas to deploy the coverage based on the population centres. That is, cells are not intended to cover all the area but only the populated centres. This option can be selected by geotype, being the default option to be applied only in rural geotypes.

6.3.4. **Step 2. Calculating the number of GSM sites for macro cells required in terms of traffic**

The third step is to determine the number of necessary sites to serve voice and data traffic demand as well as associated signalling requirements. The diagram below shows the dimensioning algorithm used for this purpose.

Please note this algorithm is used for different potential configurations of the sites, depending on the number of sectors (2 or 3) and spectrum bands used. The two sector cells are applicable only for roads or railways geotypes.

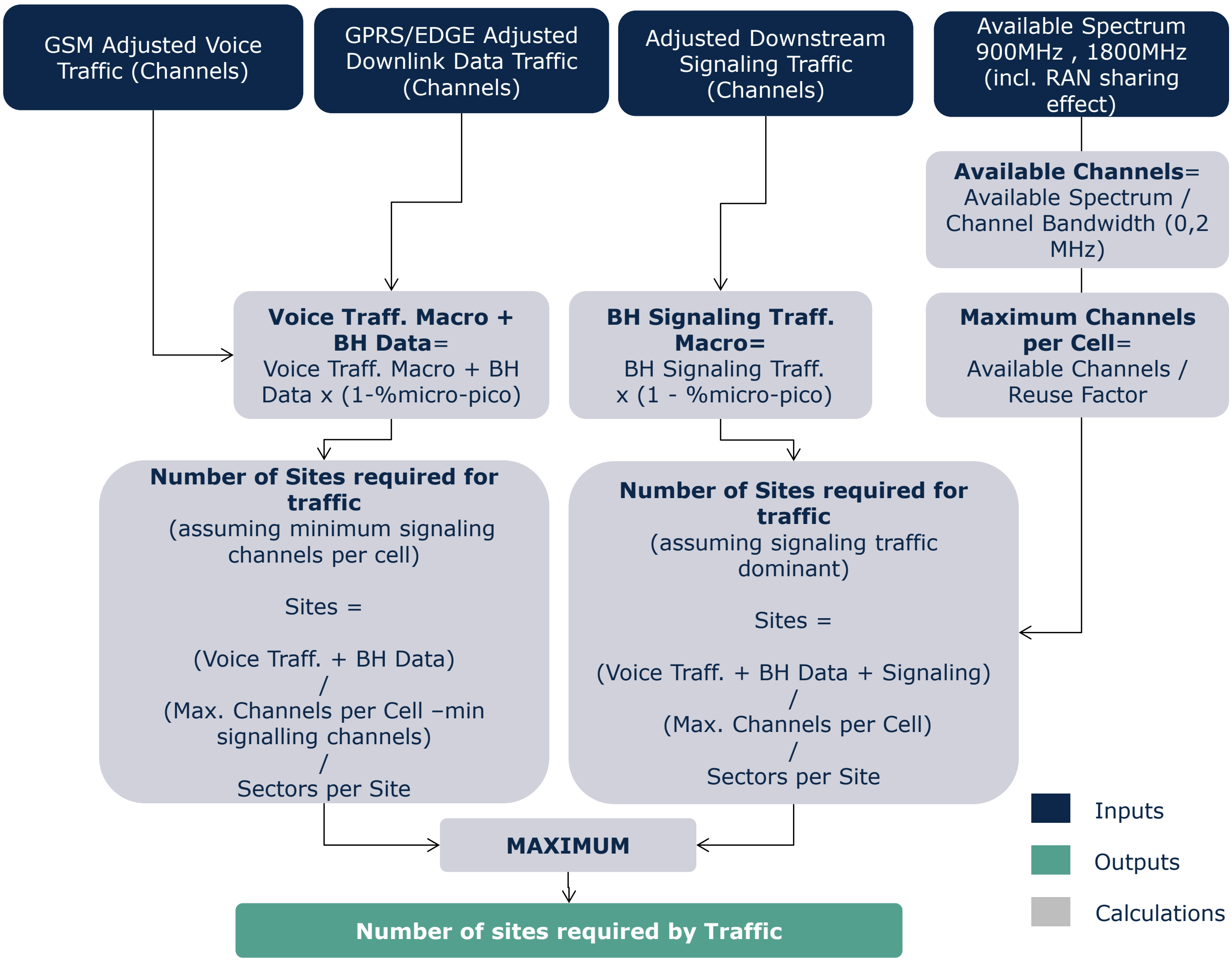

Exhibit 6.3: Algorithm for calculating the number of sites for GSM traffic (step 2). [Source: Axon Consulting]

The following aspects are of interest in relation to the algorithm for calculating the number of GSM sites based on traffic:

- The total traffic in the dominant busy hour is multiplied by a factor (1 -% micro) to eliminate the percentage of traffic served by micro cells. This percentage depends on the geotype

- The available spectrum has a direct impact on the number of sites, since it determines the maximum number of channels per cell
- The frequency reuse factor depends on the number of sectors per site and the use of micro equipment in the geotype. Using the parameter of the number of TRX by micro equipment, the frequency reuse factor will increase in proportion to ensure there are always available frequencies for micro equipment in geotypes where they exist
- The estimation of the number of sites takes into account the need of at least two channels per cell dedicated to signalling

Using these rules the following parameters are obtained:

- K: the number of base stations needed to meet demand when employing only band 1 (700-900MHz)
- L: the number of base stations needed to meet demand when employing only band 2 (1800-2600MHz).

6.3.5. Step 3. Calculating the optimal configuration and number of sites

Step 3 of the dimensioning algorithm determines the number of macro sites required for each possible configuration of the site, taking into account coverage and capacity constraints. Based on this result, the optimal configuration is defined as that which minimises the number of required sites, as it is assumed that the costs associated with construction and maintenance of the site are the most significant. Given the adoption of a yearly approach for determining the configuration of the network, this process is totally independent of the network status in previous years.

6.3.6. Step 4. Calculating the number of macro network elements

Once the number of sites required and the corresponding configuration has been identified, step 4 proceeds to calculate the number of required macro network elements. These include the number of base stations (which can support both 700-

900 MHz and 1800-2600 MHz cards at the same time[5]) and number of necessary TRX[6]. Note that the base stations are differentiated into bi and tri-sector.

The figure below illustrates the calculation algorithm used for determining the number of macro network elements necessary.

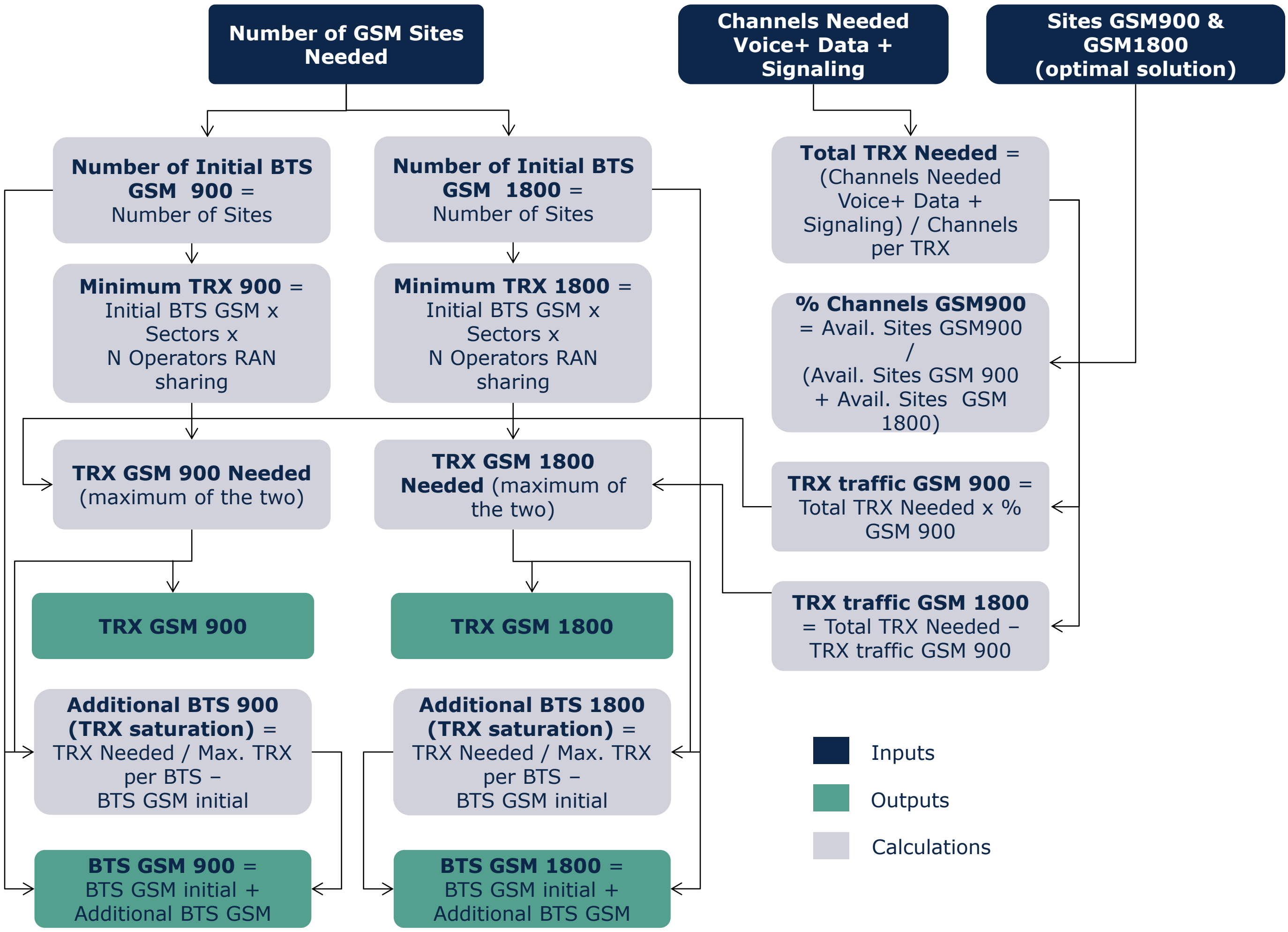

Exhibit 6.4: Algorithm for calculating the number of macro network elements. (Step 4) [Source: Axon Consulting]

The following aspects, when applicable, are of interest in relation to the algorithm for calculating the number of macro network elements:

- Regarding the distribution of the number of TRX GSM 700-900 and GSM 1800-2600, it is assumed that this distribution is proportional to the number of channels for each frequency band and therefore is also proportional to the spectrum available for each band

[5] The bands are referenced as 900 and 1800 in the remainder of the document, for simplicity purposes.
[6] Transmitter and receiver cards used in BTSs

- The algorithm takes into account that each location must have at least one base station. Also, at least one TRX per sector is required
- If the number of TRX per base stations exceeds the limit that supports the base station (technical limitations), it is assumed that new BTS equipment will need to be installed in order to accommodate additional TRX. These BTS in the chart above are called "extra" base stations

6.4. Radio access dimensioning UMTS/HSPA

6.4.1. Presentation of the dimensioning algorithm for radio network UMTS/HSPA

The dimensioning algorithm for UMTS (including HSPA) is organised into nine steps, as shown in the chart below.

Like the other dimensioning modules, this algorithm runs separately for each geotype considered. Unlike in GSM radio dimensioning, for UMTS it is necessary to perform the dimensioning separately for the uplink and downlink to determine which one is dominant.

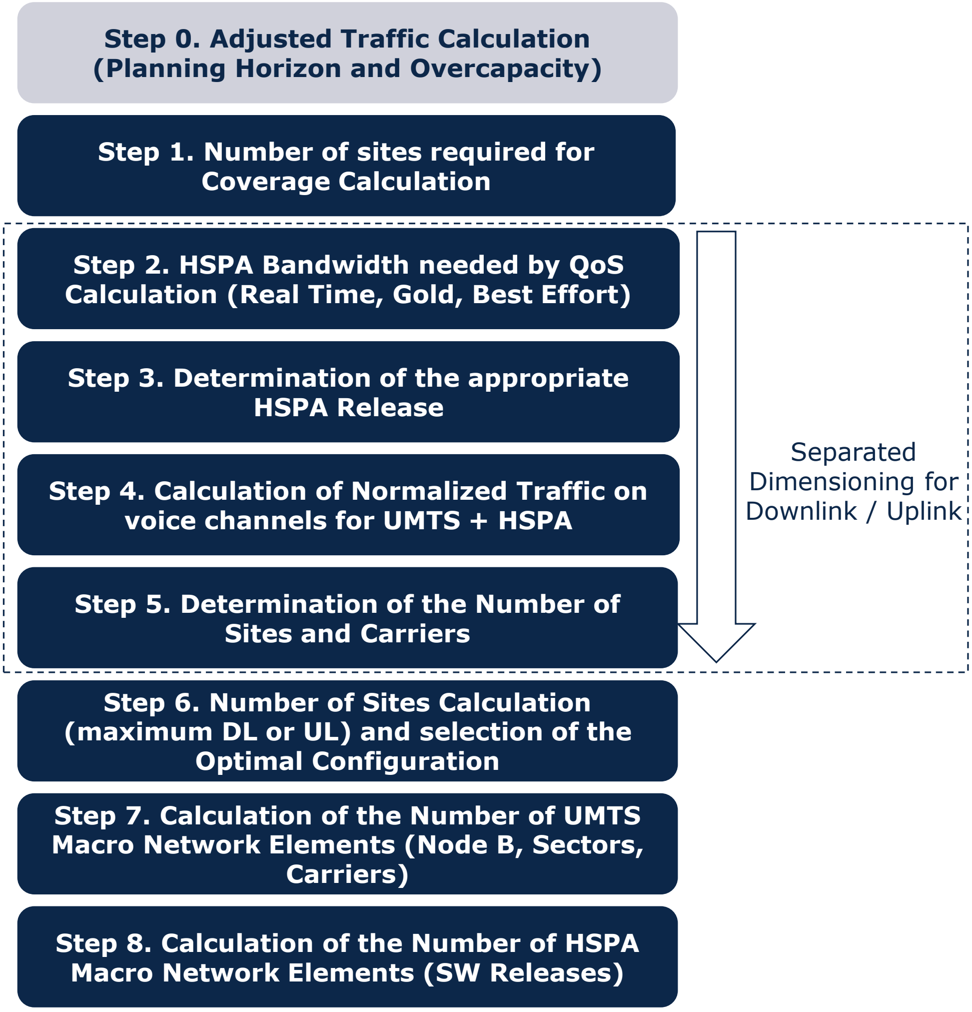

Exhibit 6.5: Steps for radio dimensioning UMTS/HSPA. [Source: Axon Consulting]

The dimensioning algorithm of the UMTS radio access network is implemented in the '6B CALC DIM UMTS' of the model. Each step is described in further detail in the following sections.

6.4.2. Step 0. Adjusted traffic calculation (planning horizon and efficiency factor)

A preliminary step to dimensioning a UMTS/HSPA network is the calculation of the traffic. In the calculation of this traffic, denominated "adjusted traffic", two factors are involved:

1. The effect of the planning horizon
2. Overcapacity for security reasons

The UMTS/HSPA radio network dimensioning in terms of traffic is carried out from the drivers listed below:

- DRIV.UMTS.CS.Voice
- DRIV.UMTS.CS.VideoCalls
- DRIV.UMTS.Data PS.PS64-DL
- DRIV.UMTS.Data PS.PS64-UL
- DRIV.UMTS.Data PS.PS128-DL
- DRIV.UMTS.Data PS.PS128-UL
- DRIV.UMTS.Data PS.PS384-DL
- DRIV.UMTS.Data PS.PS384-UL
- DRIV.UMTS.Data HSPA-B.HSPA-Best Effort-DL
- DRIV.UMTS.Data HSPA-B.HSPA-Best Effort-UL
- DRIV.UMTS.Data HSPA-QoS.HSPA-Gold-DL
- DRIV.UMTS.Data HSPA-QoS.HSPA-Gold-UL
- DRIV.UMTS.Data HSPA-QoS.HSPA-Real Time-DL
- DRIV.UMTS.Data HSPA-QoS.HSPA-Real Time-UL

Drivers are split into those associated with different UMTS carriers' capabilities (12.2 kbps voice, CS64 kbps, PS64kbps, PS128kbps and PS384kbps[7]) and HSPA data[8]. For each of these types, a differentiation between uplink (UL) and downlink (DL) is introduced.

The following aspects are of particular interest:

- The mapping of voice and video telephony UMTS is performed similarly to the mapping of GSM voice services. That is, adding a percentage of "idle" or inactive traffic to represent time unbilled but during which the network is used (such as the time until the recipient picks up the phone, calls not answered, etc.). A factor is applied to this "increased" traffic to calculate the number of channels required (according to the Erlang B formula) for a given blocking probability
- Referring to the services mapped on drivers of UMTS data carrier capacity (PS64 kbps, PS 128 kbps and PS 384 kbps) an over sizing factor representing the necessary retransmissions due to errors in the channel is taken into account. In

[7] PS refers to packet switching and represents the available transmission standards on UMTS
[8] HSPA drivers are also divided based on QoS.

addition to these parameters, an "idle" occupancy rate of the channel to model the times is considered, during which the user is assigned a channel but not transmitting or receiving any data

The busy hour rate applies to all drivers outlined above. For voice and video calls, the factor of radio access service is used depending on whether the services is either on-net (using the radio network at both ends of the communication) or off-net (using a single communication endpoint).

6.4.3. Step 1. Calculating the number of sites required for coverage

The dimensioning algorithm that calculates the minimum number of sites for UMTS coverage is similar to that used for GSM. Calculation of equipment requirements for coverage is worked out for each geotype, generally from the coverage area.

The model is able to calculate the minimum number of sites required for coverage for 1900MHz band.

The site coverage radius is adjusted based on geotype class, defining a percentage of the maximum radius as a function of the propagation conditions for each geotype.

The figure below illustrates the calculation of the minimum number of sites associated with UMTS coverage.

