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

Description of the BULRIC Model for Fixed networks

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AXON

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1. Introduction

This report describes the modelling approach, model structure and calculation process that is followed in the development of the Bottom-up Long Run Incremental Cost (BU-LRIC) Model for fixed networks ('the model') commissioned by the Office of Utilities Regulation of Jamaica (hereinafter, the OUR) to Axon Partners Group (hereinafter, Axon Consulting).

The model has the following main characteristics:

- It calculates the network cost of the services under the LRIC, LRIC+ and SAC cost standards.
- It is based on engineering models that allow the consideration of multiple year time frames (2013-2020)[1]

This section presents the main methodological aspects considered in the development of the Model and provides an overview of the structure of this Document.

1.1. Methodological choices

The structural and methodological key choices have been set by the OUR in its methodological document "*Cost Model for Fixed Termination Rates – Principles and Methodology*" published in July 1, 2015 (hereinafter, 'the Methodology').

The following exhibit contains a summary of the methodological framework that has been set for the development of the Model.

[1] The model can be extended in future updates up to a total of 25 years

Methodological Issue	Approach Adopted
Cost elements considered	This model considers the following cost elements: ▶ Network CapEx ▶ Network OpEx ▶ Licenses ▶ Frequency usage fees and way fees[2] ▶ Retail costs ▶ G&A costs
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 the price of that year.
Annualisation method	Tilted annuities method is used for all the assets, which allows the consideration of the evolution of network prices, while avoiding potential deviation due to uncertainty of traffic forecasts.
Cost Standard	LRIC, LRIC+ and SAC are 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 2013) as well as forecasted data (up to 2020) to represent the future network roll-out.
Operator Modelled	The model considers a reference operator which has similar characteristics (i.e. demand) to the incumbent, LIME.
List of services considered	Services are disaggregated according to their type (i.e. Voice traffic and Non-voice traffic), the segment (i.e. retail and wholesale) and their destination/origin (i.e. on-net, outgoing, incoming, etc.)
Definition of the increments	Increments are defined based on the type of the services, specifically: ▶ Voice termination ▶ Other voice services ▶ Non-voice services
Geotypes	Geotypes are based on density of access lines, considering density of access lines in population centres.

Methodological Issue	Approach Adopted
Network topology design	The network is designed based on a modified scorched node approach, which allows the elimination of clearly identifiable inefficiencies, based on the current network of LIME.
Boundary between access and core networks	The access network would include the assets between the customer's premise and the line card (included), while all the equipment above the line card would be considered as a part of the distribution/core network. The model considers as access network all the access equipment above the line cards (no included).
Core network Technologies	The model considers a mix of technologies: - Legacy TDM switching - NGN core network Also, the model considers a progressive migration from TDM to NGN technology.
Transmission technologies	Incorporates the following mix of technologies: - SDH Fibre transmission - Native Ethernet fibre transmission - WDM Fibre transmission - Microwaves The model considers a progressive migration from SDH to Ethernet transmission technology.

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

1.2. Structure of the document

The reminder of this document describes the modelling approach followed, the structure of the model and the calculation processes and algorithms used. The document is structured as follows:

- **General Architecture of the Model**, introduces the general structure of the model, from the Input module to the Network Dimensioning and Costing modules.
- **Model inputs**, describes the relevant inputs needed for the model.

[2] Only if the operators prove that they represent a relevant part of their costs.

- **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 exercise addressed to obtain the geographical information required for the BULRIC Model.
- **Dimensioning Module**, illustrates the criteria followed in order to design the network and calculate the number of resources required to serve the demand and capacity constraints.
- **Costs Calculation Module**, shows costs calculation (OpEx, Depreciation and Cost of Capital) associated to the network resources dimensioned in the Dimensioning Module. Additionally, it shows the calculation of common cost per increment.
- **Cost imputation to services**, presents the methodology used for the allocation of resources' cost to the services under the three scenarios LRIC, LRIC+ and SAC. Additionally, it shows the calculation of demand scenarios used for allocating costs to services.

2. General Architecture of the Model

This section introduces the general structure of the model. The following Figure shows the function of the blocks and their interrelationship in the model.

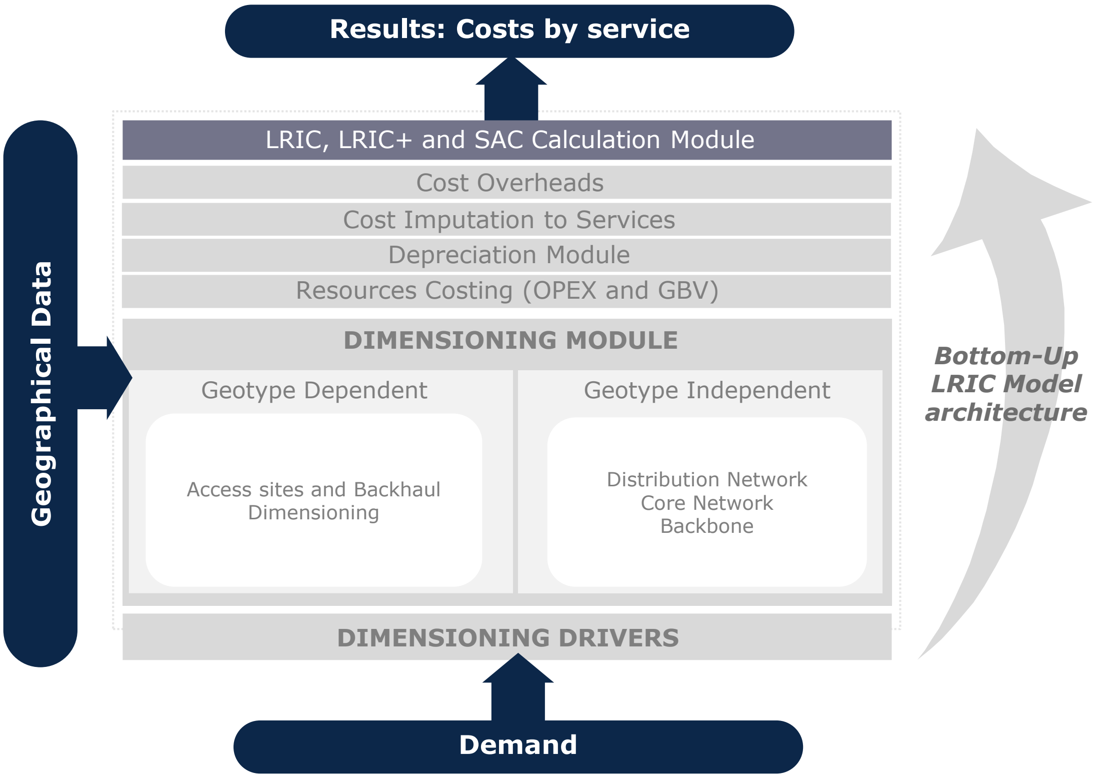

Exhibit 2.1: Structure of the model [Source: Axon Consulting]

Several calculation blocks can be identified above, namely:

- **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.
- **Cost Calculation (OpEx and CapEx):** Calculating cost of resources obtained after network dimensioning, in terms of OpEx and CapEx (GBV).
- **Depreciation module:** Annualising CapEx based on a tilted annuities methodology.
- **Cost imputation to services**: Obtaining pure incremental costs (LRIC), plus Common costs (LRIC+) and Stand Alone costs (SAC) of services.

- **Cost overheads:** Calculating those cost categories as a mark-up (i.e. retail costs, working capital and G&A).

The following sections develop each block of the model.