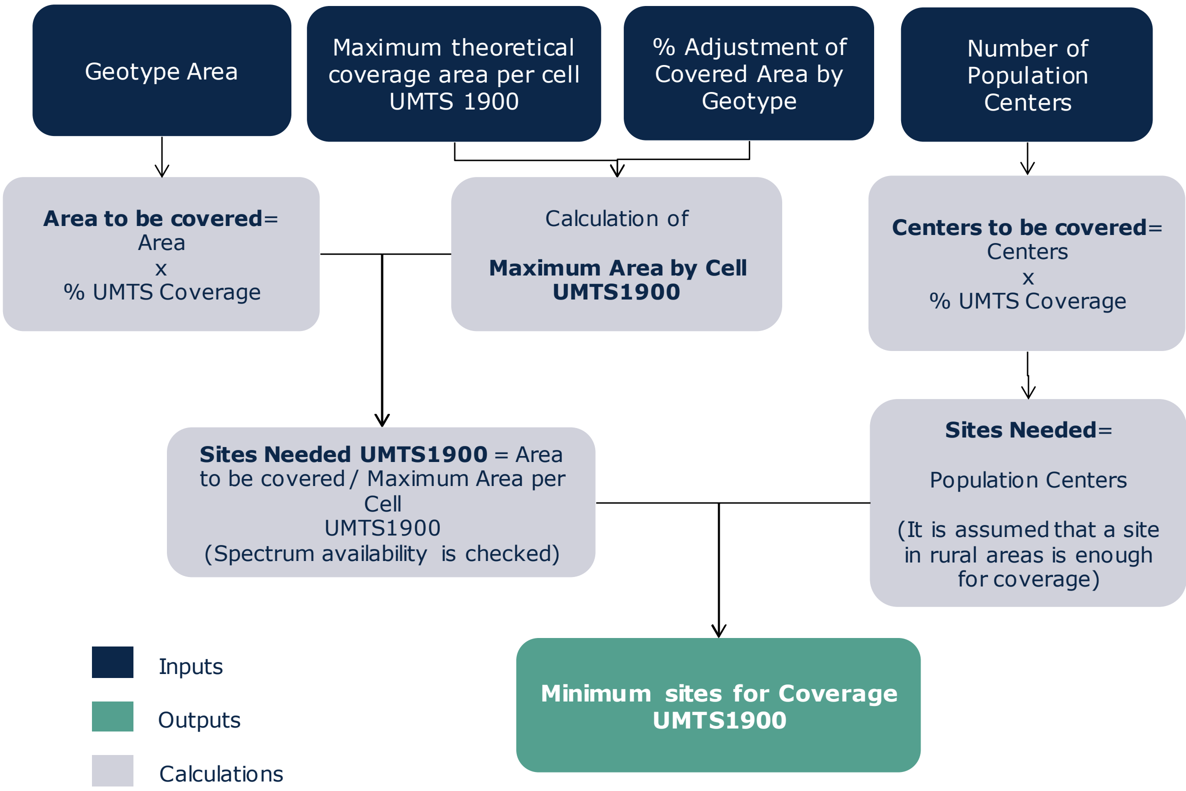

Exhibit 6.6: Algorithm for calculating the number of Sites for UMTS coverage (step 1) [Source: Axon Consulting]

The maximum coverage area per cell is calculated according to the following formula:

$$MaximumCellArea = \frac{3 \times \sqrt{3}}{2} \times (MaxRadius \times RadiusReductionFactor)^2$$

Where MaxRadius represents the maximum coverage radius, RadiusReductionFactor is a reduction factor of the maximum coverage radius depending on geotype, and the constant factor corresponds to the area of a hexagon.

Additionally, it is common in spread areas to deploy the coverage based on the population centres. This would mean providing coverage of only the populated areas.

6.4.4. Step 2. Calculation of the bandwidth needed for HSPA

As described in Step 0, the HSPA traffic grouped in the HSPA drivers collects the average traffic associated with the demand without any kind of adjustment for quality of service.

Step 2 of the dimensioning algorithm accurately calculates required bandwidth to dimension for HSPA in order to meet the needs associated to the traffic for different qualities of service based on Erlang formulas.

The following figure shows the calculation process to obtain the bandwidth needed for HSPA considering QoS.

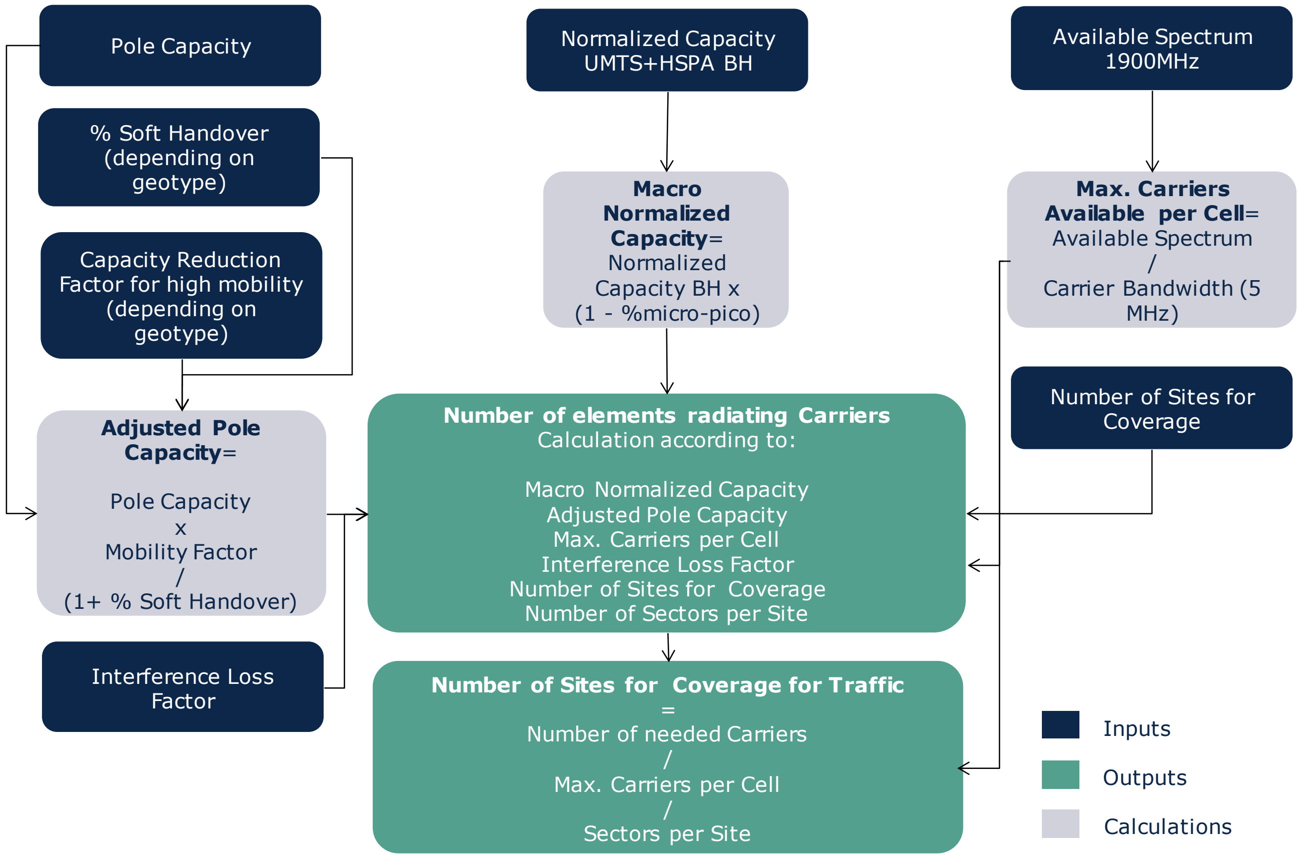

Exhibit 6.7: Algorithm for calculating capacity needed for HSPA traffic, considering QoS (step 1) [Source: Axon Consulting]

Please note: Real Time (RT), Gold and Best Effort (BE) refer to different HSPA services assuring different levels of Quality of Service (QoS).

The calculation is based on the following assumptions:

- The needed bandwidth for traffic real time and gold is determined by the adjusted traffic multiplied by a dimensioning factor. This factor is obtained after apply the Erlang B formula for real time traffic and Erlang C for gold traffic
- Part of the overcapacity allocated to real time and gold traffic (due to the QoS assurance) can be used for best effort traffic

6.4.5. **Step 3. Determination of HSPA release**

This step determines the HSPA release considered for radio dimensioning based on the traffic intensity.

First and last year of release availability are taken into account. In the last year of availability all base stations will be updated to subsequent release, independent of traffic intensity.

6.4.6. Step 4. Calculation of UMTS+HSPA normalised capacity

This step calculates, from total capacity requirements of different bearers of UMTS and HSPA, a normalised capacity expressed in simultaneous voice users (equivalent to a channel).

This conversion is based on the concept of "pole capacity" or maximum capacity, which reflects maximum capacity of an isolated cell equipped with a single carrier in the event of all traffic belonging to a single bearing capacity. In general, the maximum capacity of the cell is a reasonably linear function for situations where traffic from different bearers coexist so that the use of a standard traffic is acceptable.

The figure below illustrates the mechanism used for the calculation of normalised capacity UMTS+HSPA:

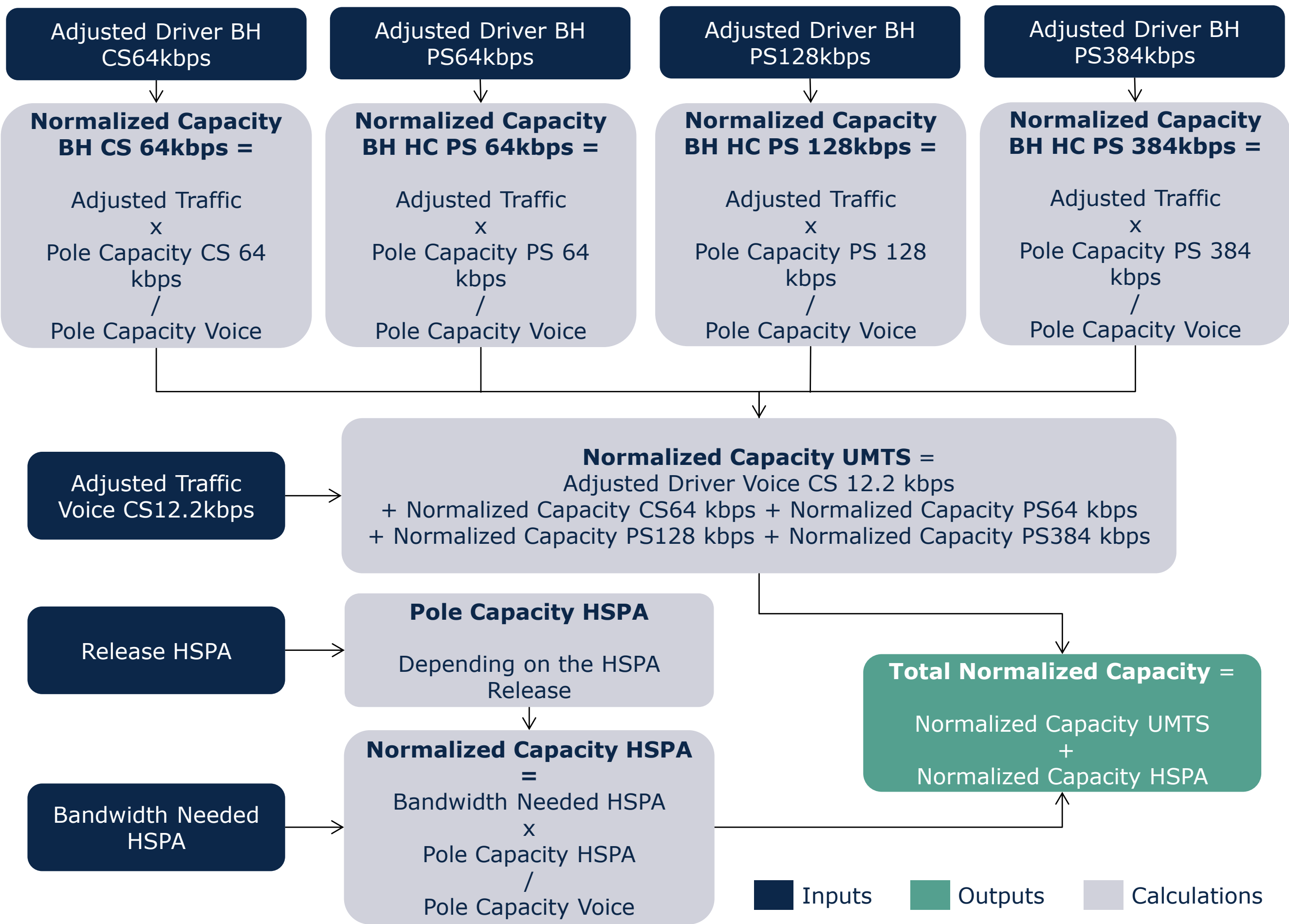

Exhibit 6.8: Algorithm for the calculation of normalised pole capacity. [Source: Axon Consulting]

6.4.7. Step 5. Calculation of the required number of UMTS sites for macro cells based on traffic

The third step is to determine the number of required UMTS sites to serve voice and data traffic demand (and their associated signalling requirements.) The illustration below shows the dimensioning algorithm used for this purpose. This algorithm is used for different potential configurations of the sites depending on the number of sectors (3) and the frequency band (1900 MHz) employed.

It is worth noting that the estimation of the number of sites for UMTS is performed separately for the upstream (UL) and downstream (DL).

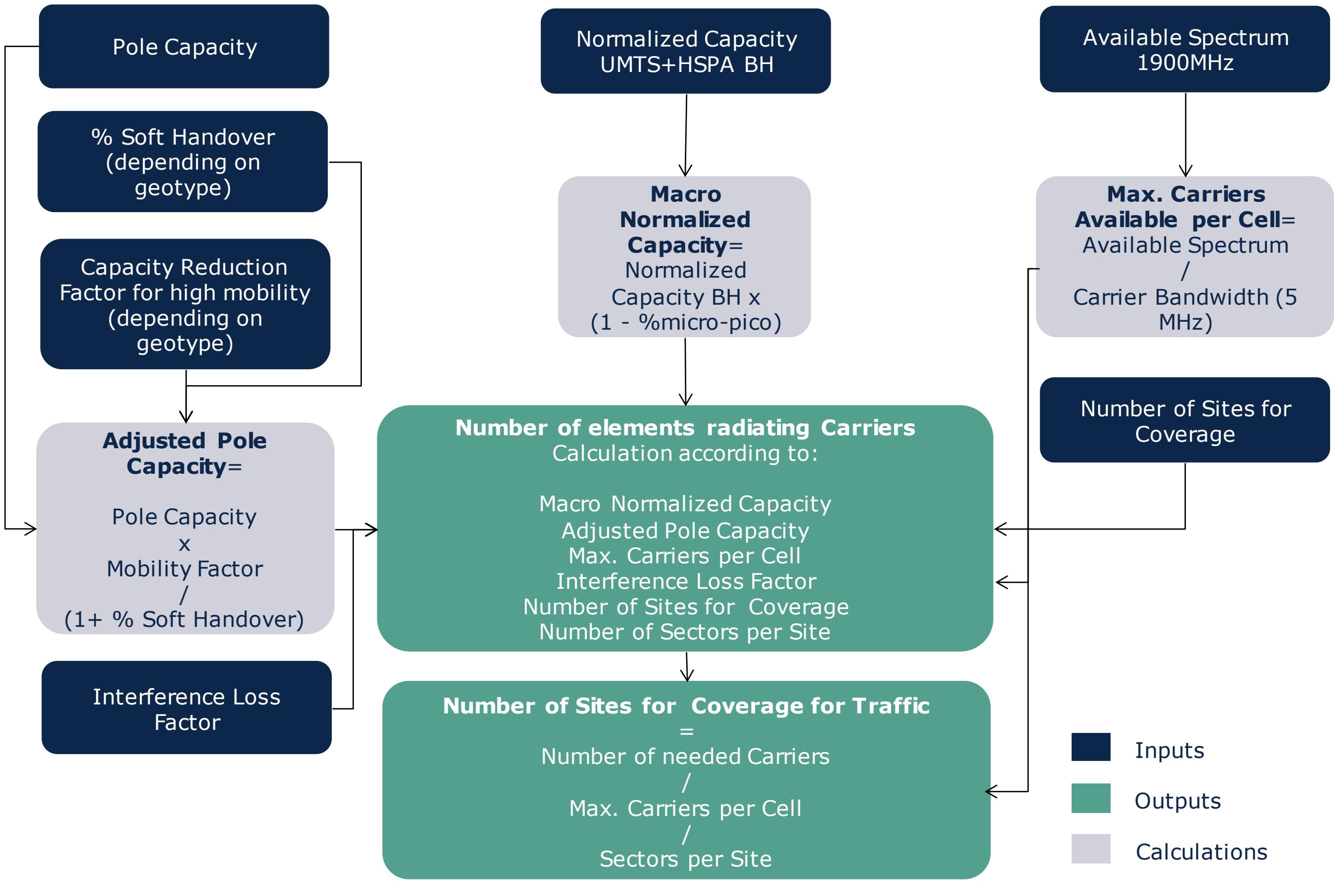

Exhibit 6.9: BH Algorithm for calculation of the number of sites for UMTS traffic (step 5) [Source: Axon Consulting]

Further details of the steps taken to calculate number of sites required:

- The total normalised capacity in the dominant busy hour is multiplied by a factor (1 -% micro) to eliminate the percentage of traffic served by micro cells. This percentage is dependent on each geotype
- The maximum capacity of an isolated cell (Pole Capacity) is adjusted to take into consideration the impact of Soft Handover and loss of capacity for mobility

(especially important in road or rail class geotypes). This maximum adjusted capacity is called Pole Capacity adjusted

- It must be taken into account that in UMTS, as carrier frequencies are reused in cells attached for traffic growth, the maximum capacity per carrier tends to decrease as a result of the interference. In the model, this effect is reflected as follows:

  Equation A:

$$CapacityPerCarrier = PoleCapacityNormalized \times (1 - \%Frequency\,Reuse \times InterferenceLossFactor)$$

  Where the Interference Loss Factor is the ratio between the maximum capacity of a carrier in a "multiple cell" (all adjacent cells use the same carrier) and the maximum capacity of the cell in an environment of "single cell" or solitary confinement.

$$InterferenceLossFactor = \frac{PoleCapacityCarrierMultipleCell}{PoleCapacityCarrierSingleCell}$$

- From this, it is possible to determine the number of required carriers (radiating elements) to meet total traffic. The number of traffic carriers comes from the following expression:

  Equation B

$$Number\ of\ Traffic\ Carriers = \frac{TotalNormalizedCapacity}{CapacityPerCarrier}$$

  In this case, the number of sites required is given by:

$$Sites = \frac{Number\ of\ Traffic\ Carriers}{MaxCarriersPerSector}$$

6.4.8. **Step 6. Calculation of optimal configuration and number of sites**

Step 6 of the dimensioning algorithm determines the appropriate configuration, based on the number of sites required in Step 5.

In the calculation in Step 5, both traffic and coverage requirements are already considered. Minimum configuration is considered as that which minimises the number of necessary sites, as it is assumed that the costs associated with construction and maintenance of the site are the most significant of the radio access network.

6.4.9. Step 7. Calculation of the number of macro network elements

Once the number of required sites is determined, along with the corresponding configuration, Step 7 calculates the number of necessary macro network elements. These include the number of base stations (which can support both cards, 700-900 MHz and 2100 MHz, at the same time) and the number of carriers. Please note that base stations split into bi- and tri-sector.

The figure below illustrates the calculation algorithm used for determining the number of necessary macro network elements:

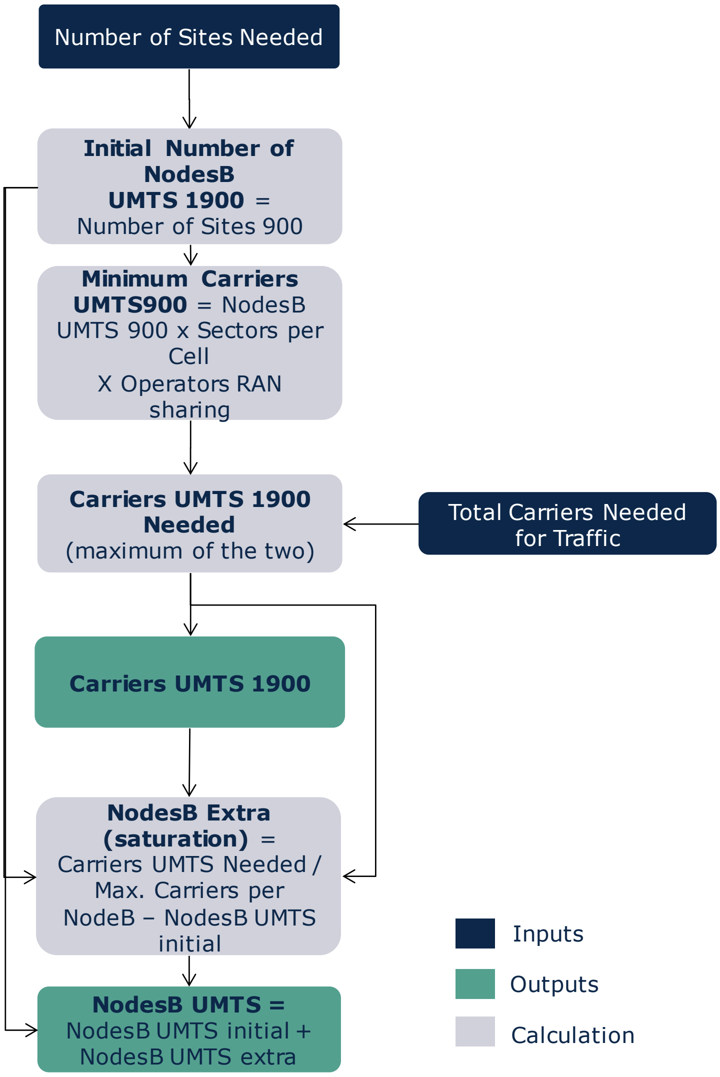

Exhibit 6.10: Algorithm for calculation of the number of macro network elements. (Step 7) [Source: Axon Consulting]

The following aspects, when applicable, are of interest in connection with the algorithm for calculating the number of macro network elements:

- The algorithm takes into account that each location must have at least one base station. At least one carrier per sector is required
- If the number of carriers per base station exceeds the limit that supports the base station (technical limitations), it is assumed that new Nodes B equipment will need to be installed in order to accommodate additional carriers. These Nodes B are called "additional" nodes B in the previous chart

6.4.10. Step 8. Calculation of the quantity of HSPA Equipment Needed (SW enabling)

Step 8 of the dimensioning algorithm determines the amount of necessary equipment (software enabling or licenses) to cover HSPA services' traffic.

In general, the number of Nodes B requiring an HSPA software update is provided by the following formula:

$$NodesB_{HSPA} = NodesB \times \frac{\%CoverageHSPA}{\%CoverageUMTS}$$

The software release is determined in Step 3.

The figure below illustrates the calculation algorithm for determining the number of necessary HSPA upgrades.

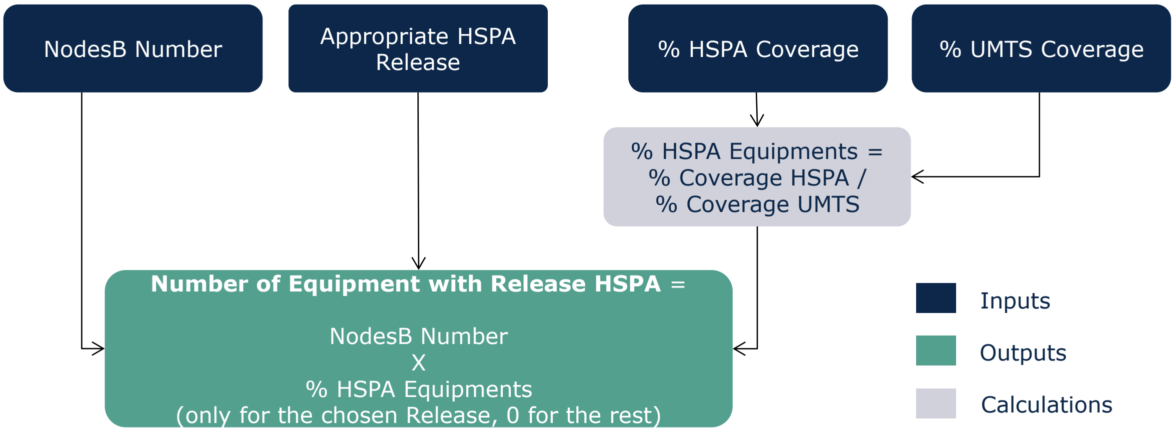

Exhibit 6.11: Algorithm for calculation of the number of HSPA upgrades necessary (step 8) [Source: Axon Consulting]

6.5. **Radio access dimensioning LTE**

6.5.1. **Presentation of the dimensioning algorithm for radio network LTE**

The dimensioning algorithm for LTE is organized in eight steps, as shown in the chart below.

Like the other dimensioning modules, this algorithm runs separately for each geotype considered. Like in UMTS radio dimensioning, for LTE it is necessary to perform the dimensioning separately for the uplink and downlink to determine which one is dominant.

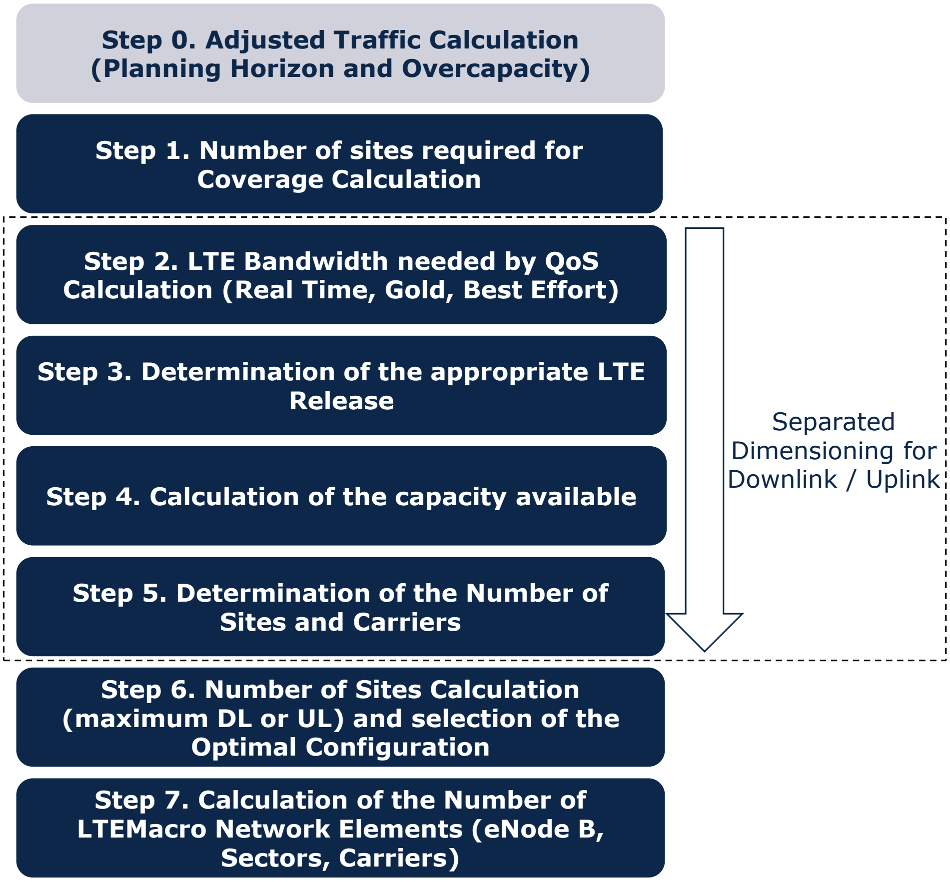

Exhibit 6.12: Steps for radio dimensioning LTE [Source: Axon Consulting]

For LTE dimensioning, three bands are modelled – a low band that includes the frequencies 700MHz and 900MHz, a medium band that includes 1800MHz and 2600MHz and a high band with 2600MHz. This aggregation is needed to avoid producing too many changes of carriers and bands during calculations. This simplification is reasonable because propagation characteristics are similar in the frequencies included in each band.

For the capacity dimensioning, the carriers' separation is maintained to obtain the actual capacity. For instance, in the of case an operator who has 5MHz in the 800MHz band and 10MHz in the 900MHz band, the model recognises that there is one 5MHz carrier and one 10MHz carriers in the low band (and not one 15MHz carrier).

Each step is described in further detail in the following sections.

6.5.2. Step 0. Adjusted traffic calculation (planning horizon and efficiency factor)

A preliminary step to dimensioning an LTE network is the calculation of the traffic network dependent. In the calculation of this traffic, denominated "adjusted traffic‟, two factors are involved:

1. The effect of the planning horizon.
2. Overcapacity for security reasons.

The LTE radio network dimensioning in terms of traffic is carried out from the drivers listed below:

- DRIV.LTE.Data LTE-B.Best Effort-DL
- DRIV.LTE.Data LTE-QoS.Gold-DL
- DRIV.LTE.Data LTE-QoS.Real Time-DL
- DRIV.LTE.Data LTE-B.Best Effort-UL
- DRIV.LTE.Data LTE-QoS.Gold-UL
- DRIV.LTE.Data LTE-QoS.Real Time-UL
- DRIV.LTE.SIGNAL.SIGNAL

Drivers are split into sub sections according to their qualities of service and signalling[9]. For each of these types, a differentiation between uplink (UL) and downlink (DL) has been introduced.

The following aspects are of particular interest:

[9] Channel switched services (i.e. voice, video calls) is managed as data traffic by the LTE network, ensuring that the QoS is adequate for those services. Therefore, the CS services have been allocated to the drivers related to real time traffic.

- The mapping of voice and video telephony LTE is performed similarly to the mapping of UMTS services. That is, adding a percentage of "idle" or inactive traffic to represent time unbilled but during which the network is used (such as the time until the recipient picks up the phone and calls not answered). To this "increased" traffic a factor is applied to calculate the number of channels required (according to the Erlang B formula) for a given blocking probability
- Referring to the services mapped on drivers of LTE data services, an over sizing factor representing the necessary retransmissions due to errors in the channel is taken into account. In addition to these parameters, an "idle" occupancy rate of the channel to model the times during which the user is assigned a channel but not transmitting or receiving any data is considered.

The busy hour rate applies to all the drivers outlined above and, for voice and video calls, the factor of radio access service is used, depending on whether the service is on-net (using the radio network at both ends of the communication) or off-net (using a single communication endpoint).

6.5.3. **Step 1. Calculating the number of sites required for coverage**

The dimensioning algorithm for the minimum number of sites for LTE coverage is similar to that used for UMTS and GSM. The calculation of equipment requirements for coverage is carried out for each geotype, generally from the coverage area.

The model is able to calculate the minimum number of sites required for coverage for all the bands. In the case of LTE, as it has been stated before, the model considers three bands: low (800MHz and 900MHz), medium (1800MHz and 2600MHz) and high (2600MHz).

The site coverage radius is adjusted based on geotype class, defining a percentage of the maximum radius as a function of the propagation conditions for each geotype.

The figure below illustrates the calculation of the minimum number of sites associated with LTE coverage:

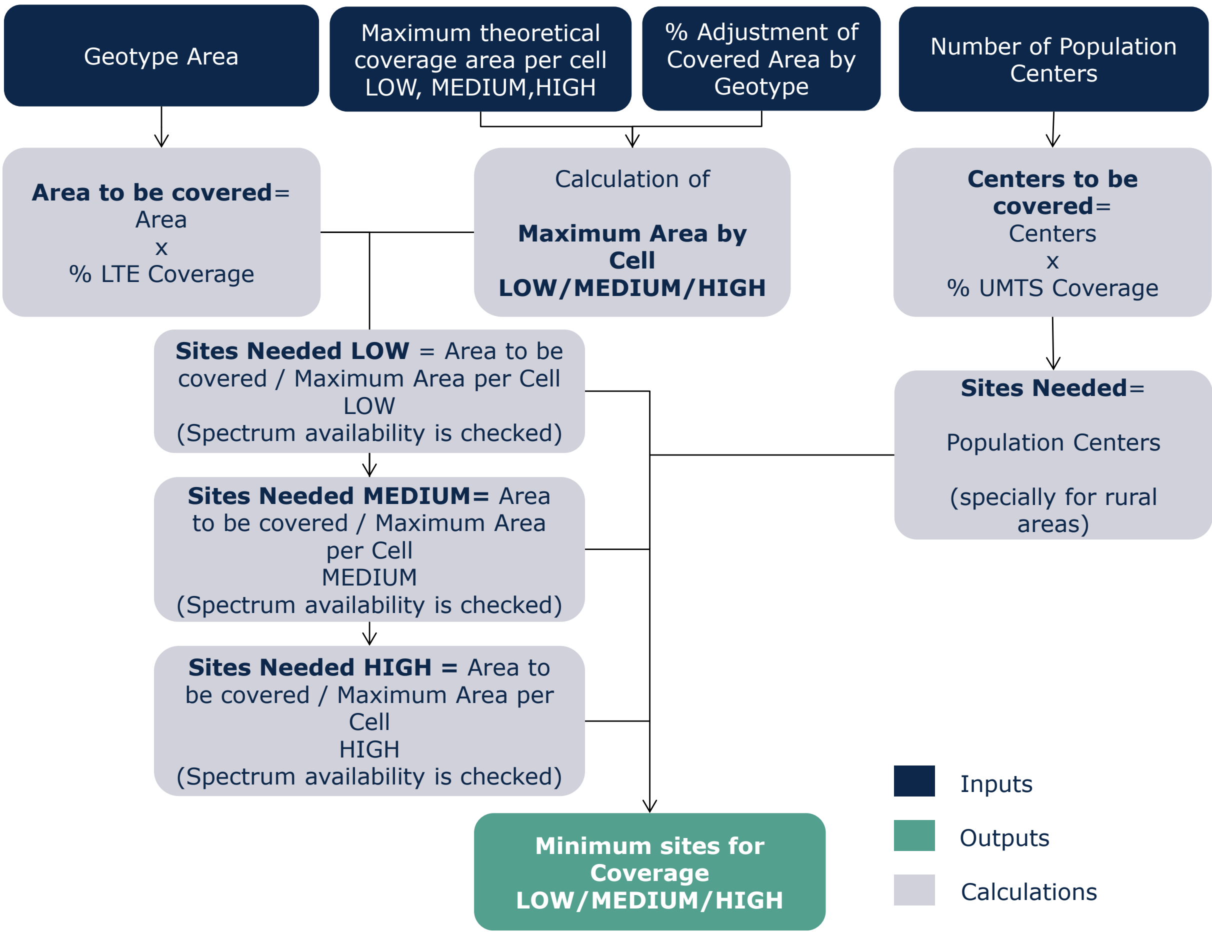

Exhibit 6.13: Algorithm for calculating the number of sites for LTE coverage (step 1) [Source: Axon Consulting]

The maximum coverage area per cell is calculated according to the formula:

$$MaximumCellArea = \frac{3 \times \sqrt{3}}{2} \times (MaxRadius \times RadiusReductionFactor)^2$$

Where MaxRadius represents the maximum coverage radius (different for bands LOW, MEDIUM, HIGH), RadiusReductionFactor is a reduction factor of the maximum coverage radius, depending on geotype. The constant factor corresponds to the area of a hexagon.

Additionally, it is common in spread areas to deploy the coverage based on the population centres. This means to cover only the populated centres, not the entire area. If this option is available, it can be selected by geotype.

6.5.4. Step 2. Calculation of the bandwidth needed for LTE

As described in Step 0, the LTE traffic grouped into drivers collects the average traffic associated with the demand without any kind of adjustment for quality of service.

Step 2 of the dimensioning algorithm accurately calculates required bandwidth to dimension for LTE in order to meet the needs of the traffic for different qualities of service, based on Erlang formulas.

The following figure shows the calculation process to obtain the bandwidth needed for LTE, considering QoS.

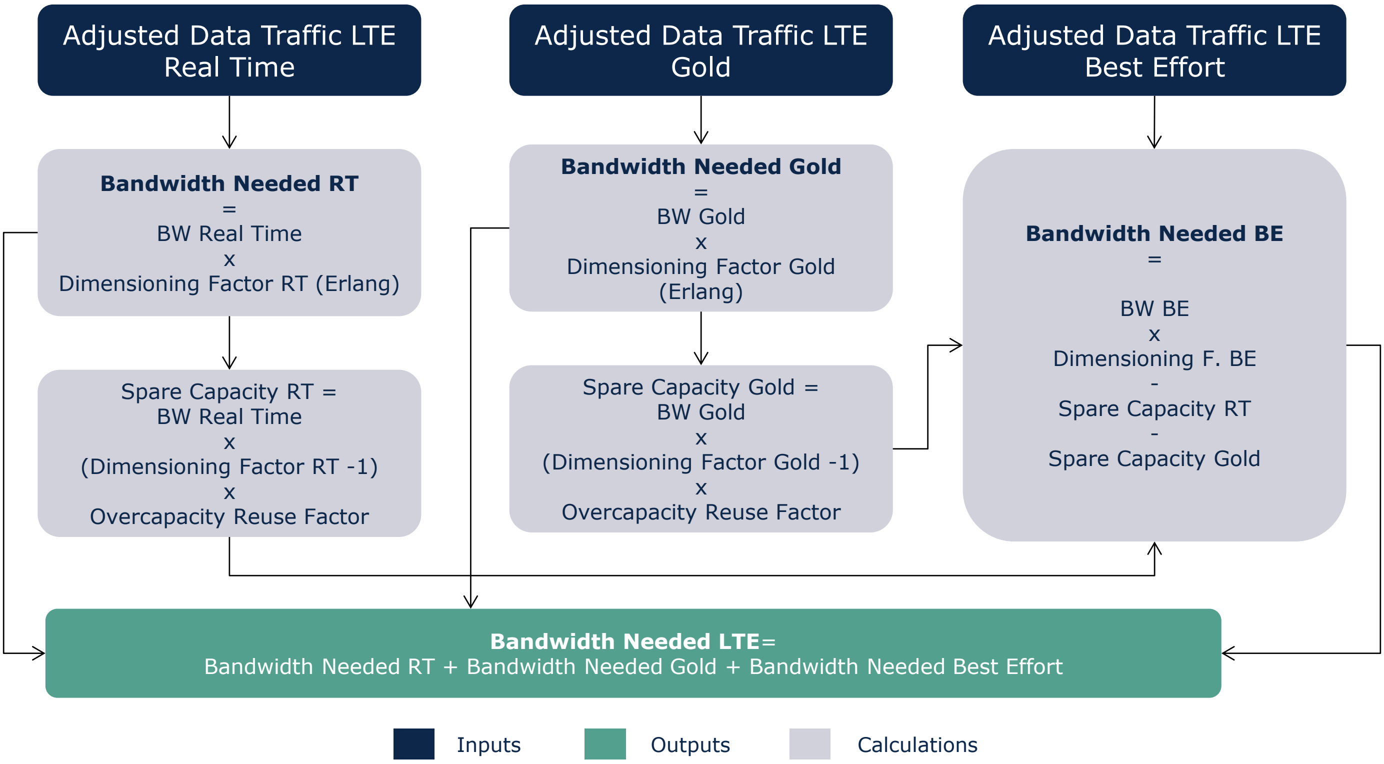

Exhibit 6.14: Algorithm for calculating capacity needed for LTE traffic, considering QoS. (step 1) [source: Axon Consulting]

This calculation is based on the following assumptions:

- The voice and video traffic is contained in real-time traffic
- The needed bandwidth for traffic real-time and gold is determined by the adjusted traffic multiplied by a dimensioning factor. This factor is obtained after applying the Erlang B formula for real-time traffic and Erlang C for gold traffic
- Part of the overcapacity allocated to real-time and gold traffic (due to the QoS assurance) can be used for best-effort traffic

6.5.5. **Step 3. Determination of LTE release**

This step determines the LTE release considered for radio dimensioning based on the traffic intensity and the configurations included in each release.