3. Model inputs

Demand is the main input for a BULRIC model, by definition. However, additional data is required. The following table presents the input worksheets, outlining the information contained in each one of them:

Name	Title	Input Information
1A INP DEMAND	Demand Input	▶ The demand that is needed to be supported by the network (e.g. subscribers, voice traffic, data traffic)
1B INP NW STATISTICS	Network Statistics	▶ The call and data statistics registered in the operator's network.
1C INP UNITARY COSTS	Unitary Costs Input	▶ Unitary costs (differentiating CAPEX and OPEX) for each resource/cost item.
1D INP COST TRENDS	Input: Cost Trends	▶ Cost trends of the unitary costs by resource (differentiating CAPEX and OPEX).
1E INP EXCHANGE RATES	Exchange Rates Input	▶ Exchange rates between currencies considered in the model.
1F INP COST OVERHEADS	Overhead Costs Input	▶ Overheads considered in the model (Working capital, G&A and Retail Costs).
2A INP NW	Network Input	▶ Network parameters needed for the dimensioning of the network (e.g. equipment's capacity, standard constants).
2B INP GEO ACCESS	Access Sites Geographical Inputs	▶ Number of cabinets and remote nodes per geotype. ▶ Number of voice lines and broadband lines per geotype. ▶ Migration factor and migration evolution per geotype.
2C INP GEO EDGE	Edge Sites Geographical Inputs	▶ Number of edge nodes per type. ▶ Number of voice lines and broadband lines per edge type. ▶ Number of cabinets and remote nodes connected under each edge type.
2D INP GEO DIST	Distribution Sites Geographical Inputs	▶ Number of local nodes per type. ▶ Number of voice lines per local type. ▶ Number of remote nodes connected under each local type. ▶ Number of distribution nodes per type. ▶ Number of voice lines and broadband lines per distribution type. ▶ Number of edge nodes connected under each distribution type.

Name	Title	Input Information
2E INP GEO CORE	Core Sites Geographical Input	▶ Number of local nodes connected under each core location. ▶ Number of distribution nodes connected under each core location. ▶ Number of voice and data lines connected under each core location. ▶ Distribution of core platforms and equipment per core location.
2F INP GEO LINKS	Transmission Links Geographical Input	▶ Percentage of access nodes connected with fibre per geotype. ▶ Percentage of access nodes connected with microwave per geotype. ▶ Average distance between nodes connected in ring per geotype. ▶ Number of access nodes connected in ring per geotype. ▶ Average distance between nodes connected in tree per geotype. ▶ Daisy chain factor per geotype. ▶ Fibre link types for backbone transmission. ▶ Microwave link types for backbone transmission. ▶ Percentage of capacity for carried traffic per link type. ▶ Number of fibre and microwave links per type. ▶ Average length of fibre and microwave links per type.
2G INP BUSY HOUR	Busy Hour Input	▶ The percentage of traffic in the busy hour per service category.
2H INP IDLE	Idle Traffic Input	▶ Idle traffic is defined as the percentage of time that the user is using the network but is not being counted as traffic. For example, the time required for the establishment of a call (e.g. ringing time) is considered idle time. The percentage of idle traffic is calculated based on traffic statistics.
2I INP RESOURCES LIFE	Input: Useful Lives	▶ Useful lives for the annualisation of resources costs.
2J INP ERLANG	Input: Erlang Tables	▶ Erlang tables to be used when dimensioning the equipment required to satisfy the demand.
2K INP HORIZON	Planning Horizon and Dimensioning Overcapacity Input	▶ The planning horizon represents the years in advance previously considered for the dimensioning of the network. ▶ Overcapacity is the security margin between the maximum traffic expected and the installed capacity.

Exhibit 3.1: Input information used in the model. [Source: Axon Consulting]

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:

- Dimensioning drivers concept
- Mapping services to drivers
- Conversion Factors from Services to Drivers

4.1. Dimensioning drivers concept

The explicit recognition of a dimensioning "Driver" in the model aims to simplify and increase transparency of the network dimensioning process.

Dimensioning drivers represent, among others, the following requirements:

- Voice traffic (Erlangs) for dimensioning of the legacy network equipment such as remote, local and tandem equipment and TDM transmission.
- Busy Hour Call Attempts (BHCA) for the dimensioning of core network equipment such as Call Session Control Functions (CSCFs) and Application Servers.
- Mbps for Ethernet transmission.
- Total number of billing events for the dimensioning of the Billing System

The following list contains the drivers used in the BULRIC model for fixed networks:

VARIABLE
DRIV.ACCESS.Traffic.Voice traffic
DRIV.ACCESS.Traffic.Data traffic
DRIV.LOCAL.Traffic.Voice traffic
DRIV.EDGE.Traffic.Voice traffic
DRIV.EDGE.Traffic.Data traffic
DRIV.DISTRIBUTION.Traffic.Voice traffic
DRIV.DISTRIBUTION.Traffic.Data traffic

VARIABLE
DRIV.CORE.Traffic.Voice traffic
DRIV.CORE.Traffic.Incoming Voice traffic
DRIV.CORE.Traffic.Outgoing to off-net Voice traffic
DRIV.CORE.Traffic.VMS traffic
DRIV.CORE.Traffic.Data traffic
DRIV.CORE.Traffic.International Voice traffic
DRIV.CORE BHCA.Traffic.Total BHCA
DRIV.CORE BHCA.Traffic.Outgoing BHCA
DRIV.CORE BHCA.Traffic.Incoming BHCA
DRIV.CORE BHCA.Traffic.Outgoing to off-net BHCA
DRIV.CORE BILLING.Billing.Events
DRIV.BACKBONE.Traffic.Voice traffic
DRIV.CONVERTER.Traffic.Outgoing to on-net Voice traffic
DRIV.INTERCONNECTION.Traffic.Fixed termination
DRIV.INTERCONNECTION.Traffic.Mobile termination
DRIV.INTERCONNECTION.Traffic.Intl Termination
DRIV.INTERCONNECTION.Traffic.National freephone termination
DRIV.INTERCONNECTION.Traffic.International freephone termination
DRIV.INTERCONNECTION.Traffic.Home Country Ix
DRIV.COSTS SPECIFIC.Traffic.Emergency services specific costs
DRIV.COSTS SPECIFIC.Traffic.National DQ specific costs
DRIV.COSTS SPECIFIC.Traffic.International DQ specific costs
DRIV.COSTS SPECIFIC.Traffic.Own freephone specific costs
DRIV.COSTS SPECIFIC.Traffic.Wholesale billing

Exhibit 4.1: List of Drivers used in the model (Sheet '0C 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

Each of these two steps is discussed below in more detail.

4.2. Mapping 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.

For example, voice on-net calls should be contained in the drivers used to dimension the access network (in order to properly dimension the ports required per remote node) as well as in the drivers used to dimension the distribution and core networks.

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

List of relationships	
SERVICE (Variable Name)	**DRIVER (Variable Name)**
Voice Traffic.Outgoing.Retail.On-net	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.Off-net to mobile	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.On-net	DRIV.LOCAL.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.Off-net to mobile	DRIV.LOCAL.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.On-net	DRIV.BACKBONE.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.Off-net to mobile	DRIV.BACKBONE.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.On-net	DRIV.CORE BHCA.Traffic.Total BHCA
Voice Traffic.Outgoing.Retail.Off-net to mobile	DRIV.CORE BHCA.Traffic.Total BHCA
Voice Traffic.Outgoing.Retail.On-net	DRIV.CORE BILLING.Billing.Events
Voice Traffic.Outgoing.Retail.Off-net to mobile	DRIV.CORE BILLING.Billing.Events

Exhibit 4.2: Except from the Mapping of Services into Drivers (Sheet '3A 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 has been worked out representing the number of driver units generated by each demand service unit. In general, conversion factors calculation consists of four subfactors, in compliance with the following structure:

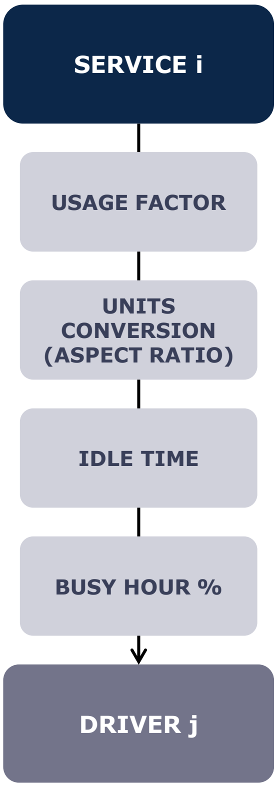

Exhibit 4.3: Conversion Process from Services to Drivers [Source: Axon Consulting]

The conversion factor thus includes the following items:

1. Usage factor (UF)
2. Units conversion (UC)
3. Idle Time (IT)
4. Busy Hour factor (BH)

Finally, the relationship between a given service and a driver is obtained by following the formula outlined below:

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

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 make sure on-net services will use the equipment twice as much as off-net services (one for the caller and one for the receiver).

However, when obtaining drivers for core dimensioning, it is necessary to consider that, for example, not all voice calls will make use of Tandem-Tandem transmission, since a percentage of them will be made within the same tandem node 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.

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 case of converting minutes of voice 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 the percentage where the recipient is not available (device off, out of coverage...), and TM the average call time in minutes.

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:

1. Time required setting 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:

   $$Idle\ time\ (connection) = ART/ACD$$

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

2. 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:

   $$Idle\ time\ (unattended\ calls) = \frac{\frac{PNRC}{1-PNRC-PO} * ART + \frac{PO}{1-PNRC-PO} * AT}{ACD}$$

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

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

5. Geographical Analysis

5.1. Introduction

The design of fixed access networks requires an extensive analysis of the geographical zones to be covered, as it will have a direct impact on the length and number of cables that are to be deployed.

The main purposes of this analysis are the following:

- Aggregate access nodes locations into geotypes.
- Aggregate distribution and core nodes locations into different categories.
- Characterising the backhaul links under each geotype in terms of distances between network elements and capacity for carried traffic.
- Characterising the backbone links under each category in terms of distances between network elements and capacity for carried traffic.

This information is later used for the dimensioning of the access network and part of the transmission network, as described in further detail in section 6.

The steps followed in order to carry out the geographical analysis have been split according to network sections:

- Nodes characterisation
- Backhaul transmission characterisation
- Backbone transmission characterisation

5.2. Nodes characterisation

The first step in the geographical analysis is the characterisation of nodes. It consists in analysing the nodes information according to the following aspects:

- Definition of different types or geotypes.
- Number of nodes connected under each type.
- Number or voice lines and data lines connected under each type.

The specifications and results of the analysis are shown in the following sections.

5.2.1. **Access nodes**

Based on the available information on the number and distribution of the access nodes locations, we have proceeded to aggregate a total of **[CONFIDENTIAL]** access locations into geotypes, which have been used for dimensioning the Operator's network.

Geotypes considered in the model are defined as follows:

GEOTYPE	Description
URBAN_DENSE	▶ Samples with an access line density higher than 700 lines/km2
URBAN	▶ Samples with an access line density between 350 and 700 lines/km2
SUBURBAN_DENSE	▶ Samples with an access line density between 250 and 350 lines/km2
SUBURBAN	▶ Samples with an access line density between 150 and 250 lines/km2
RURAL_DENSE	▶ Samples with an access line density between 100 and 150 lines/km2
RURAL	▶ Samples with an access line density less than 100 lines/km2

Table 5.1: Characterisation of geotypes [Source: Axon Consulting]

Following this approach, the geotype of each access node location has been set according to the number of lines connected, the area of coverage and the geotypes of other access nodes in the nearest population centre.

Based on the geotype definitions, the geographical characterisation of the access nodes locations is obtained. As a result, the geographical distribution of nodes by geotype is shown in the exhibit below.

[CONFIDENTIAL]

Exhibit 5.1: Geographical distribution of access nodes by geotype [Source: Axon Consulting]

[END CONFIDENTIAL]

The table below shows the main characteristics of each one of the geotypes defined, once the access nodes locations have been assigned to them:

[CONFIDENTIAL]

Geotype	Voice lines	Broadband lines	Remote nodes	Cabinets
URBAN_DENSE				
URBAN				
SUBURBAN_DENSE				
SUBURBAN				
RURAL				
RURAL_SPREAD				
TOTAL				

Table 5.2: Information of year 2014 regarding the aggrupation of Access nodes locations into geotypes [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

Additionally to the geotype characterisation of access nodes and according to the Methodology, it is important to define a migration percentage of the access nodes from Legacy to NGN technology, i.e. migration of remotes nodes to cabinets.

The next table shows the migration percentage through the time modelled per geotype. It is assumed that at the end of the period (2020) all the network has been migrated to NGN technology.

Geotype	2015	2016	2017	2018	2019	2020
URBAN_DENSE	30%	70%	100%	100%	100%	100%
URBAN	30%	70%	100%	100%	100%	100%
SUBURBAN_DENSE	20%	40%	70%	100%	100%	100%
SUBURBAN	20%	40%	70%	100%	100%	100%
RURAL	20%	35%	50%	65%	80%	100%
RURAL_SPREAD	20%	35%	50%	65%	80%	100%

Table 5.3: Migration percentage of access nodes from Legacy to NGN technology [Source: Axon Consulting]

For calculating the number of remotes nodes and cabinets the following considerations are taken into account:

- The initial number of nodes considered in the model corresponds to the plant of 2014.
- The number of access nodes increased when legacy nodes are replaced, i.e., in some geotypes more than one cabinet is installed for replacing one remote node. This aims to shorten the loop and get better quality of service.

The number of cabinets to be installed for each remote node migrated is named migration factor. The migration factor in each of the geotypes is shown in the following table:

[CONFIDENTIAL]

Geotype	Migration factor
URBAN_DENSE	
URBAN	
SUBURBAN_DENSE	
SUBURBAN	
RURAL	
RURAL_SPREAD	

Table 5.4: Migration factor of access nodes [Source: Axon Consulting]

[END CONFIDENTIAL]

As a result, in the exhibit below it is shown the migration profile for the access nodes:

[CONFIDENTIAL]

Exhibit 5.2: Migration profile for the access nodes [Source: Axon Consulting]

[END CONFIDENTIAL]

5.2.2. **Local exchange nodes**

Based on the available information on the number of access nodes connected to each local exchange location, we have proceeded to aggregate a total of **[CONFIDENTIAL]** local locations into four different and independent categories for each node type (Small, Medium, Large an Extra-large nodes), which have been used for dimensioning the Operator's network.

Categories considered in the model for local nodes are defined as follows:

Local Node Type	Description
Extra large	▶ Nodes under which more than 24.000 lines are connected
Large	▶ Nodes under which between 16.000 and 24.000 lines are connected
Medium	▶ Nodes under which between 8.000 and 16.000 lines are connected
Small	▶ Nodes under which less than 8.000 lines are connected

Table 5.5: Characterisation of Local node types [Source: Axon Consulting]

When for certain node there is not defined a TDM host or an IP first aggregation node, the nearest superior node has been assigned.

Based on the category definitions, the geographical characterisation of the local exchange locations is obtained.

The next table shows the main characteristics of each one of the categories defined for modelling the local exchanges, once the local nodes locations have been assigned to them. The values of remotes nodes and Voice lines represent the connections under each Local node type:

[CONFIDENTIAL]

Local Node Type	Number of local exchange nodes	Number of remote nodes connected below	Number of voice lines connected below
Extra large			
Large			
Medium			
Small			
TOTAL			

Table 5.6: Information of year 2014 regarding the aggrupation of local nodes locations into categories [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

5.2.3. **Edge nodes**

Based on the available information on the number of access nodes connected to each edge node location, we have proceeded to aggregate a total of **[CONFIDENTIAL]** edge locations into four different and independent categories for each node type (Small, Medium, Large an Extra-large nodes), which have been used for dimensioning the Operator's network.