For instance, the modulation scheme and the use of technologies like MIMO. The starting release included in the model is 3GPP's Release 8.

First and last year of release availability are taken into account. In last year of availability all base stations will be updated to subsequent release, independently of traffic intensity.

6.5.6. **Step 4. Calculation of the capacity available**

One of the factors that has to be taken into account is the wide flexibility the LTE technology allows. In LTE there are multiple bandwidths available (1.4, 3, 5, 10, 15 and 20 MHz). Therefore, the model calculates the optimum configuration of the available spectrum in order to maximise the use of the different bandwidths.

The calculation of the capacity available is similar to the one used for UMTS. However, there are certain differences between these technologies. For instance, soft-handover is not available in the LTE standard.

Another difference is the treatment of inter-cell interference. UMTS is based on Code Division Multiple Access (CDMA). This technology allows several subscribers to use the same frequency in the same cell. However, LTE is based on Orthogonal Frequency Division Multiplexing (OFDM) which means that users using the same frequency will interfere with each other's communications.

On the other hand, OFDM divides the resources (time and spectrum) in Physical Resource Blocks (PRBs). The network intelligence allocates different PRBs to those users that can produce interferences. This concept is called Inter-Cell Interference Coordination (ICIC). The logic of this practice is shown in the following figure:

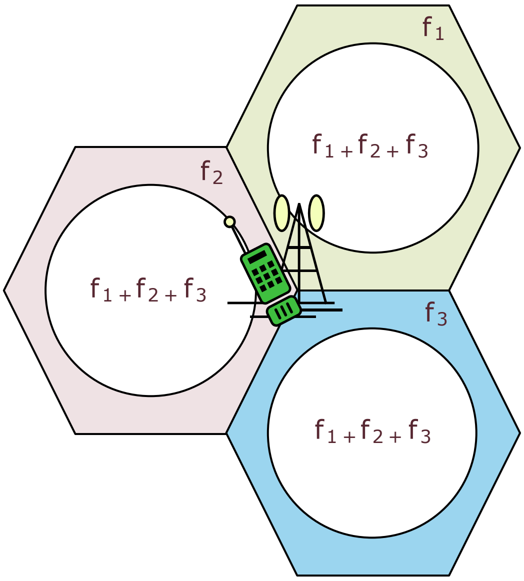

Exhibit 6.15: Inter-cell interference coordination in LTE. [Source: Axon Consulting]

Although this technique enables the avoidance of interference when using the same frequencies in all the cells, the maximum bit rate reached in the cell borders will be lower than expected. Therefore, the model considers a factor that represents the average decrease in capacity that can be handled by the eNode B.

The following figure shows the calculation process for the adjusted capacity available.

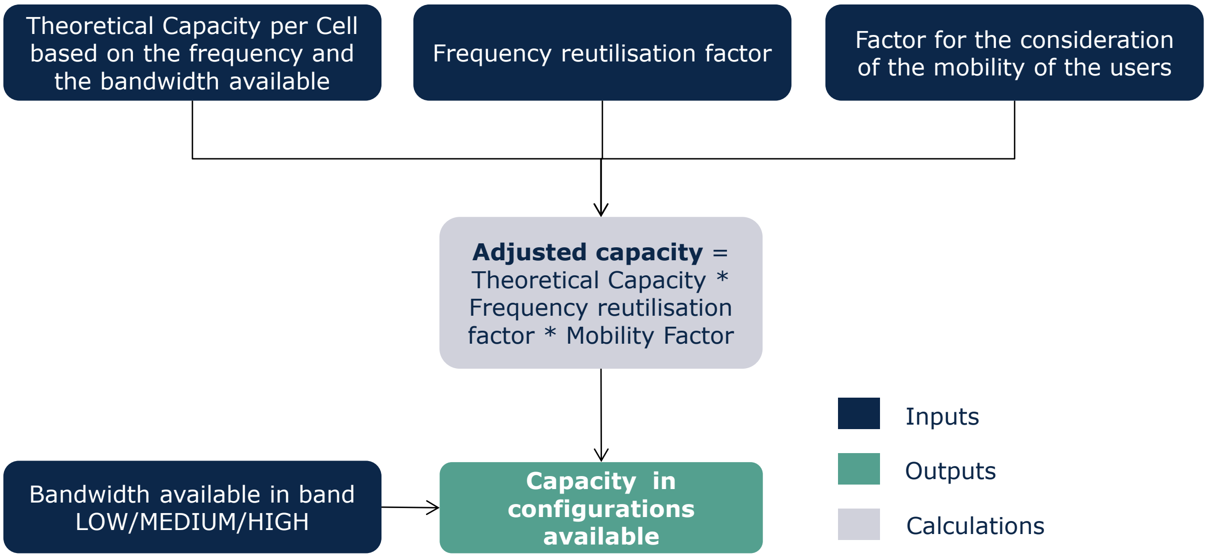

Exhibit 6.16: Calculation of the adjusted capacity available. [Source: Axon Consulting]

6.5.7. Step 5. Calculation of the required number of LTE sites for macro cells based on traffic

For the calculation of LTE sites for macro sites, the model implements the same methodology used for GSM and UMTS networks (described in sections 6.3.4 and 6.4.7, respectively). However, for LTE three bands have been defined (LOW, MEDIUM, HIGH). Therefore, the model considers three variables, instead of two.

The following exhibit shows the calculation process for the sites needed for each band:

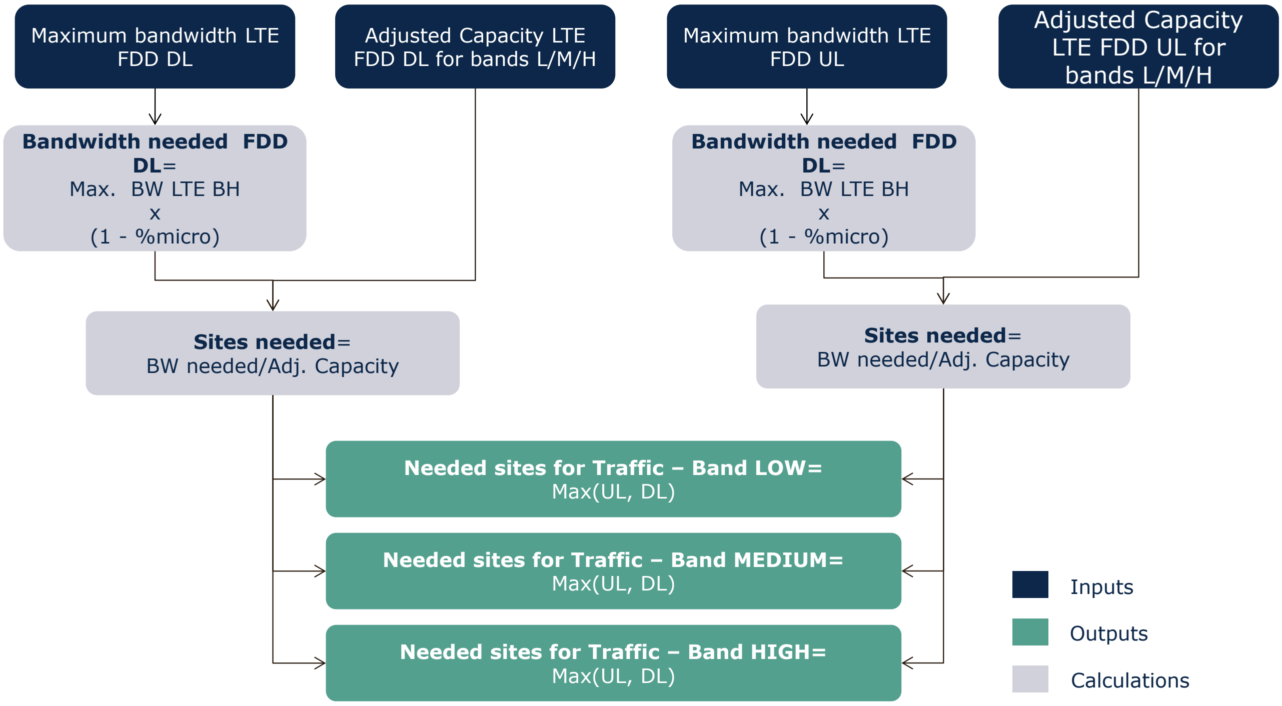

Exhibit 6.17: Calculation algorithm of the required sites for traffic LTE by band [Source: Axon Consulting]

6.5.8. Step 6. Calculation of optimal configuration and number of sites

Step 6 of the dimensioning algorithm determines the appropriate configuration based on the number of sites required in Step 5.

In the calculation in Step 5, both traffic and coverage requirements are already considered. The minimum configuration is considered as that which minimises the number of necessary sites, as it is assumed that the costs associated with construction and maintenance of the site are the most significant.

6.5.9. Step 7. Calculation of the number of macro network elements

Once the number of required sites is determined, along with the corresponding configuration, Step 7 calculates the number of necessary macro network elements. These include the number of base stations (eNode B) and the number of carriers. Please note that base stations are split between bi and tri-sector.

The figure below illustrates the calculation algorithm used for determining the number of necessary macro network elements:

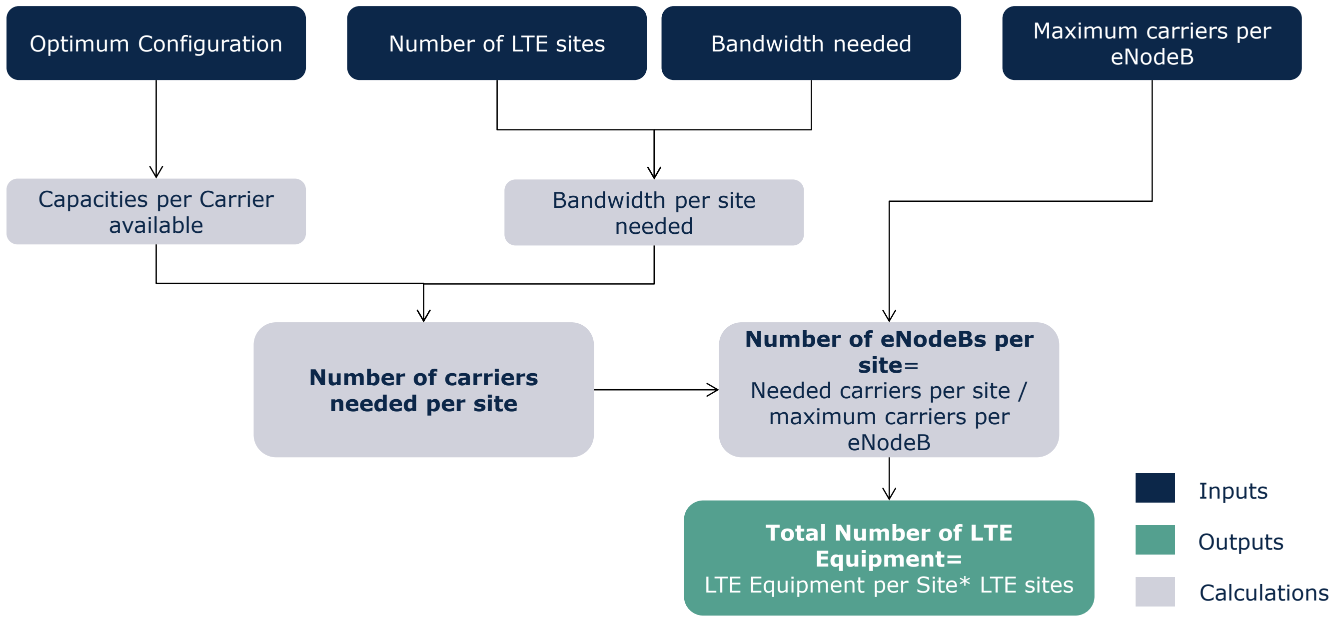

Exhibit 6.18: Algorithm for Calculation of the number of LTE macro network elements (Step 7) [source: Axon Consulting]

6.6. Radio sites dimensioning

The radio sites dimensioning block is responsible for the calculation of the required number of sites. Additionally, this block obtains the number of necessary antennas for each technology.

When designing the access network for different technologies an indicator of the number of sites required for each band is obtained. However, it is common practice among operators to reuse the site to co-locate the equipment of different bands and technologies, thus cutting costs.

For the dimensioning of sites the following steps apply:

Exhibit 6.19: Steps for calculating the co-location of radio sites. [source: Axon Consulting]

Throughout the following subsections the three steps shown in the figure above are explained in detail.

6.6.1. Technology co-location

Once the number of radio sites needed for each technology (from radio dimensioning modules) is known, the co-location between different technologies is estimated. These data need to be differentiated between tower-roof locations (which will be separated later) and micro-cell sites.

These sites may be co-located, producing the following combinations:

- GSM+UMTS+LTE
- GSM + UMTS
- UMTS + LTE
- GSM + LTE
- GSM Only
- UMTS Only
- LTE Only

To group the locations in all possible combinations the algorithm shown in the picture below has been followed. Notably, this is done separately for tower-roof locations (on one side) and micro (on the other).

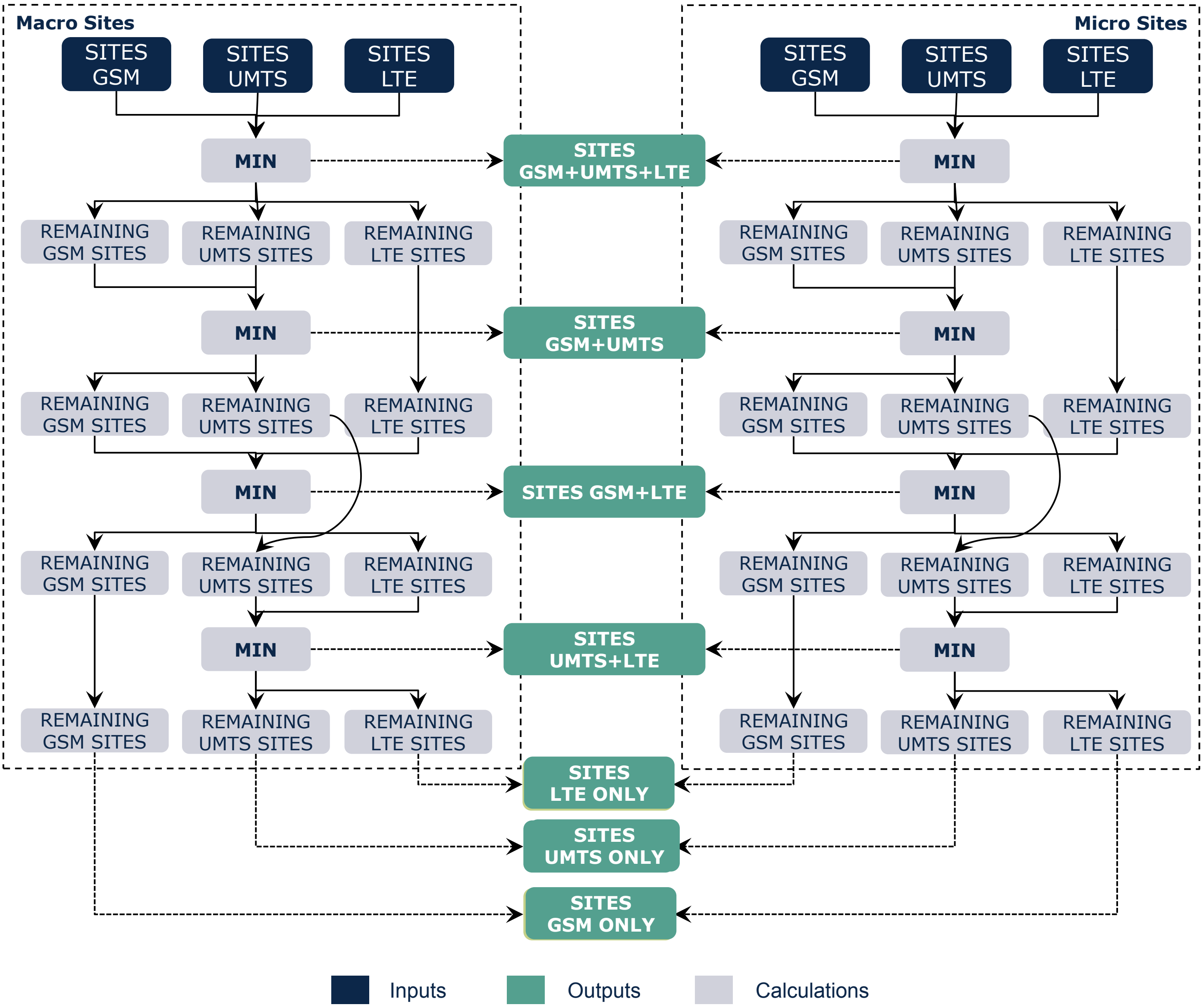

Exhibit 6.20: Algorithm used for the calculation of technology co-location [source: Axon Consulting]

The steps followed throughout the algorithm are outlined below:

1. Calculation of the co-location sites with the three technologies. To do this, the minimum of the three technologies is taken and a maximum percentage of maximum co-location is applied.
2. Calculation of the number of sites not yet co-located for each technology.
3. Calculation of the co-location sites of UMTS and GSM, taking the minimum of the remaining sites and applying a factor of maximum percentage of co-location.
4. Calculation of the number of sites not yet co-located for each technology.

5. This process is repeated for the remaining combinations, ending with the sites that are not co-located with any other technology (GSM only, UMTS only and LTE only).

Maximum co-location percentage factors represent the various reasons which a site may not cause a site not to be suitable for more than one technology (for example, because of radio propagation issues).

6.6.2. **Calculation of the total number of sites**

Once sites are optimised with different combinations of co-location, it is possible to get the total number of sites of each type (roof, tower and micro).

The procedure below is followed:

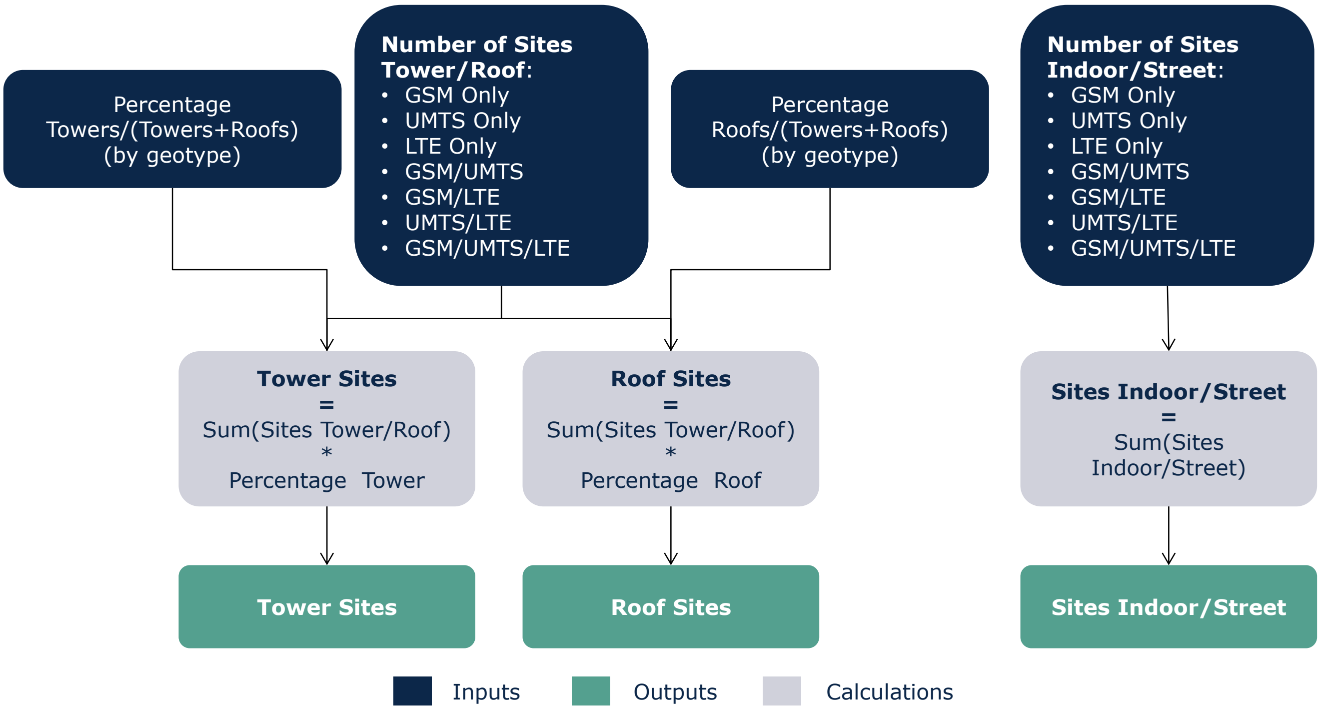

Exhibit 6.21: Procedure followed to calculate the total number of sites [source: Axon Consulting]

As shown in the chart above, the process is different for roof-tower sites and micro stations.

In the case of micro station sites, the number of sites of each of the co-location combinations is added.

To obtain the total number of rooftop/tower sites, in a first instance the number of sites of all combinations of locations roof/tower is added. To calculate the sites to be placed on rooftops and on towers, the actual percentage of installed sites for each type and for each geotype is then considered.

6.7. Backhaul network dimensioning

6.7.1. Introduction to backhaul dimensioning

The backhaul module is responsible for dimensioning the transmission part of radio sites to the controllers (BSC, RNC) along with the dimensioning of controlling elements. The backhaul dimensioning algorithm is implemented in the '6E CALC DIM BACKHAUL' sheet of the model.

The topology used for the backhaul network is based on the following structure:

- Radio Site – Hub: a connection point to point from radio sites to a traffic aggregator equipment (hub). The percentage of radio sites that connect directly to the controller may be configured

The definition of the topology to be used is made for each geotype and differentiates between microwave and fibre (leased line option is always considered point to point). Topology is defined by two parameters:

- Number of aggregation (N) represents the number of aggregators in the ring. The case of N = 1 represents the point to point topology
- Redundancy factor (R) can be 1 or 0. When this parameter is configured to 1, the network will have redundancy. Please note that to set a ring topology, R must be equal to 1

The following illustrations show the network topologies that can be used in the model:

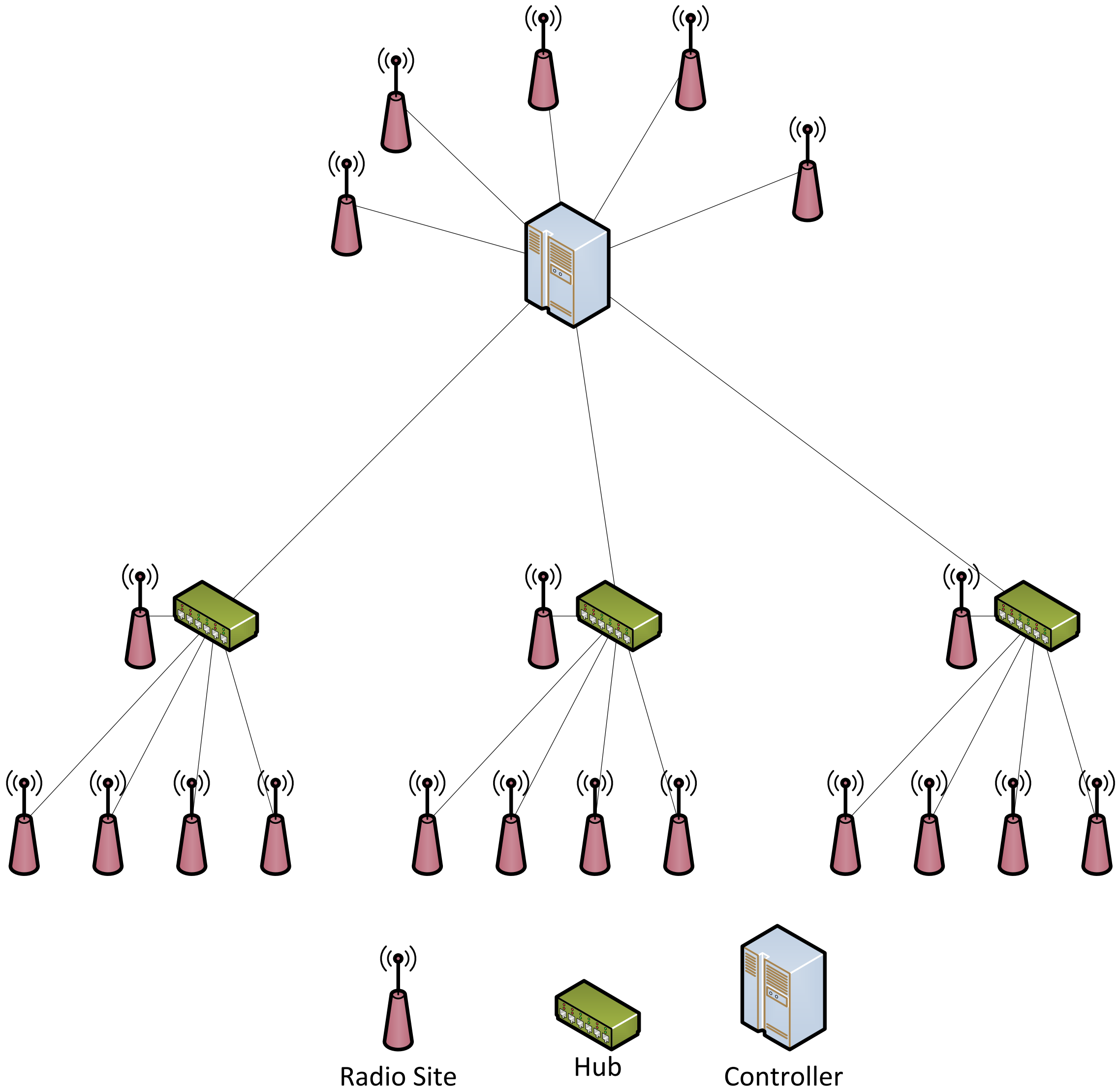

Exhibit 6.22: Topology scheme for backhaul network with point-to-point links. [source: Axon Consulting]

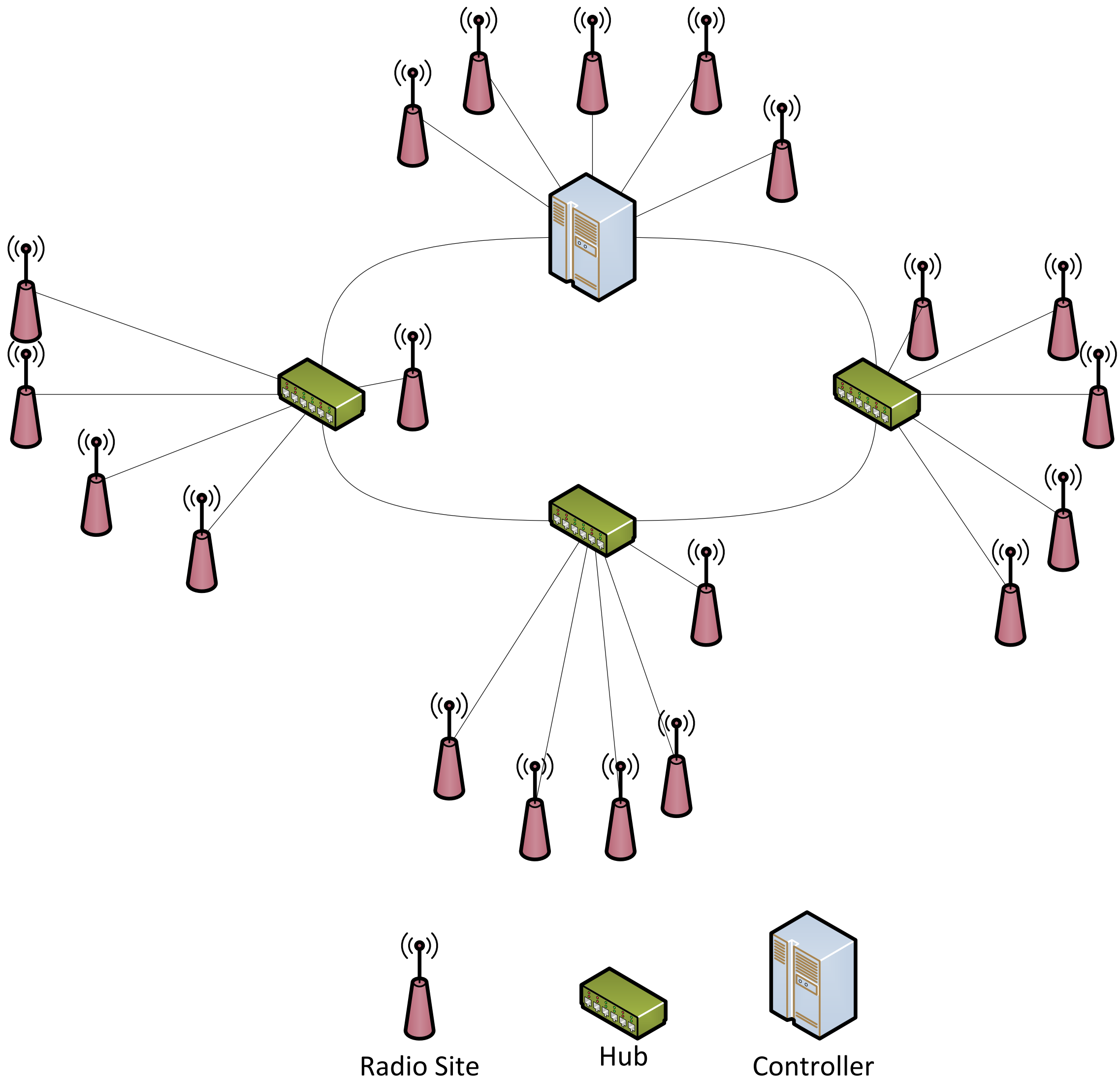

Exhibit 6.23: Topology scheme for backhaul network with ring connection between hubs and the controller [Source: Axon Consulting]

As shown in the chart, the elements considered in the backhaul network topology are:

- Transmission links between radio site and the hub or the controller, which may use a mix of different technologies (microwave, leased lines or fibre)
- Hubs or backbone centres: the traffic from radio sites is added in this element. The aggregator is placed in the location of a radio site hence there being a direct link
- Controllers: these include controllers of different technologies (GSM for BSC, RNC for UMTS and switches for LTE). The locations are shared by all three technologies and, similarly to the aggregators, controllers are located in a shared location with a radio site and an aggregator in the same location of a core site

6.7.2. **Dimensioning algorithm for backhaul network**

The dimensioning algorithm for a backhaul network is organised into six–steps, as shown in the illustration below.

It is important to clarify that, like the other dimensioning modules this algorithm runs separately for each geotype considered.

In the case of steps 2 and 3, the algorithm also runs for each node type (i.e., in the case of base stations with GSM, GSM and UMTS, etc.) and link type (radio hub location).

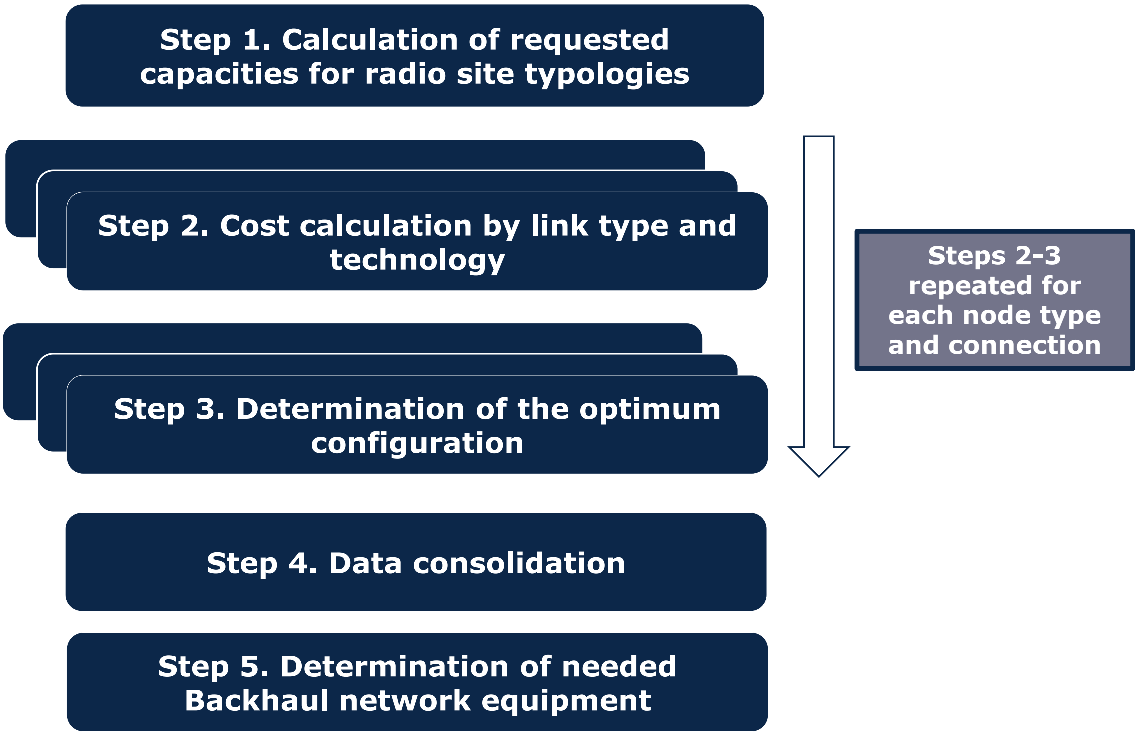

Exhibit 6.24: Steps for backhaul dimensioning. [Source: Axon Consulting]

6.7.3. **Step 1. Calculation of requested capacities**

In Step 2 the backhaul transmission requirements for each type of site are calculated. That is, radio sites are distinguished between those with only GSM technology, those with only UMTS radio and so on. This process is carried out differently for radio site-backbone centres links, hence the need for the following step.

Calculation of required capacities for radio site – Hub (Backbone centres) links

To determine the capacity (bandwidth) required of the links between the radio site and hub, the model first calculates average bandwidth per base station type depending on the number of sites and bandwidth required, by technology[10].

Having calculated the average bandwidth required for GSM, UMTS and LTE base station, the capacity is determined for each type of site as the sum of the capacities located on the site, as shown in the illustration below[11]:

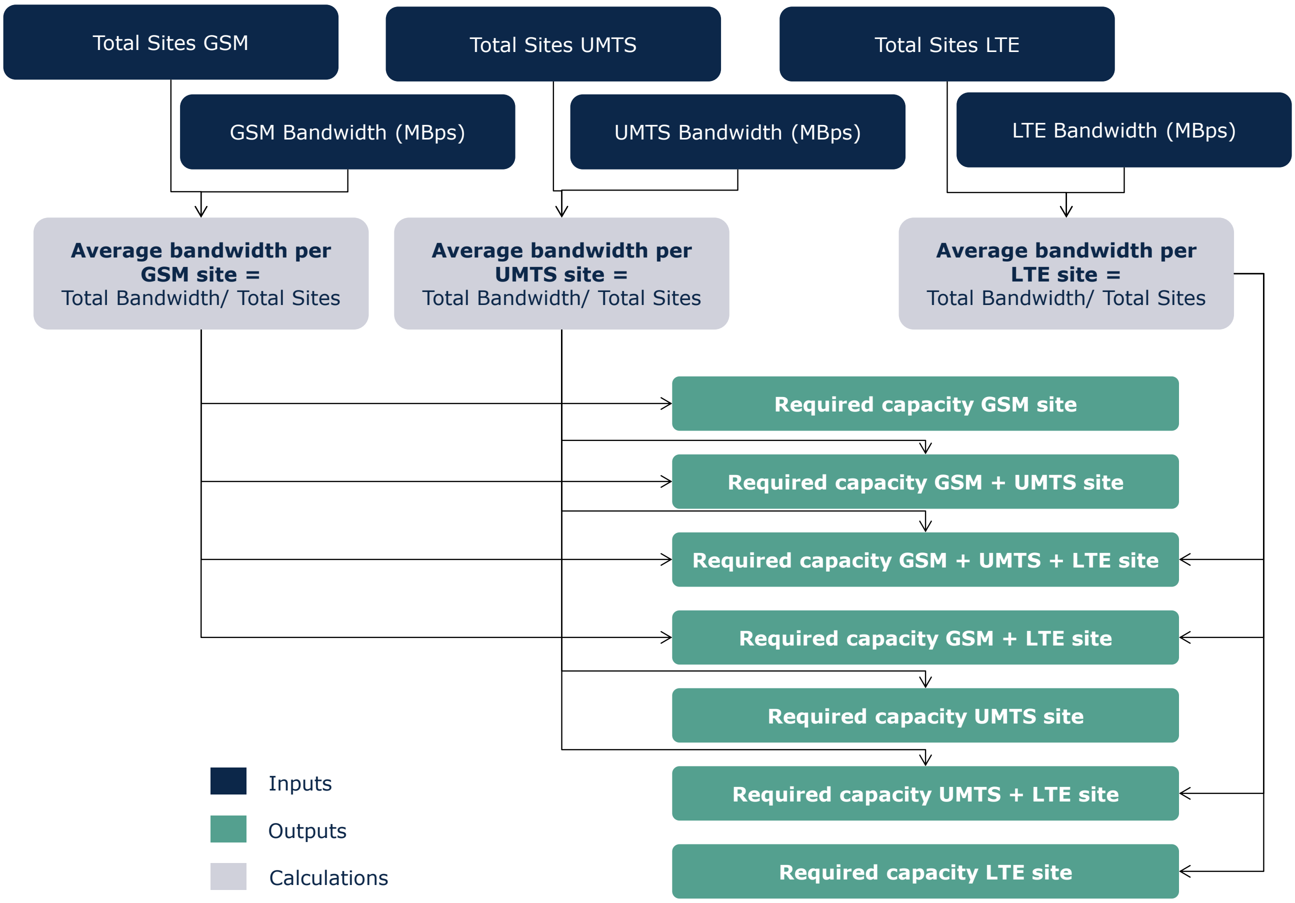

Exhibit 6.25: Calculation of required capacity by radio site typology. [Source: Axon Consulting]

[10] Note that for the conversion of voice and/or video minutes bit rates are used, and they may differ from those in the radio access.

[11] Note that in all cases a minimum granularity of links needed by technology is considered. This is to prevent combined GSM and UMTS traffic within a single E1 for example, because traffic will not be added at that level.

6.7.4. **Step 2. Cost calculation by link and technology**

In Step 2 costs associated to all links are determined. This calculation is performed for each link and for each type of technology (leased lines, fibre optic and microwave).