Categories considered in the model for edge nodes are defined as follows:

Edge Node Type	Description
Extra large	▶ Nodes under which more than 6.000 lines are connected
Large	▶ Nodes under which between 4.000 and 6.000 lines are connected
Medium	▶ Nodes under which between 2.000 and 4.000 lines are connected
Small	▶ Nodes under which less than 2.000 lines are connected

Table 5.7: Characterisation of Edge node types [Source: Axon Consulting]

When for certain node there is not defined a TDM host or an IP first aggregation node, the nearest superior node has been assigned.

Based on the category definitions, the geographical characterisation of the edge locations is obtained.

The table below shows the main characteristics of each one of the edge categories defined, once the edge nodes locations have been assigned to them. The values of remotes nodes, cabinets, Voice lines and Broadband lines represent the connections under each Edge node type:

[CONFIDENTIAL]

Edge Node Type	Number of Edge nodes	Number of legacy nodes connected below	Number of NGN nodes connected below	Number of voice lines connected below	Number of broadband lines connected below
Extra large					
Large					
Medium					
Small					
TOTAL					

Table 5.8: Information of year 2014 regarding the aggrupation of edge nodes locations into categories [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

5.2.4. **Distribution nodes**

Based on the available information on the number of edge nodes connected to the each distribution node, we have proceeded to aggregate a total of **[CONFIDENTIAL]** distribution locations into four different categories (Small, Medium, Large an Extra-large nodes).

Categories considered in the model for distribution nodes are defined as follows:

Distribution Node Type	Description
Extra large	▶ Nodes under which more than 15.000 lines are connected
Large	▶ Nodes under which between 10.000 and 15.000 lines are connected
Medium	▶ Nodes under which between 5.000 and 10.000 lines are connected
Small	▶ Nodes under which less than 5.000 lines are connected

Table 5.9: Characterisation of Distribution node types [Source: Axon Consulting]

When for certain node there is not defined a TDM host or an IP first aggregation node, the nearest superior node has been assigned.

Based on the category definitions, the geographical characterisation of the distribution locations is obtained.

The following table shows the main characteristics of each one of the distribution categories defined, once the distribution nodes locations have been assigned to them. The values of edge nodes, Voice lines and Broadband lines represent the connections under each Distribution node type:

[CONFIDENTIAL]

Distribution Node Type	Number of Distribution nodes	Number of edge nodes connected below	Number of voice lines connected below	Number of broadband lines connected below
Extra large				
Large				
Medium				
Small				
TOTAL				

Table 5.10: Information of year 2014 regarding the aggrupation of distribution nodes locations into categories [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

5.2.5. **Tandem exchange nodes**

There is not necessary a categorization for the tandem exchange locations. Based on the available information there are **[CONFIDENTIAL]** tandem locations. The next table shows the main characteristics of each one of the tandem locations. The values of local nodes and Voice lines represent the connections under each tandem core site:

[CONFIDENTIAL]

Tandem sites	Number of Local nodes connected below	Number of voice lines connected below
CORE 1		
CORE 2		
CORE 3		
CORE 4		
CORE 5		
TOTAL		

Table 5.11: Information of year 2014 about tandem nodes locations [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

5.2.6. Core nodes

There is not necessary a categorization for the IP core nodes locations. Based on the available information there are **[CONFIDENTIAL]** NGN core locations. The next table shows the main characteristics of each one of the NGN core locations. The values of distribution nodes, Voice lines and Broadband lines represent the connections under each NGN core site:

[CONFIDENTIAL]

NGN Core sites	Number of Distribution nodes connected below	Number of voice lines connected below	Number of broadband lines connected below
CORE 6			
CORE 2			
CORE 7			
CORE 5			
CORE 8			
CORE 9			
TOTAL			

Table 5.12: Information of year 2014 about NGN core nodes locations [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

5.2.7. Core platforms distribution

Additionally to the number of distribution nodes and lines connected under each core locations, the distribution of core platforms and equipment across the different core sites has to be define. This has been eventually used for dimensioning the Operator's core network.

The following tables show the distribution percentage of the demand allocated to each core location.

Core sites	CSCF	AGCF	Softswitch	AS	MGCF	Converters
CORE 1	-	-	-	-	-	-
CORE 2	100%	100%	100%	100%	100%	21%
CORE 3	-	-	-	-	-	-
CORE 4	-	-	-	-	-	-
CORE 5	100%	100%	100%	100%	100%	27%
CORE 6	-	-	-	-	-	52%
CORE 7	-	-	-	-	-	-
CORE 8	-	-	-	-	-	-
CORE 9	-	-	-	-	-	-

Table 5.13: Core platforms distribution per core site [Source: Axon Consulting]

Core sites	NMS	HSS	VMS	Billing System	International Exchange
CORE 1	-	-	-	-	-
CORE 2	100%	100%	50%	100%	100%
CORE 3	-	-	-	-	-
CORE 4	-	-	-	-	-
CORE 5	100%	100%	50%	100%	100%
CORE 6	-	-	50%	-	-
CORE 7	-	-	-	-	-
CORE 8	-	-	-	-	-
CORE 9	-	-	-	-	-

Table 5.14: Other core platforms distribution per core site [Source: Axon Consulting]

Values in the above tables are estimates based in the geographical distribution of the core sites and in the standard redundancy of typical core networks. For these reason, some of the distribution percentages per equipment add more than 100%.

5.3. Backhaul transmission characterisation

The following details are required per geotype for a proper dimensioning of the backhaul network:

- Transmission technology and topology used
- Average link distance

These aspects are detailed in following sub-sections.

5.3.1. Transmission technology and topology

Based in the available data about access nodes locations, the specify technology of transmission used in each locations, the geographical distribution of those access nodes and their categorization into geotypes, we have proceeded to calculate the percentage of nodes that use each technology.

Additionally, the topology to be deployed should be indicated for each geotype. Two topologies are used for dimensioning the backhaul network (depending on the geotype):

- Ring: This topology creates a ring connecting a number of access sites and the upper level node (e.g. local exchange). The ring is dimensioned with a capacity to handle the traffic of all the nodes connected in the same ring. This topology ensures redundancy in the case that one link crashes and is commonly used in urban and suburban areas.
- Minimum Distance Tree: The access nodes are connected to each other and, in the final step, to the upper level node (e.g. local exchange) in the way the total distance is minimised. The more external nodes will support the traffic of only one node and the ones closer to the upper node will handle typically the traffic of a number of access nodes. This aspect is represented through the use of an average daisy-chain factor.