The model first calculates the number of links required by each technology and bit rate available. Once the number of each link that is needed to satisfy the required capacity is determined, their cost is calculated.

For each technology (microwave, leased lines and fibre optic), the most cost efficient option is selected (e.g. two E1 may be cheaper than one E3).

The illustration below shows the calculation process regarding links necessary for each type of technology:

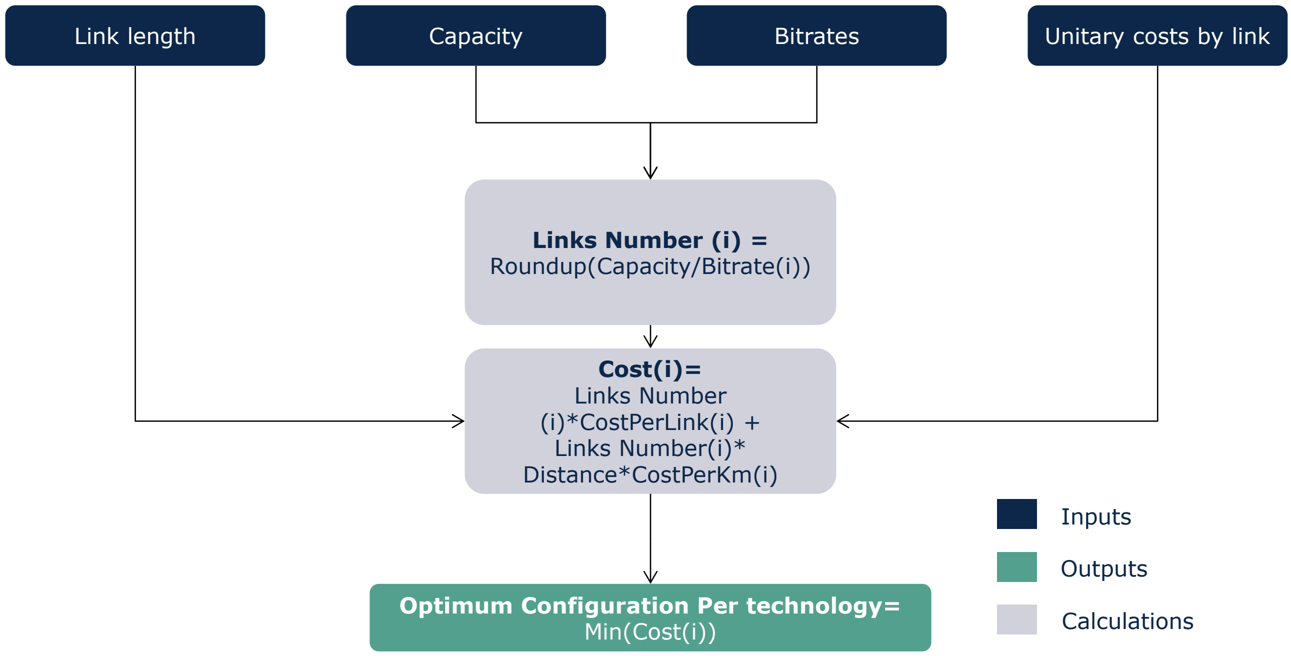

Exhibit 6.26: Calculation of optimum configuration of links needed (for each technology separately) [Source: Axon Consulting]

6.7.5. **Step 3. Determination of the optimal backhaul network**

In step three the network configuration is optimised from a costing point of view, taking into consideration a technical availability factor for each of the technologies considered.

For instance, leased lines may not be available in certain geotypes or it is not possible to use microwaves for all the sites in a geotype due to technical issues (e.g. mountainous regions).

The cheapest technology for each type of route is chosen and, applying the availability factor for that technology, the possible percentage of this type of link to be used in the geotype is determined. The procedure is then repeated for each technology in order of economic efficiency until all links are covered.

The figure below illustrates the calculation algorithm:

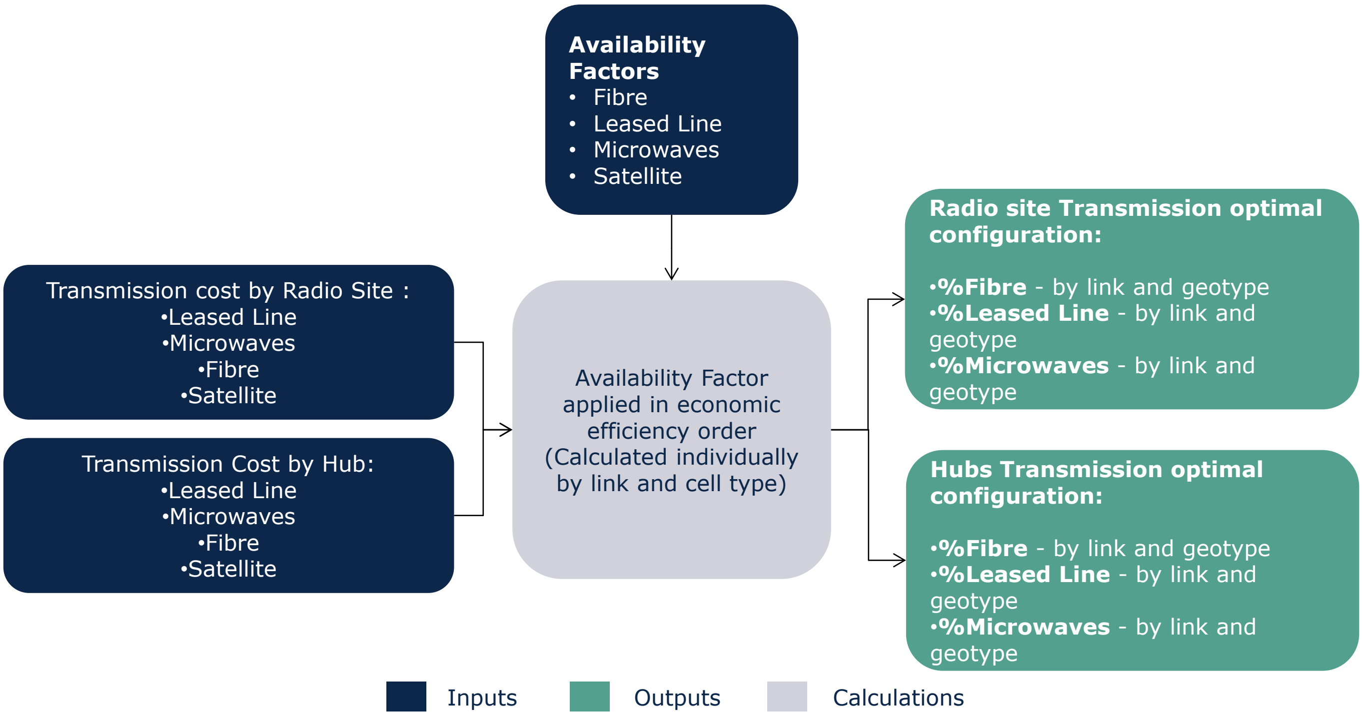

Exhibit 6.27: Optimal backhaul network determination [Source: Axon Consulting]

6.7.6. **Step 4. Consolidation of results**

This step consolidates previous steps results calculating the backhaul network requirements. Using the optimal backhaul configuration by technology type and capacities required per site, the total number of links of each type is calculated.

6.7.7. **Step 5. Calculation of number of hubs and ports**

The calculation of the number of hubs required is a function of the number of radio sites to be connected through aggregators and the defined number of radio sites per hub.

Please note that the number of ports required is a result of the estimate of the number of links of the backhaul network as each link will have an associated port in the hub element.

6.8. **Core network dimensioning**

6.8.1. **Introduction to core network dimensioning**

The core network dimensioning module is responsible for the dimensioning of the backbone network and core equipment, dealing with the central network management.

The model defines two fundamental phases for the core network:

- First phase: the core network is formed by equipment 3Gpp legacy equipment, including the separation of the control and traffic layers (MSC-S+MGW). First-phase core is adequate for GSM and UMTS
- Second phase: this phase represents the evolved core. The evolved core has the necessary equipment to support LTE Access networks and is based on All-IP transmission. Additionally, it includes IMS equipment for supporting services generated by 2G and 3G access networks

The change between first and second phases is carried out in the year selected in the control panel ("no migration" option is also available). However, if an LTE network is developed, the creation of an evolved core is needed. Therefore, the two cores can coexist from the year when the LTE access network starts to be rolled-out and the year selected for the migration of the core network.

Description of core architecture

The following illustration shows the traditional network structure (first phase) from a functional viewpoint:

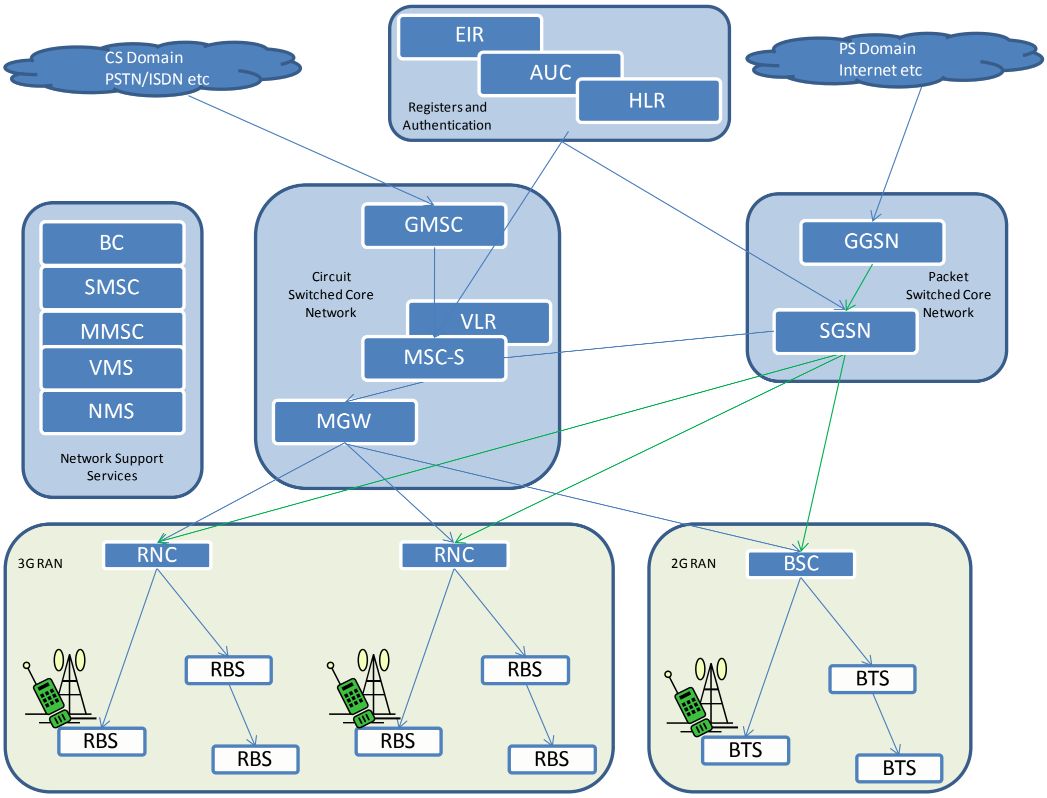

Exhibit 6.28: Schematic model of traditional network. [Source: Axon Consulting]

The main equipment making up the traditional core network is:

- **MSC-S (Mobile Switching Centre Server):** the MSC-S is responsible for managing the control of circuit call level in the mobile network, i.e. voice and video calls. The MSC manages signalling issues, user mobility and call control. It usually has other features such as built-VLR
- **MGW (Media Gateway):** the MGW is responsible for the physical transportation of voice and video calls traffic. It works in collaboration with the MSC-S to enable call circuits. The MGW also incorporates functionalities for managing STP and control plane SCCP data routing
- **GGSN (Gateway GPRS Support Node)**: the GGSN is the central element of the packet traffic network and the node that provides connectivity between the mobile network and other packet networks, such as internet access
- **SGSN (Serving GPRS Support Node)**: the SGSN is the node responsible for delivering data packets between the mobile user and the GGSN
- **HLR (Home Location Register)**: the central database containing details of all network subscribers, including data from SIM cards and MSISDN numbers associated with each one. In this database the services available in the profile of each subscriber are defined

- **SMSC (Short Message Service Centre)**: the equipment responsible for the management, delivery and storage of short messages on the mobile network
- **MMSC (Multimedia Message Service Centre)**: the equivalent of the SMSC for multimedia messages
- **VLR (Visitor Location Register)**: contains details of all users who are currently in the coverage area of the MSC. It communicates with the HLR to localise users at all times. It is usually built directly into the MSC
- **AuC (Authentication Centre)**: responsible for checking the SIM data before initiating a call and can be incorporated into the HLR
- **EIR (Equipment Identity Register**): a record of prohibited or under supervision phones in the network, usually built into the HLR
- **BC (Billing Centre)**: the equipment and services responsible for managing call billing, recharging prepaid users' credit and so on. The BC includes SCP and SDP equipment
- **NMS (Network Management System)**: the system for the maintenance of the network and its equipment
- **VMS (Voicemail System)**: the equipment that manages the mailboxes of subscribers
- **BSC (Base Station Controller)**: the part of the system's infrastructure that controls one or multiple cell sites' radio signals. It performs radio signal management functions for base transceiver stations, managing functions such as frequency assignment and handoff
- **RNC (Radio Network Controller)**: Is the governing element in the UMTS radio access network (UTRAN) responsible for controlling the NodeBs. RNC carries out radio resource management and some of the mobility management

In the NGN network (phase two), there is a fundamental change. Instead of handling circuit and packet traffic separately, all the traffic is handled as packet switched.

The following illustration shows the NGN network structure (second phase) from a functional viewpoint:

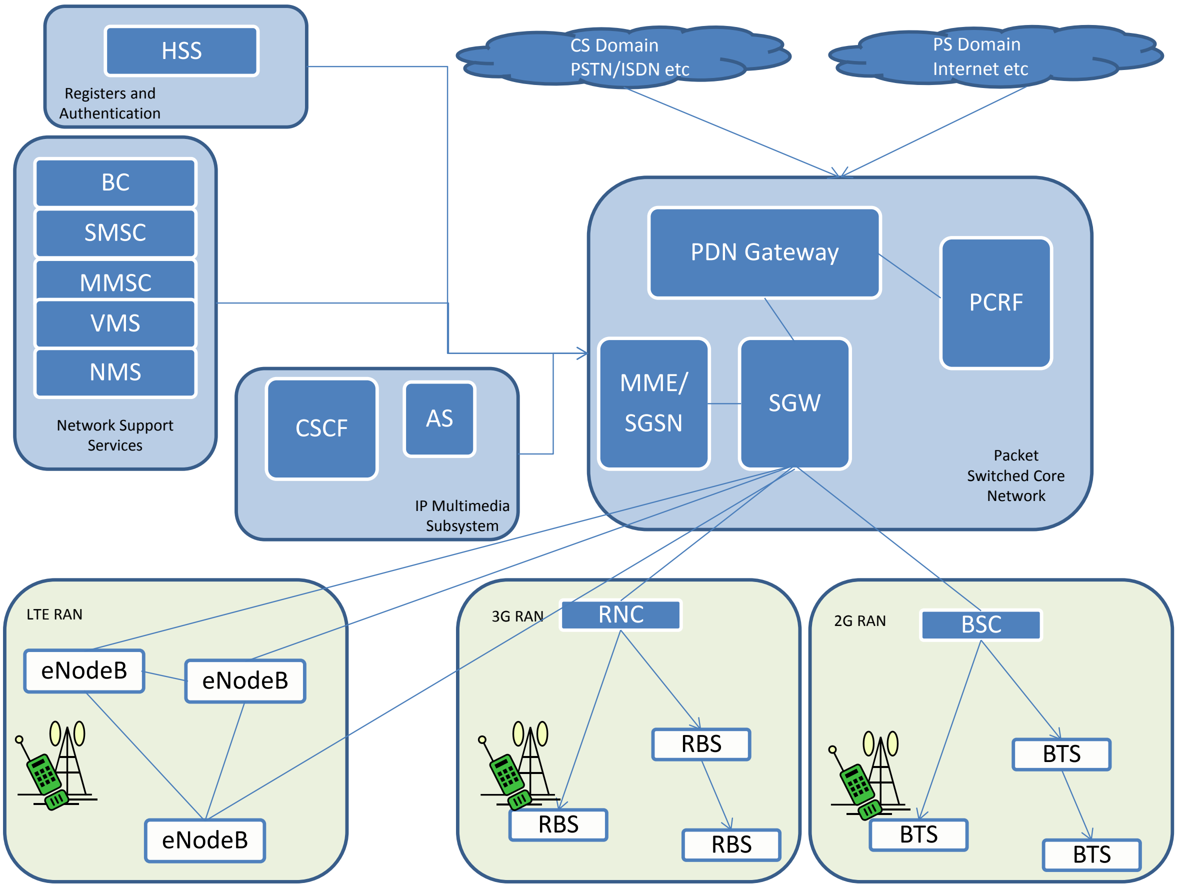

Exhibit 6.29: Schematic Model of NGN Network. [Source: Axon Consulting]

The new equipment that constitutes the NGN Core Network is:

- **MME (Mobility Management Entity)**: the main control point for subscribers and calls in the NGN network. It is responsible for subscribers monitoring and paging as well as managing their mobility along access networks. The MME combines the functionalities of the MSC and GGSN in the traditional network
- **SGW (Serving Gateway)**: responsible for routing and delivering the packages. It replaces the functionalities of MGW and SGSN in a traditional network. It can be integrated with the MME or the PGW)
- **PGW (PDN Gateway)**: connects the network with external networks. It can be integrated with the SGW
- **PCRF (Policy and Charging Rules Function)**: manages network and billing policies. It can be integrated with the SGW
- **HSS (Home Subscriber Server)**: the master database of the core network. It combines the functionalities of HLR and AUC in the traditional network, and adds the needed functionality for managing the subscribers in IP systems

- **CSCF (Call Session Control Function)**: the set of functionalities responsible for managing multimedia services based on SIP. It incorporates the functionality of session border controller for the interface user-network
- **SBC (Session Border Controller)**: interconnection equipment, responsible for managing signalling, VoIP calls set-up and other multimedia connections based on IP

From a practical point of view, in the model the logical structure of the core under both technologies is similar. The radio traffic comes to a core site, connected to the backbone and integrated with other packet networks and traditional telecommunications.

In the case of a national-scale network, it is necessary to have several core sites interconnected, so that each area has reasonable access to core services.

For dimensioning of core network, reference operator's core locations have been inputted, including the percentage of traffic that each location will handle.

For the dimensioning of the core network, four steps were considered:

1. Dimensioning of core controllers (BSC, RNC, Switches)
2. Dimensioning of core main equipment (e.g. MGW, MSC-S, SGSN, GGSN)
3. Dimensioning of interconnection (to other networks) equipment
4. Dimensioning of backbone links between core locations

In the following sections the methodology used in each of these blocks of dimensioning is explained.

6.9. Dimensioning of core equipment

The design of core equipment is mainly based on their maximum capacities and the traffic they have to bear.

In general terms, the different types of core equipment share a common dimensioning process.

In the first stage, core sites containing equipment to be dimensioned are identified. Please note that core sites, in general, may contain host different sets of equipment (i.e. not all core sites will contain MGW or MSC-S).