The following chart illustrates the difference between both topologies:

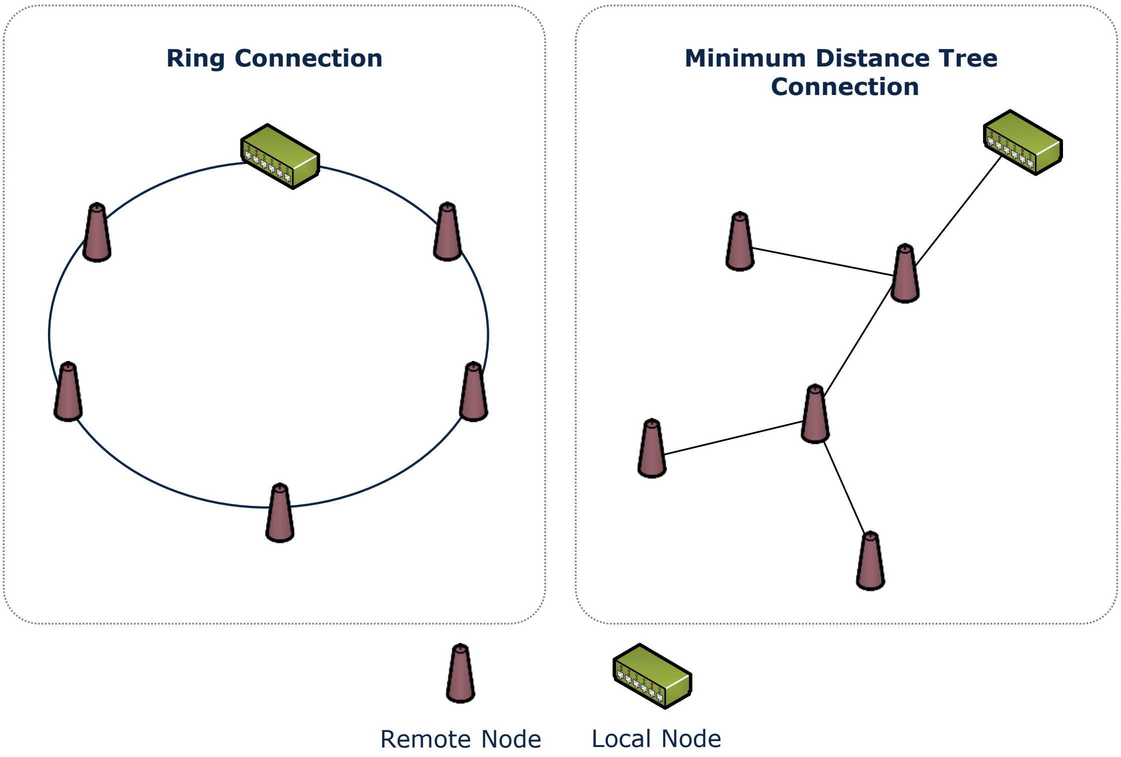

Exhibit 5.3: Topologies used for dimensioning the backhaul network [Source: Axon Consulting]

The following table presents the percentages of technologies used and the topology applied to each geotype[3]:

[CONFIDENTIAL]

[3] Please note that this section outlines the information used. For the details about the dimensioning algorithms, please see section 6.4.

Geotype	Access nodes collocated with upper level nodes[4]	% of access nodes connected by fiber[5]	% of access nodes connected by microwaves[5]	Topology[6]	Nodes by ring
URBAN_DENSE				Ring	10,00
URBAN				Ring	10,00
SUBURBAN_DENSE				Ring	5,00
SUBURBAN				Ring	5,00
RURAL				Minimum Distance Tree	N/A
RURAL_SPREAD				Minimum Distance Tree	N/A

Table 5.15: Information of transmission used for the backhaul transmission links [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

5.3.2. Average Link Distance

As indicated in the previous section, two topologies are used for dimensioning the backhaul network depending on the geotype (ring or minimum distance tree). The following sections describe the methodologies used for calculating the average distance per link and other relevant factors.

Calculation of average link distance for ring topology

The ring topology assumes that all Exchanges in a region connect to two others, obtaining a ring shape. To obtain this topology, firstly, the steps below have been followed to obtain an initial route:

1. he starting node "a_1" is the term that minimizes the following formula

$$\sum_{\forall b} d(a_1, b)$$

Where d(x,y) represents the distance from node a to node b.

[4] The transmission associated to these nodes is then intra-building and is considered negligible.
[5] From those that are not collocated.
[6] Details about the topologies is described in section 5.3.2.

1. The next Exchange "a_i" (where "i" represents the index of execution) is the one that results from the following formula

$$a_i = nc = \min d(a_{i-1}, nc)$$

2. If there are Exchanges that have not been connected, the process is repeated from the step 2

3. The last point connected is also connected to a_1 to close the ring topology

After obtaining the initial route, the Exchanges are swapped in the order list to improve the total distance within the ring, according to a 2-opt Pairwise Exchange algorithm (also called Lin-Kerninghan). Several iterations of this swapping process are calculated and the one that minimizes the total distance is selected.

The following exhibit presents an example of ring topology:

[CONFIDENTIAL]

Exhibit 5.4: Illustrative example of links between access nodes under ring topology[7] [Source: Axon Consulting]

[END CONFIDENTIAL]

The average distance has been calculated separately for legacy and NGN nodes, since the cabinets are typically closer in urban and suburban areas. The following table presents the results of the analysis:

Geotype	Average link distance – Legacy (km)	Average link distance – NGN (km)
URBAN_DENSE	4,88	1,43
URBAN	2,78	3,00
SUBURBAN_DENSE	5,06	3,87
SUBURBAN	5,06	3,87

Table 5.16: Information of backhaul transmission links for connecting access nodes through ring topology [Source: Axon Consulting based in data provided]

[7] Please note that the distances used in the algorithm are road distances. The exhibit shows straight line distance for presentation purposes.

Calculation of average link distance for minimum distance tree topology

The Minimum Distance Tree distance calculation methodology is as follows:

2. The starting node "a_1" is the term that minimizes the following formula

$$\sum_{\forall b} d(a_1, b)$$

   Where d(x,y) represents the distance from node a to node b.

3. To obtain the next node "a_i" (where "i" represents the index of execution), the distances from the not yet connected node to the already connected are obtained.
4. The minimum distance from those obtained in step 2 is selected. This distance is related to the link between one already connected node and the new node a_i.
5. If there are nodes that have not been connected, the process is repeated from the step 2.

As a result of this calculation the Euclidean distances between the network elements is obtained for each geotype.

The following illustration provide an illustrative example of the links dimensioned between access nodes.

[CONFIDENTIAL]

Exhibit 5.5: Illustrative example of links between access nodes under minimum tree topology[8] [Source: Axon Consulting]

[END CONFIDENTIAL]

Additionally, the daisy chain effect is calculated for the Minimum Distance Tree Topology. The daisy chain effect represents the fact that, for a tree topology, the traffic of one Exchange is not just handled by the ports of the Exchange because the traffic will also be transmitted through other Exchanges´ ports.

In the following exhibit an example of this effect is shown.

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[8] Please note that the distances used in the algorithm are road distances. The exhibit shows straight line distance for presentation purposes.

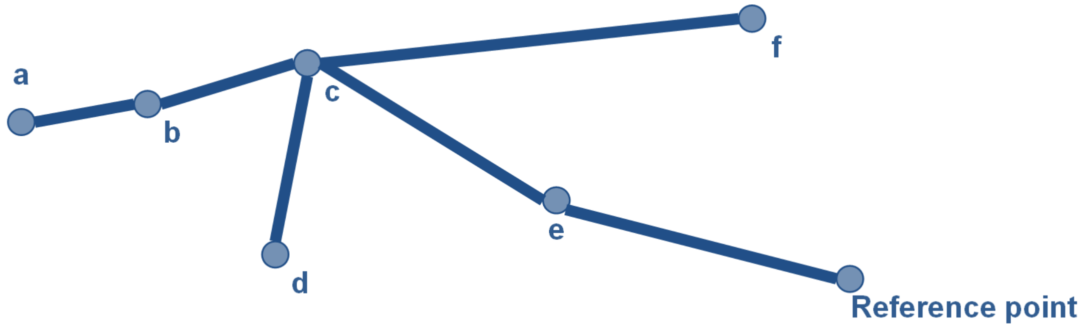

Exhibit 5.6: Example of the Daisy Chain effect [Source: Axon Consulting]

As it can be observed in the previous exhibit, the traffic generated by Exchange "a", has to be transmitted four times (by Exchanges a, b, c and e) to reach the reference point. The reference point is the one where the traffic is aimed at. In the analysis, the reference point is the starting Exchange a_1 obtained in the 1st step described previously. The daisy chain effect for each Exchange is the number of links used to reach the reference point.

This process has been performed for each geotype using such topology, obtaining the average length of transmission links and the average capacity multiplier (daisy chain factor) that has to support each link. The following table summarized these factors:

Geotype	Average distance for Nodes in Tree (km)	Daisy Chain Factor
RURAL	5,00	3,63
RURAL_SPREAD	6,41	2,66

Table 5.17: Average distance and daisy factor of transmission links per geotype [Source: Axon Consulting]

5.4. Backbone transmission characterisation

Unlike in the case of the backhaul network, the backbone is heterogeneous and, therefore, the routes are difficult to be estimated based on general theoretical methodologies. Therefore, the existing network in Jamaica have been analysed in order to define a reference backbone network for a fixed operator. The reference operator backbone combines both fibre and microwave links.

The following sections present the backbone network defined for each technology.

5.4.1. **Backbone Fibre Network**

Based on the available information of the fibre transmission network the following reference backbone has been defined:

[CONFIDENTIAL]

Exhibit 5.7: Designed Backbone fibre transmission network [Source: Axon Consulting]

Exhibit 5.8: Designed Backbone fibre transmission network in Kingston [Source: Axon Consulting]

[END CONFIDENTIAL]

All the link connections have been classified into different types according to the nature of the link, topology and the geographic locations. Additionally, according to the information of capacity supported by the connections and the road distance, we have estimated the capacity and distances per link for each one of the link types defined.

The following table summarizes all the factors by link type, which have been eventually used for dimensioning the Operator's fibre transmission network.

[CONFIDENTIAL]

Links Type	% of capacity over total traffic[9]	# of links	Average link length (km)
Subsea System			
Ring 1			
Ring 2			
Ring 3			
Ring 4			
Fibre Link Type 1			
Fibre Link Type 2			
Fibre Link Type 3			
Fibre Link Type 4			
Fibre Link Type 5			
Fibre Link Type 6			
Fibre Link Type 7			
Fibre Link Type 8			
Fibre Link Type 9			
Fibre Link Type 10			
Fibre Link Type 11			

Table 5.18: Information of backbone fibre transmission links per link type [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

5.4.2. Backbone Microwave Network

Based on the available information of the microwave transmission network about maps and capacity of the links, the reference operator's backbone microwave transmission network has been defined as follows:

[CONFIDENTIAL]

Exhibit 5.9: Designed Backbone microwave transmission network [Source: Axon Consulting]

[END CONFIDENTIAL]

[9] This factor represents the traffic handled by the corresponding link type over the total traffic generated by the subscribers. Please note that this factor is including redundancies and daisy-chain effects and, therefore, the sum adds more than 100%.

All the link connections have been classified into different types according to the nature of the link, topology and the geographic locations. Additionally, according to the information of capacity supported by the connections and the Euclidian distance between coordinates, we have estimated the capacity and distances per link for each one of the link types defined.

The following table summarizes all the factors by link type, which have been eventually used for dimensioning the Operator's microwave transmission network.

[CONFIDENTIAL]

Links Type	% of capacity over total traffic[10]	# of links	Average link length (km)
MW Link Type 1			
MW Link Type 2			
MW Link Type 3			
MW Link Type 4			
MW Link Type 5			
MW Link Type 6			
MW Link Type 7			
MW Link Type 8			
MW Link Type 9			
MW Link Type 10			
MW Link Type 11			
MW Link Type 12			
MW Link Type 13			
MW Link Type 14			

Table 5.19: Information of backbone microwave transmission links per link type [Source: Axon Consulting based in data provided]

[END CONFIDENTIAL]

[10] This factor represents the traffic handled by the corresponding link type over the total traffic generated by the subscribers. Please note that this factor is including redundancies and daisy-chain effects and, therefore, the sum adds more than 100%.

6. Dimensioning Module

The Dimensioning Module calculates the network's resources required to serve the demand of the reference operator. The following diagram illustrates the network structure considered:

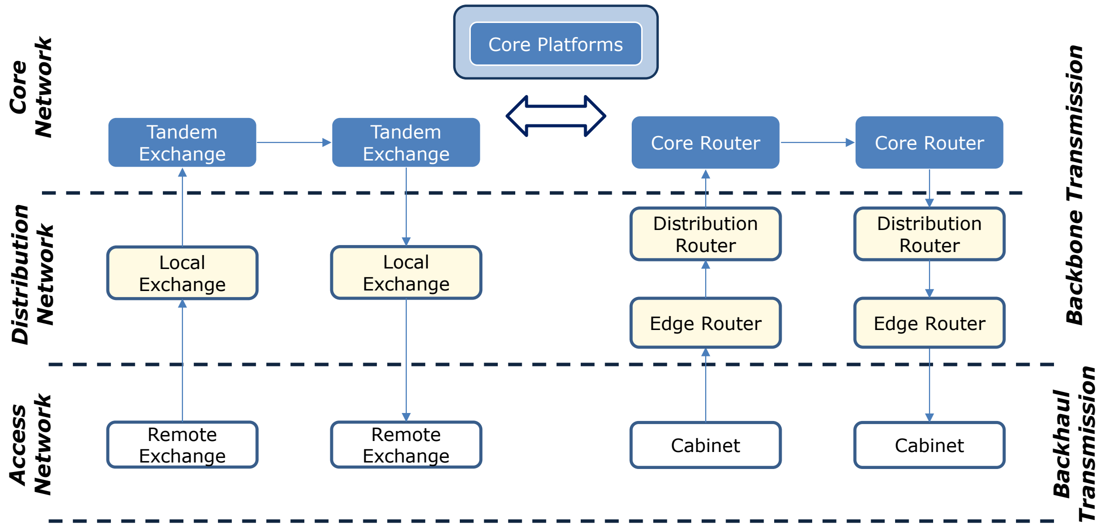

Exhibit 6.1: Schematic diagram of the network structure modelled for legacy and NGN technology [Source: Axon Consulting]

The following sections describe each network block:

- Access Network Dimensioning
- Distribution Network Dimensioning
- Core Network Dimensioning
- Backhaul Transmission Network Dimensioning

The algorithms used for calculating the fibre requirements for cabinets backhaul is equivalent to the one applied for the remote nodes with the exception that ethernet technologies are used (instead of TDM).

- Backbone Transmission Network Dimensioning
- Direct Costs Dimensioning

6.1. Access Network Dimensioning

The following steps are followed for the calculation of the access network elements:

- Remotes nodes dimensioning
- Cabinets nodes dimensioning

The aggregation switch considered in the cabinets is equivalent to the one in the remote nodes. Therefore, the algorithm used for the calculation of the ports is equivalent to the one described in section 6.1.1.

- Sites and Energy

The access network dimensioning algorithms are implemented in the worksheet '6A CALC DIM ACCESS' of the Model. The following sections provide further detail about the algorithm of each specific step.

6.1.1. **Remotes nodes dimensioning**

The exhibit below presents an overview of the remote nodes architecture that is being modelled.