The required capacity for each core link is then calculated from the dimensioning drivers. The percentage of network traffic related to different core locations has been obtained from the reference operator's documentation.

Once the capacity required for each location of the network is obtained, the calculation of equipment requested is carried out. The result is dependent both on capacity requirements and the equipment's technical constraints.

It is important to underline that granularity effects have been taken into account by considering each core location separately, in order to resemble the reference operator's core network topology and structure.

In the following sections the dimensioning particularities for each equipment type are presented.

6.9.1. Dimensioning of core controllers

The controllers considered are the following:

- BSC (Base Station Controller): controls multiple BTSs (2G). It handles allocation of radio channels, frequency administration, power and signal measurements from the user terminal and handovers from one BTS to another (when both BTSs are controlled by the same BSC). A BSC also reduces the number of connections to the Media Gateway (MGW) and allows for higher capacity connections to the MGW
- RNC (Radio Network Controller): the RNC (3G) is an important network element in third-generation access networks. It handles mobility management, link management, call processing and handover mechanisms. In carrying out such functions, the RNC has to reliably accomplish a tough set of protocol processing activities at a swift pace and with the expected performance
- Switch: In LTE Networks, the radio sites (eNodes B) incorporate all the functionalities performed by the controllers in the previous generations. Therefore, instead of a controller, only a switch that aggregates the traffic from the eNodes B is required

Controller equipment calculations are carried out according to the general methodology outlined in the previous paragraph.

The first step taken in controllers dimensioning is the identification of the reference traffic on which to base calculations.

Starting from the drivers' original values, the previously introduced concepts of planning horizon and efficiency factor are applied. From now on, these concepts will always be applied.

Additionally, certain data from the access network is required for the dimensioning of the controllers (e.g. number of cells, transmission cards installed).

The overall core traffic and data from the access network, is split into portions, according to the percentage of traffic carried by each single location. The purpose of this step is to recognise which amount of traffic has to be managed by each location hosting the class of equipment considered.

The model also determines whether each technology (GSM, UMTS and LTE) has been deployed in the area to be managed by the location. This mechanism is needed to ensure that the controllers are only installed in those areas covered by certain technology. For instance, if UMTS has not been rolled out in an area, no RNC is installed in the corresponding core location.

Once the amount of traffic and access information for each location is obtained, the number of controllers required is calculated by applying the technical constraints (depending on the technology) provided by the reference operator:

$$Controllers\ for\ Location\ n \geq \frac{Parameter\ (n)}{Technical\ Constraint\ (n)}$$

Where the parameter can be a driver or information from the access network, the technical constraint depends on the equipment used (size, manufacturer, etc.). For the dimensioning of controllers, several parameters and constraints are considered, taking into account the more restrictive. More specifically, the following parameters are considered:

- BSC constraints:
  - Busy-Hour Call Attempts (BHCA)
  - Number of time slots
  - Number of sectors or cells
- RNC constraints:
  - Busy-Hour Call Attempts (BHCA)
  - Number of nodes B
  - Data traffic in Mbps
- Switch constraints:
  - Total traffic in Mbps

At the end of the process, the amount of equipment calculated for each location is totalled, and the total number of BSCs, RNCs and switches requested in the network is obtained.

6.9.2. Dimensioning of core main equipment

The dimensioning of core main equipment builds upon the concepts outlined for core dimensioning in paragraph 6.9. The calculation procedure is equivalent to that described for controllers dimensioning in paragraph 6.9.1.

The details of each functionality are stated below.

MGW dimensioning

The MGW is responsible for managing the circuit traffic calls between core locations, in cooperation with the MSC-S. Since all circuit traffic of the network passes by MGW equipment, it is considered appropriate to take a minimum of one MGW per core site. The MGW is used to route at a physical level all data from the control layer sent by the MSCs. The capacity limit of the MGW is based on the total traffic of circuit calls at any time.

The relation used to dimension MGW is the following:

$$MGW\ Number\ for\ SITEn \geq \frac{Core\ \ Voice\&Video\ Traffic\ by\ SITEn\ (Erlangs)}{Technical\ Constraint\ (Erlangs)}$$

NGN Network Equipment

MME (Mobility Management Entity)

The MME is the central equipment for calls and users control, replacing the functions of MSC and GGSN. We considered it appropriate to take a minimum of one MME per core site. Its capacity limit is defined by the number of Simultaneous Active Users (SAU) that it can handle:

$$MME\ SAU = Simultaneous\ Active\ Users\ \ by\ SITEn\ (SAU)$$

SGW (Serving Gateway)

The SGW is responsible for routing and delivering data packages of users. It replaces the functions of the MGW and SGSN in the traditional network. SGW functionality can be integrated in the MME or PDN GW. We assume that there is dedicated equipment in each core site. It is dimensioned based on the amount of traffic (Mbps) it can handle.

$$SGW\ Mbps = Traffic\ by\ SITEn\ (Mbps)$$

PGW (Packet Data Network Gateway)

The PGW connects the SAE Core network with external networks. It can be integrated in the SGW. As in the case of the SGW, its capacity limit will be the traffic.

$$SGW\ Mbps = \ Traffic\ (Mbps)$$

PCRF (Policy and Charging Rules Function)

The PCRF is the generic name for the system in charge of network policy management and billing. It can be integrated in the PDN GW. Its capacity limit is measured in the number of total subscribers in the network.

$$PCRF\ Subs = \ Subscribers\ (\#subs)$$

HSS (Home Subscriber Server)

The HSS is the database of the NGN network. It includes the functionalities of HLR and AUC of the traditional network. Additionally, the HSS is in charge of managing subscribers in an All-IP network. It is dimensioned based on the number of subscribers in the network.

$$HSS\ subs = \ Subscribers\ (\#subs)$$

CSCF (Call Session Control Function)

The CSCF aggregates all the functionalities responsible for managing multimedia services based on SIP. It also includes the functionality of the session border controller for the interface user-network. Its capacity is measured in SAU.

$$CSCF\ SAU = Simultaneous\ Active\ Users\ \ (SAU)$$

Centralised equipment

The following functionalities are considered as network support and are not directly involved in traffic managing. Therefore, they will be centralised in one core site for all the member states.

MSC-S dimensioning

The MSC-S is one of the fundamental pieces of core network equipment responsible for management and circuit call control in the core. The MSC-S capacity limits are based on the number of peak call attempts in the busy hour. It is assumed that the

VLR functionality is included in the MSC-S equipment. For the dimensioning of the MSC-S the following formula is applied, taking into account that these equipment is shared among member states:

$$MSCs\ BHCA = \ Core\ \ BH\ Call\ Attempts\ by\ SITE\ (BHCA)$$

GGSN dimensioning

The GGSN is another component of the fundamental core equipment. It provides data interconnection between the packet core and external packet networks like the internet. Data traffic from users must go through a GGSN to reach the internet, but radio equipment does not connect directly, but rather to the SGSN. Therefore, there is no need to put a core GGSN at each site. In fact, all that is required is a GGSN where the operator is able to interconnect with external networks resulting in a reduced number of central locations. The capacity of the GGSN is limited by the amount of Mbps it can manage. the following formula is applied:

$$GGSN\ Mbps = \ Core\ \ Data\ traffic\ \ by\ SITEn\ (Mbps)$$

SGSN Dimensioning

The SGSN is responsible for establishing packet data connections with end users and delivering data packets between them and the GGSN in both directions. Radio controllers are connected directly to the SGSN and it is defined it takes at least one SGSN per core site. In the case of SGSN, the node capacity limit is defined by the amount of Mbps it is able to manage.

$$SGSN\ Mbps = \ Core\ \ Data\ traffic\ \ by\ SITEn\ (Mbps)$$

HLR Dimensioning

The HLR is the central users' data register and is centralised in the core network. HLR communicates with MSC-S and SGSN equipment, but not directly with the radio network. For this reason, a HLR at each core site is not required, and a minimum of one HLR in the whole network would suffice. The capacity limit of the equipment is the size of the database, hence it is a function of the total number of network subscribers.

$$HLR\ Subs = \ Total\ Network\ Subscribers\ (\#subs)$$

SMSC Dimensioning

SMSC is the equipment responsible for the management and delivery of SMS messages. It communicates with radio access equipment through the MSC-S;

therefore it is not necessary to have one in each core site. SMSC is limited by the number of SMS it can manage in the busy hour.

$$SMSC\ BH\ SMS = Number\ of\ SMS\ in\ BH\ (\#sms)$$

MMSC Dimensioning

MMSC is the equipment responsible for the management and delivery of MMS (multimedia messages). It communicates with radio access equipment through the SGSN. Therefore it is not necessary to have one in each core site. MMSC is limited by the number of MMS it can manage in the busy hour.

$$MMSC\ MMS = Number\ of\ MMS\ in\ BH\ (\#mms)$$

BC (Billing Centre)

It is the common name of all the systems and functionalities involved in managing all the billing process in the network. Therefore, it is usually dependent on the number of events recorded (e.g. calls, SMS, data sessions). BC includes the functionalities SCP and SDP.

$$BC\ Billing\ events = Billing\ events\ in\ the\ busy\ hour\ (\#BE)$$

VMS (VoiceMail System)

VMS is the automatic recording, storing and delivery system for voice messages. Its capacity limit is based on the number of active voicemails.

$$VMS\ Voicemails = Active\ Voicemails\ (\#AVM)$$

6.10. Dimensioning of backbone links between core locations

For the dimensioning of backbone links, the actual links of the MNO have been taken into account and their average will form the reference operator’s backbone network, both in terms of topology and technology (leased lines, microwaves or optical fibre).

With that purpose, all the backbone links considered have been introduced in the model, including the distance, the technology employed and the percentage of traffic. This percentage of traffic is based on the information provided by the operators to better represent the average of the two MNOs backbone networks.

Since the requirements in terms of traffic are set individually for the links, the dimensioning algorithm calculates the minimum bit rate (among those available to the specific technology) ensuring sufficient capacity to each link.

7. Cost Calculation Module

The purpose of this module is to calculate the gross book value (GBV) and OpEx associated with the required network resources coming from the dimensioning module. This section presents the steps to obtain these expenses, as illustrated in the following figure:

Exhibit 7.1: Resources costing. [Source: Axon Consulting]

The following sections each step in detail.

7.1. Step1. Determination of resource unit costs and cost trends

For the definition of the unitary costs of the resources considered in the model, two inputs are needed:

- Historic unitary costs: separated into CapEx and OpEx (for those resources where applicable). Unitary costs can be introduced in any of the currencies accepted in the model (i.e. Caribbean Dollar, US Dollar)
- Cost trends: For each resource a cost trend can be introduced, outlining the expected evolution of its prices (both CapEx and OpEx separately) in the short/medium term

Once historic unit costs and cost trends have been introduced, the model will apply the trend where unit costs have not been introduced (usually in future years). The formula used for the application of cost trends is the following.

$$Unit\ Cost\ (year) = Unit\ Cost\ (year - 1) * \left(1 + Trend\ (year)\right)$$

7.2. Step 2. Calculation of GBV, OpEx and G&A

Once the number of network elements and other resources is obtained in the dimensioning modules, the calculation of the GBV, G&A and annual OpEx is obtained based on P*Q basis:

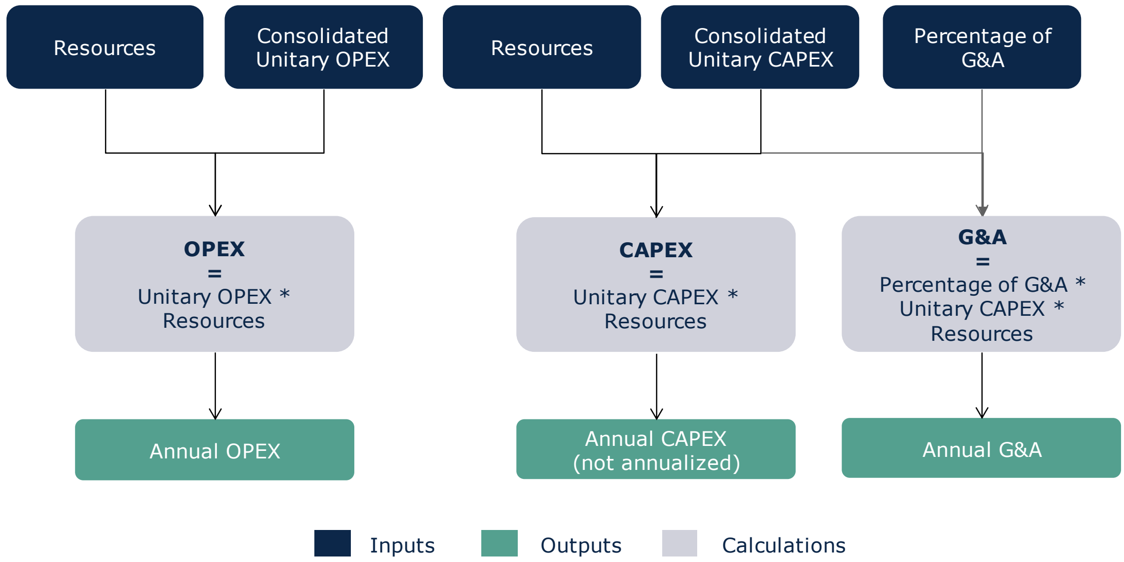

Exhibit 7.2: Algorithm for the calculation of GBV, G&A and OpEx [Source: Axon Consulting]

Aligned with the methodology, G&A percentage is based on the GBV of network assets, compared to the total GBV, as explained in the following formula:

$$Percentage\ of\ G\&A = \frac{General\ and\ Administrative\ Expenses (G\&A)}{Gross\ Book\ Value\ (GBV)}$$

8. Depreciation Module

The depreciation is based on tilted annuities methodology, as defined in the principles and methodology defined by ECTEL.

Tilted annuities adapt the profile of the costs recovery with the objective of recognising the variations in asset prices. For example, if prices of assets decrease, a new entry in the market could have a great advantage over existing operators because it will benefit from best prices and therefore lower depreciation costs.

With the variable depreciation method, if prices decrease, a higher proportion of the asset is recovered during the initial periods so the same cost will be recognised for both entries, not taking into account the time when they entered the market.

For this reason, the model obtains the annuity value using the following formula:

$$Annuity(WACC) = \frac{WACC - \Delta p}{1 - \left(\frac{1+\Delta p}{1+WACC}\right)^{Asset\ Life}} \times Asset\ Value$$

Where:

- $WACC = the\ weighted\ average\ cost\ of\ capital$;
- $\Delta p = rate\ of\ price\ change$ ("tilt");
- $Asset\ Value = the\ current\ investment\ cost\ of\ the\ asset$;
- $Asset\ Life = the\ useful\ life\ of\ the\ asset$.

For the application of the weight average cost of capital (WACC), it is important to bear in mind that the equipment is already adjusted for inflation when the cost trends and currency exchange rates are applied. Therefore, the effect of the inflation is eliminated from the WACC to avoid including it twice.

Even though the tilted annuities do not separate the depreciation from the cost of capital components (as may be done in straight line depreciation methodology), the model splits such components for presentation and transparency purposes. In order to do so, the following formulas are applied:

- $Depreciation = Annuity(0)$
- $Cost\ of\ Capital = Annuity(WACC) - Annuity(0)$

9. Incremental Costs Calculations

This section presents the methodology followed to calculate the costs of the services under the LRIC+ standard.

The incremental cost associated to each increment is the reduction in the costs calculated by the model due to ceasing the provision of the services included in that increment. This cost is expressed mathematically as the difference between the cost of total demand and the cost obtained when the level of demand for the services included in the increment are set to zero, leaving all others unchanged:

$$INCREMENTAL\ COST(increment1) = F(v1, v2, v3, vN, C) - F(0, v2, v3, vN, C)$$

Where F is the formula that represents the bottom-up model (which calculates the cost according to demand and coverage), vi^{vi} represents the demand volume of increment i and C represents the coverage.

Throughout this chapter the process of defining increments and the process of calculating the costs are described.

9.1. Increment definition

To calculate the incremental costs, increments are defined as groups of services. Therefore, services have to be assigned to increments.

In the BULRIC model, the following increments (sheet '0F PAR INCREMENTS') are defined as per the established methodology:

- Voice
- Data and other services

Once the increments outlined are defined, each service needs to be assigned to one of these increments.

9.2. Incremental Cost Calculation

The following figure illustrates a representation of a simplified scheme of the calculation flow utilised for the incremental cost calculation of all increments:

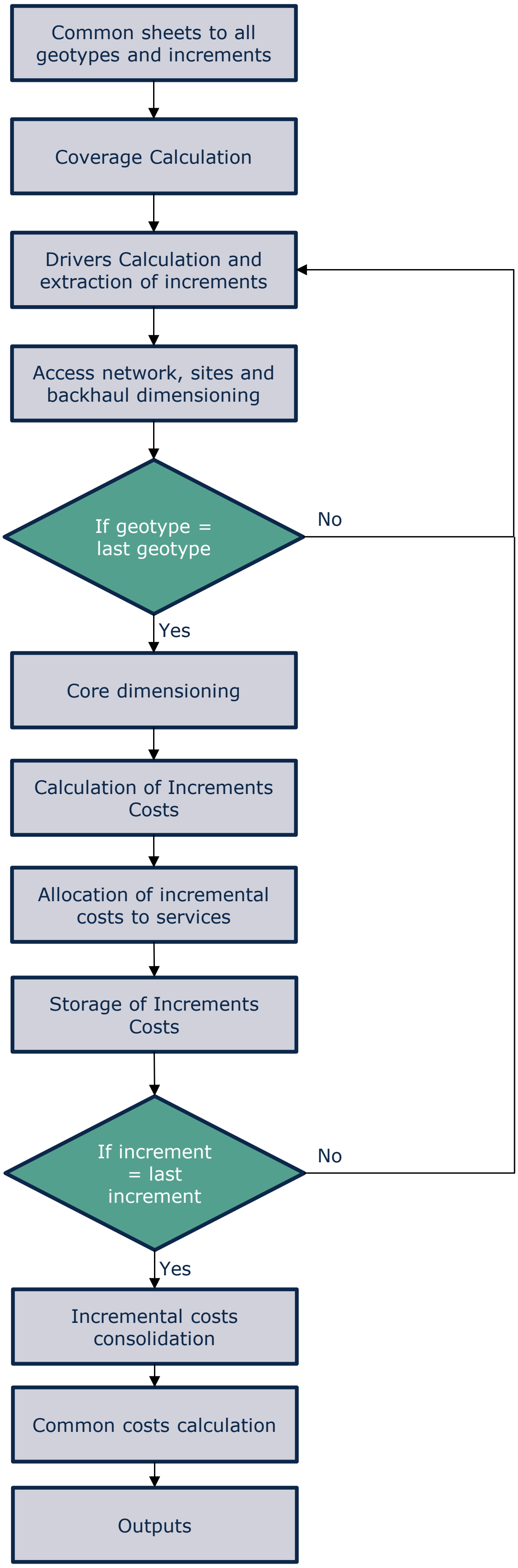

Exhibit 9.1: Simplified scheme of the calculation flow for of all increments [Source: Axon Consulting]

Please note that in sheet '5E CALC DRIVERS CONSOL', the services included in the increment considered at a particular time are subtracted, which represents the step 'Drivers Calculation and Extraction of Increments' in the chart, shown above. After subtracting this traffic, the model is run following the steps described in this document.