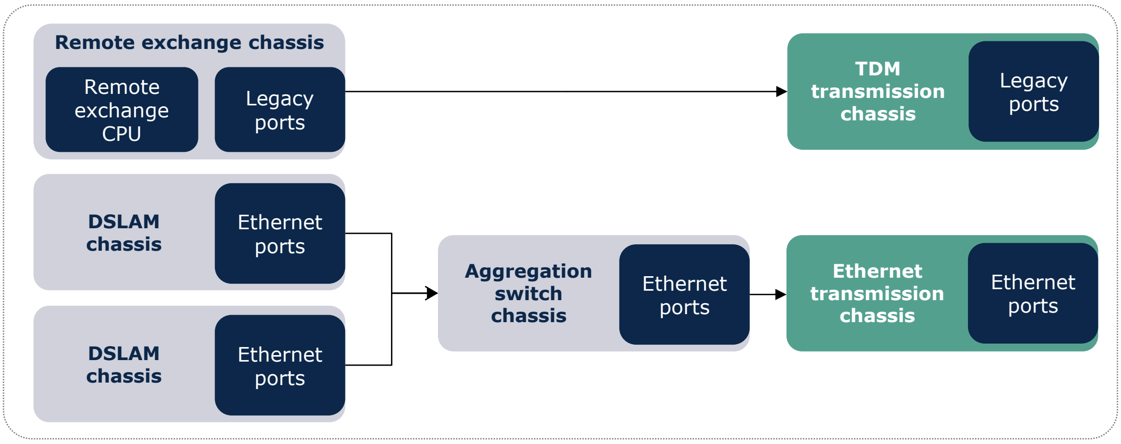

Exhibit 6.2: Architecture of the modelled Remotes Nodes [Source: Axon Consulting]

As it has been described in section 1.1, the model includes the equipment above line cards. Please note that transmission equipment (i.e. backhaul) is dimensioned in section 6.4. Accordingly, the following equipment should be identified in remotes nodes:

- **Remote exchange chassis**: Main unit for the provision of voice services, where the processor, line cards and ports are connected[11].

[11] The cost of this equipment does not include the cost that would be associated to the access line cards, based on the average cards dedicated to access over the total cards in the chassis.

- **Remote exchange CPU**: Processor installed in the remote chassis for traffic switching.
- **Legacy ports**: Cards to convey the voice traffic in legacy nodes. Please note that a number of bitrates is considered.
- **DSLAM chassis:** Represents a rack and processor used for the provision of ADSL services[11].
- **Aggregation switch chassis:** Element that aggregates the traffic of DSLAMs in the same location before sending it to the Edge router.
- **Ethernet ports:** Cards to convey data traffic in legacy nodes. Please note that a number of bitrates is considered.

The algorithm for dimensioning the elements listed above is organised into five steps, as shown in the chart below:

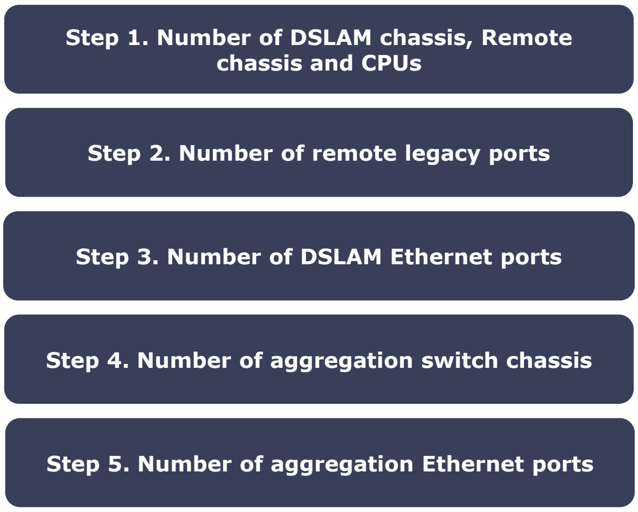

Exhibit 6.3: Schematic Steps for the dimensioning of the Remotes Nodes [Source: Axon Consulting]

The following subsections provide further detail about each specific step of the algorithm.

Step 1. Number of DSLAM chassis, Remote chassis and CPUs

The first step in the dimensioning of the Remotes Nodes consists in the calculation of the number of DSLAM chassis, Remote chassis and Remotes exchanges processing power required in the network. The quantity required of such elements is calculated according to the algorithm outlined below <u>for each geotype</u> (see section 5.2):

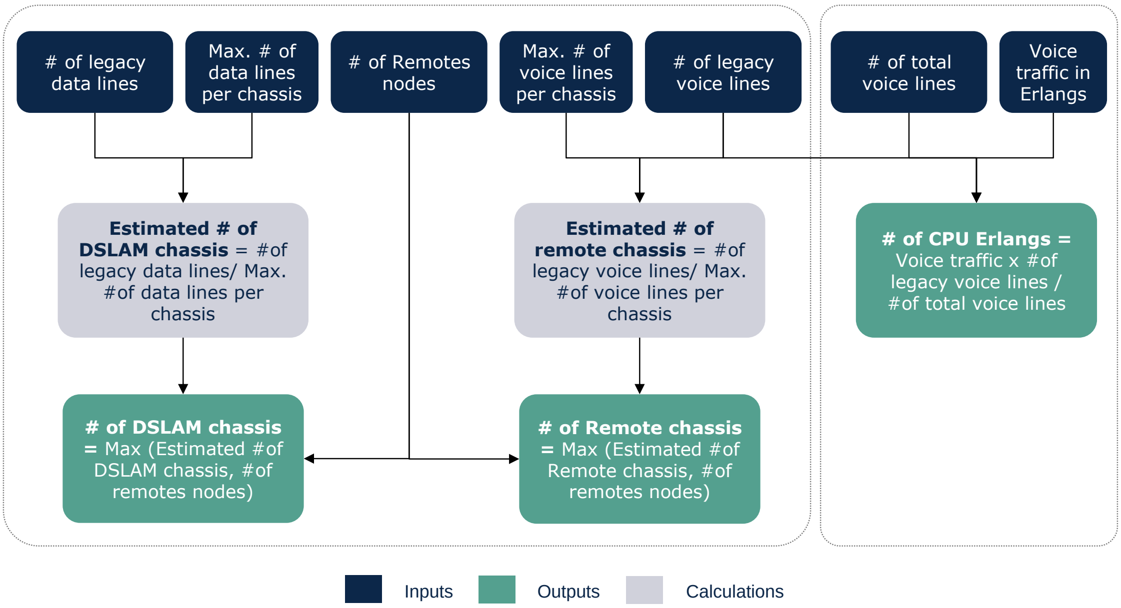

Exhibit 6.4: Algorithm for calculating the number of DSLAM chassis, Remote chassis and CPUs [Source: Axon Consulting]

As shown above, ate least one remote chassis and one DSLAM chassis is considered in each node. Additional chassis are calculated based on the maximum number of lines that each chassis can support.

Step 2. Number of remote legacy ports

The second step in the dimensioning of the Remotes Nodes consists in the calculation of the number of remote legacy ports, i.e. the ports required for legacy transmission of the voice traffic. It is calculated according to the algorithm outlined below for each geotype (see section 5.2):