After finishing the execution of an increment, the increment's annual costs (defined as the difference between the total costs, previously obtained, and costs obtained by removing the increment's traffic) are allocated to services[12] and saved in sheet '11E MAC SERVICES COST'. This step represents the 'Storage of Increments Costs' in the preceding chart.

It should be stressed that, for incremental costs, the full model must be run as many times as the number of increments, plus one, to obtain the total cost[13].

9.3. **Common cost calculation**

Once each of the increments defined are run, the incremental costs per services are consolidated and common network costs are calculated as the difference between the total cost base obtained under the LRIC standard and the total incremental costs extracted, as explained in the following formula:

$$Common\ Costs^{14} = FAC - PureLRIC(1) - PureLRIC(2) - PureLRIC(3)$$

Aligned with the methodology, the common costs are allocated to services though routing factors (effective capacity approach).

Once the services' common costs are calculated, the LRIC+ methodology is calculated using the following formula:

$$LRIC + Cost = Pure\ LRIC\ cost + Common\ Costs$$

[12] This step considers the same methodology of using routing factors as employed for the allocation of costs under the FAC standard, described in section 9 of this document.
[13] This loop is controlled by the Visual Basic macro that manages the execution flow of the model's sheets.
[14] The common costs represent the cost of the network needed to carry the traffic from any point to any other point in the Member State.

10. Cost Overheads

As defined in the methodology and principles defined by the ECTEL, the OpEx related network working capital should be calculated as a percentage of network OpEx (overheads).

Based on the information available, the most suitable alternative found has been the calculation of a percentage overhead over network costs, similarly to what is applied for the working capital.

Based on this methodology, network OpEx working capital is calculated as follows:

- Network OpEx working capital:

$$Network\ Opex\ Working\ Capital = WCOverhead * Network\ OpEx$$

Please note that the overhead percentages are calculated based on the operator's overall financial statements consistent with the formula above.

Annex A. Detailed Geographical Analysis by Member State

This annex presents the geographical analysis results for each member state.

A.1. Geographical analysis for access network

The following information represents the geographical information results, as used for dimensioning access nodes and the backhaul network.

In accordance with the consideration mention in section 5.2.4, the population centres of all the countries have been aggregated into geotypes, as is shown in the exhibits below.

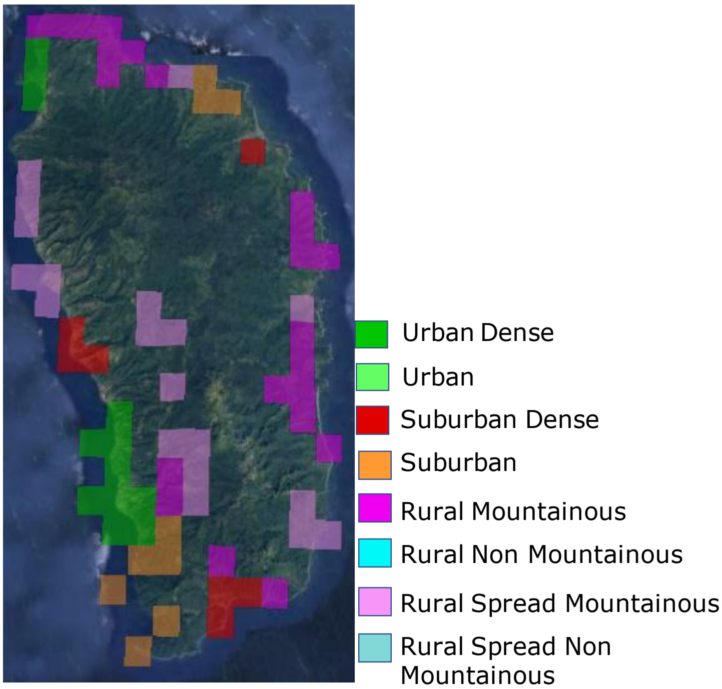

Exhibit A 1. Population centre geotypes for Dominica [Source: Axon Consulting]

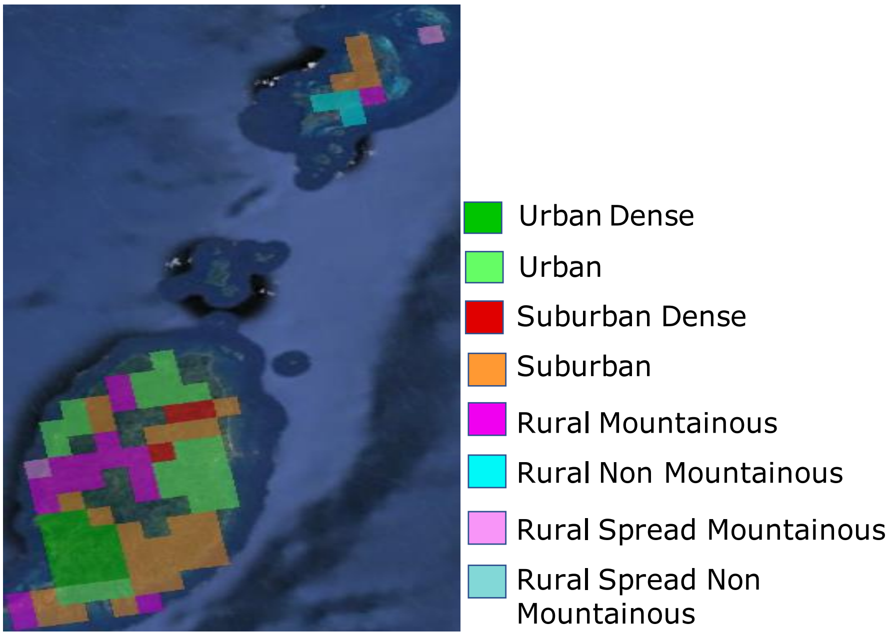

Exhibit A 2: Population centre geotypes for for Grenada. [Source: Axon Consulting]

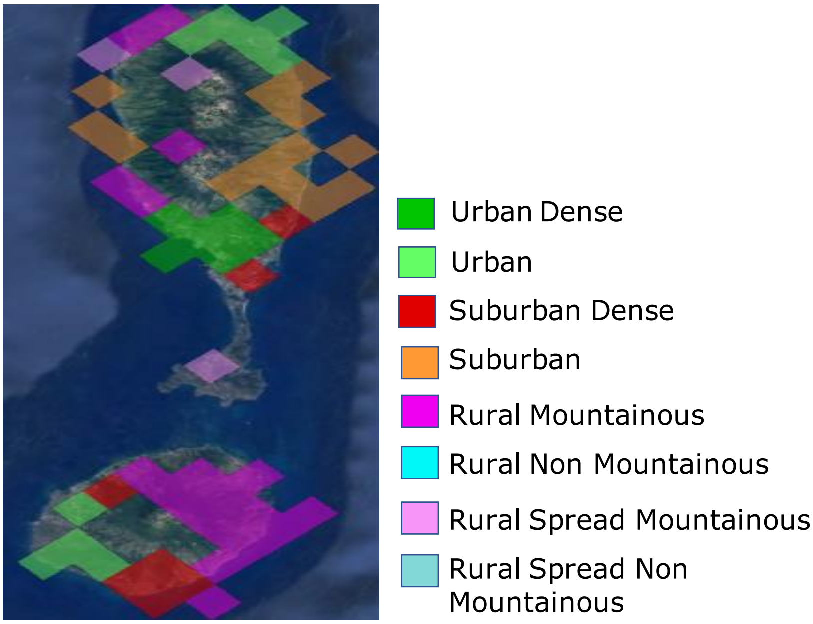

Exhibit A 3: Population centre geotypes for St Kitts and Nevis. [Source: Axon Consulting]

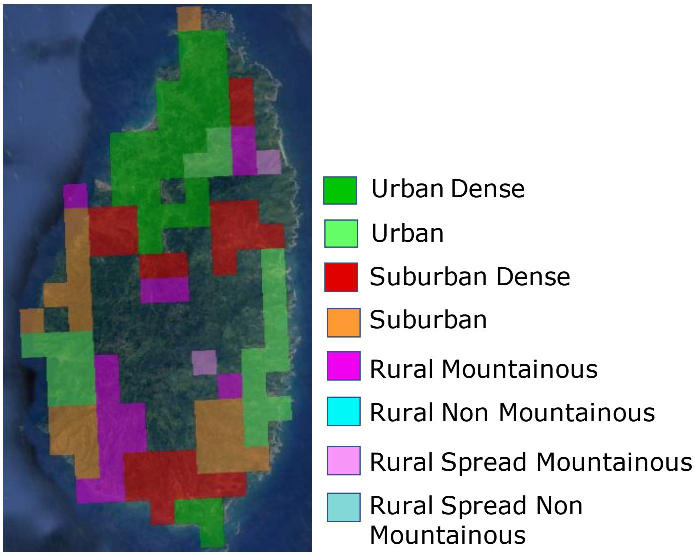

Exhibit A 4: Population centre geotypes for St Lucia [Source: Axon Consulting]

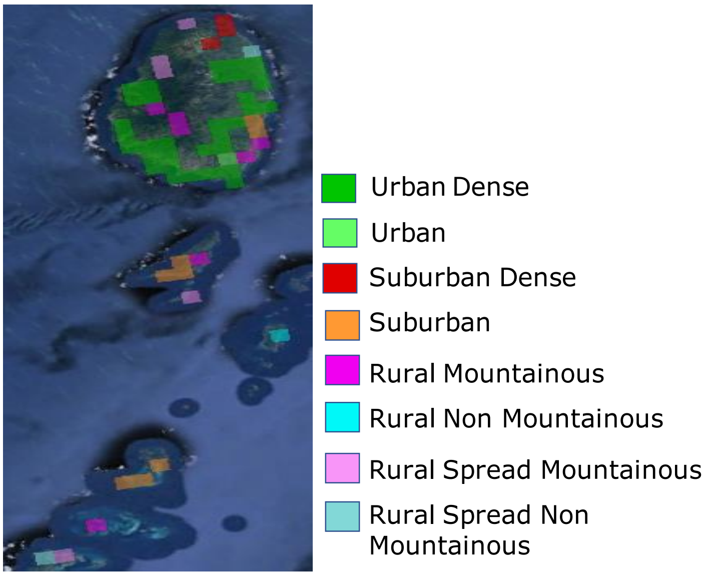

Exhibit A 5: Population centre geotypes for St Vincent and the Grenadines. [Source: Axon Consulting]

The following tables show the main characteristics of the geotypes defined in the model for member states.

Geotype	Area	Population	Population centres
URBAN_DENSE	55	31,635	21
URBAN	-	-	-
SUBURBAN_DENSE	35	10,710	9
SUBURBAN	39	7,888	11
RURAL_SPREAD-NON MOUNTAINOUS	-	-	-
RURAL_SPREAD-MOUNTAINOUS	82	9,897	19
RURAL-MOUNTAINOUS	102	12,550	46
RURAL-NON MOUNTAINOUS	-	-	-
TOTAL	**314**	**72,680**	**106**

Table A 1. Information regarding the grouping of samples into geotypes for Dominica [Source: Axon Consulting]

Geotype	Area	Population	Population centres
URBAN_DENSE	48	25,757	48
URBAN	96	36,632	90
SUBURBAN_DENSE	12	3,365	12
SUBURBAN	128	28,981	86
RURAL_SPREAD-NON MOUNTAINOUS	-	-	-
RURAL_SPREAD-MOUNTAINOUS	8	335	2
RURAL-MOUNTAINOUS	68	9,941	35
RURAL-NON MOUNTAINOUS	16	1,814	4
TOTAL	**375**	**106,825**	**277**

Table A 2. Information regarding the grouping of samples into geotypes for Grenada [Source: Axon Consulting]

Geotype	Area	Population	Population centres
URBAN_DENSE	24	19,584	19
URBAN	40	11,694	21
SUBURBAN_DENSE	40	5,328	28
SUBURBAN	60	10,395	21
RURAL_SPREAD-NON MOUNTAINOUS	-	-	-
RURAL_SPREAD-MOUNTAINOUS	20	1,756	3
RURAL-MOUNTAINOUS	76	6,815	28
RURAL-NON MOUNTAINOUS	-	-	-
TOTAL	**260**	**55,572**	**120**

Table A 3. Information regarding the grouping of samples into geotypes for St Kitts and Nevis [Source: Axon Consulting]

Geotype	Area	Population	Population centres
URBAN_DENSE	120	101,933	80
URBAN	84	24,870	35
SUBURBAN_DENSE	92	27,994	49
SUBURBAN	88	20,037	38
RURAL_SPREAD-NON MOUNTAINOUS	-	-	-
RURAL_SPREAD-MOUNTAINOUS	8	635	2
RURAL-MOUNTAINOUS	60	9,529	23
RURAL-NON MOUNTAINOUS	-	-	-
TOTAL	**452**	**184,999**	**227**

Table A 4. Information regarding the grouping of samples into geotypes for St Lucia [Source: Axon Consulting]

Geotype	Area	Population	Population centres
URBAN_DENSE	146	94,787	46
URBAN	8	15	1
SUBURBAN_DENSE	12	2,853	4
SUBURBAN	36	7,733	13
RURAL_SPREAD-NON MOUNTAINOUS	12	227	2
RURAL_SPREAD-MOUNTAINOUS	20	1,123	5
RURAL-MOUNTAINOUS	32	1,501	10
RURAL-NON MOUNTAINOUS	8	1,222	3
TOTAL	**273**	**109,462**	**84**

Table A 5. Information regarding the grouping of samples into geotypes for St Vincent and the Grenadines [Source: Axon Consulting]

A.2. Geographical analysis for core network

The following exhibits present the topology of the core network, traffic aggregation nodes and backbone links defined for the reference operator.

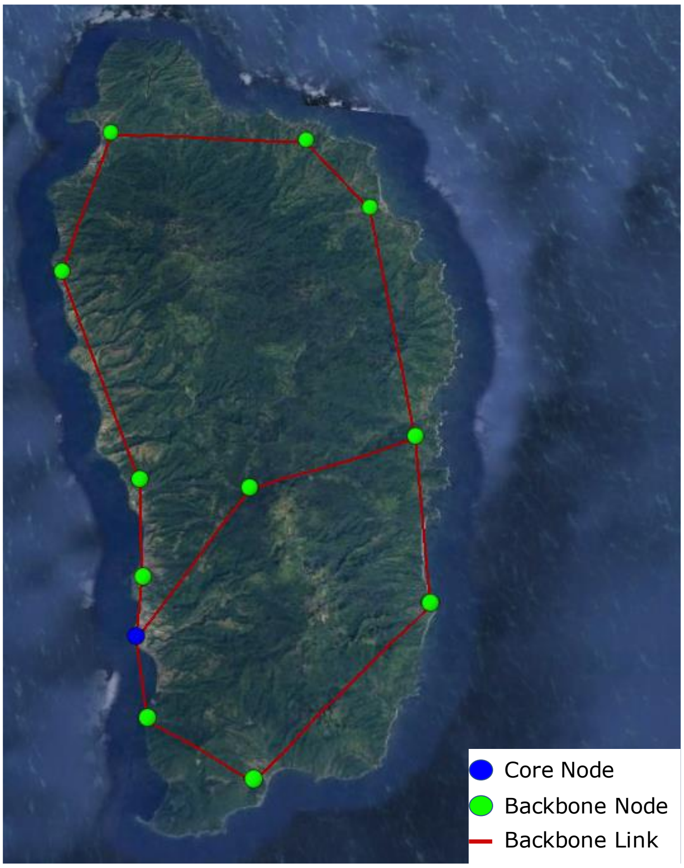

Exhibit A 6: Topology of the core network for Dominica. [Source: Axon Consulting]

Exhibit A 7: Topology of the core network for Grenada. [Source: Axon Consulting]

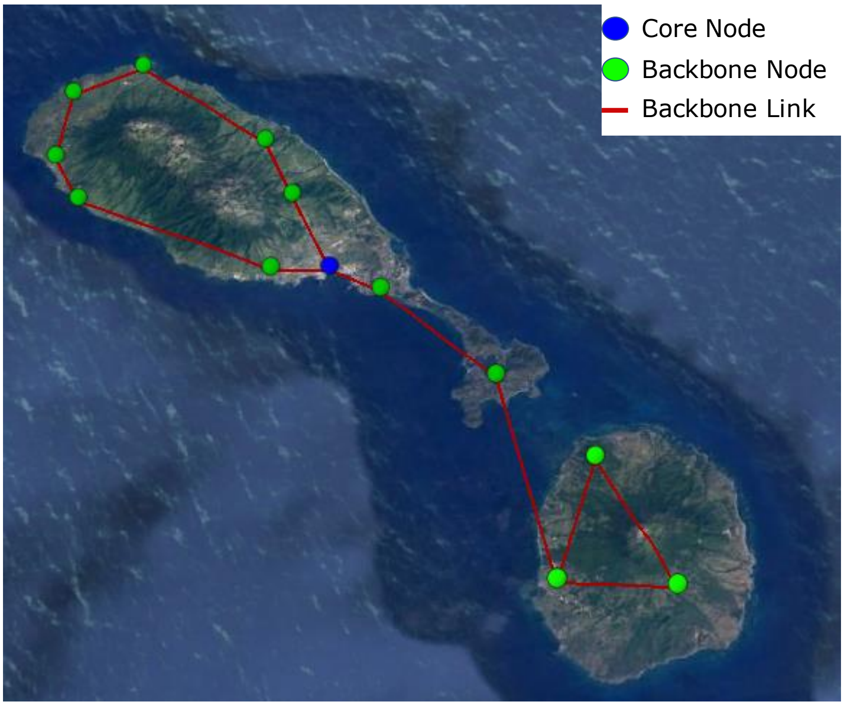

Exhibit A 8: Topology of the core network for St Kitts and Nevis. [Source: Axon Consulting]

Exhibit A 9: Topology of the core network for St Lucia. [Source: Axon Consulting]

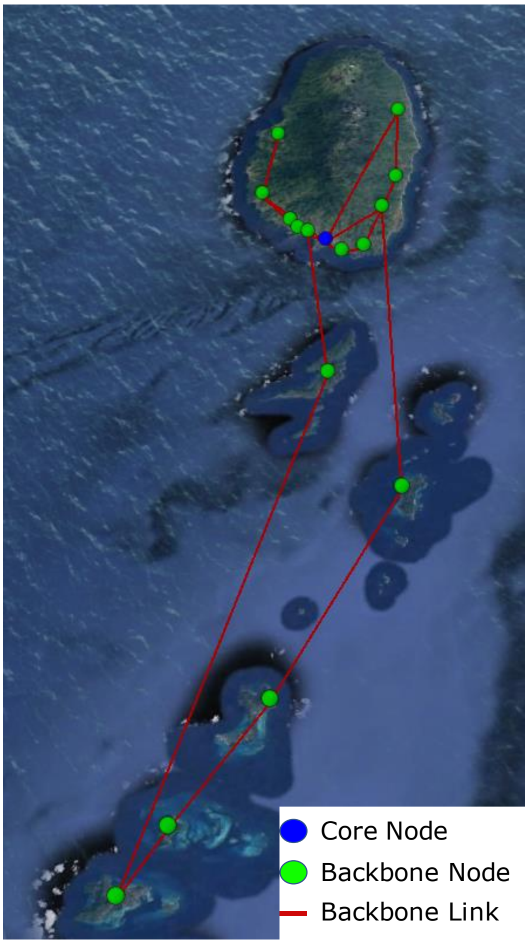

Exhibit A 10: Topology of the core network for St Vincent and the Grenadines. [Source: Axon Consulting]