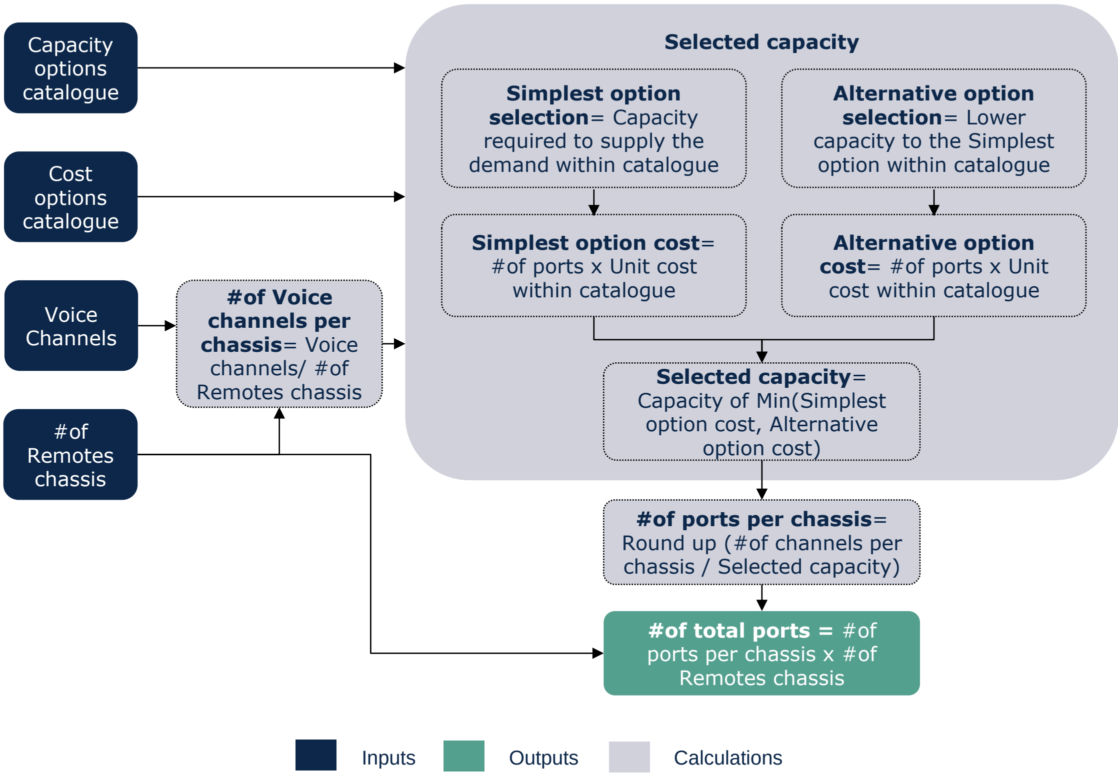

Exhibit 6.5: Algorithm for calculating the number of remote legacy ports [Source: Axon Consulting]

As shown above, the calculation of the number of ports is based on the determination of the most cost efficient capacity option. In first place, the algorithm calculates the following two potential solutions:

- **Simplest option:** The minimum capacity within the catalogue that is able to handle the traffic[12] with just one port.
- **Alternative option:** The simplest option immediate inferior capacity (that by definition would require more than one port).

The number of ports and the cost of each solution is then calculated. The one minimum cost (the most cost-efficient solution) is selected.

Finally, the total number of ports is calculated dividing the channels per chassis by the selected capacity, and then multiplied by the result of the number of Remotes chassis.

[12] Please note that the traffic is measured in number of voice channels extracted from the Erlang Table (based on the Erlangs per node and the maximum blocking probability).

Step 3. Number of DSLAM Ethernet ports

The dimensioning of the DSLAM Ethernet ports is equivalent to the algorithm used for the calculation of legacy ports:

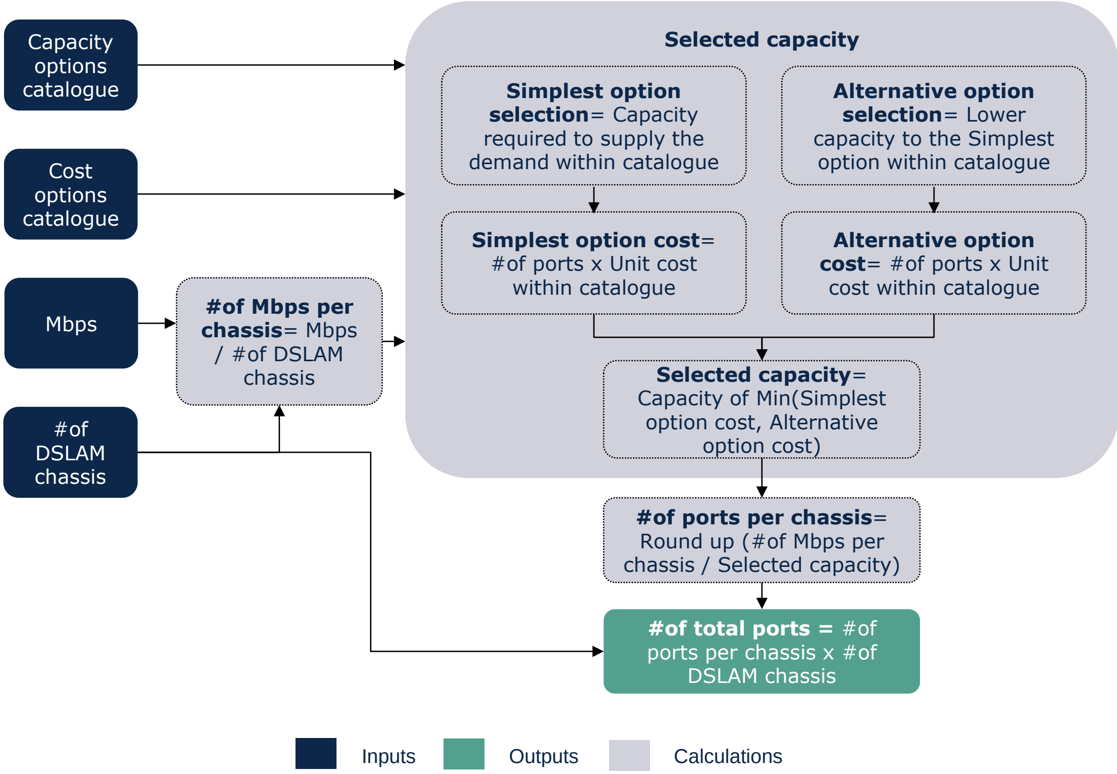

Exhibit 6.6: Algorithm for calculating the number of DSLAM Ethernet ports [Source: Axon Consulting]

The calculation of the number of DSLAM Ethernet ports is based on the determination of the ports capacity that implies a minimum cost, comparing the simplest option and the alternative option described in the previous step.

Step 4. Number of aggregation switch chassis

The quantity of aggregation switches require3d is calculated for each geotype based on the following algorithm:

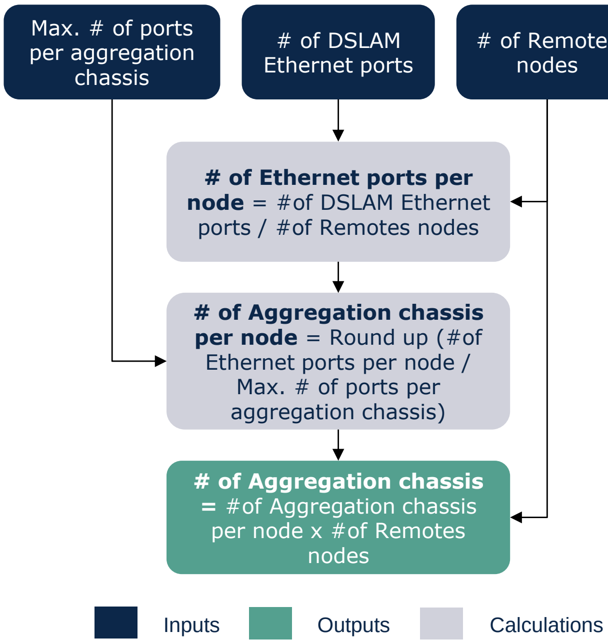

Exhibit 6.7: Algorithm for calculating the number of aggregation switch chassis in remotes nodes [Source: Axon Consulting]

As shown above, at least one chassis is considered in each node. Additional chassis are calculated based on the maximum number of Ethernet ports that can be connected per aggregation chassis.

Step 5. Number of aggregation Ethernet ports

The algorithm used for dimensioning the Ethernet ports for the Aggregation chassis is equivalent to the one described in the previous step for the DSLAM. The only difference is that the average traffic per element would be higher (please note that this element is aggregating the traffic of a number of DSLAMs).

6.1.2. **Cabinets nodes dimensioning**

The exhibit below presents an overview of the cabinet nodes architecture that is being modelled.

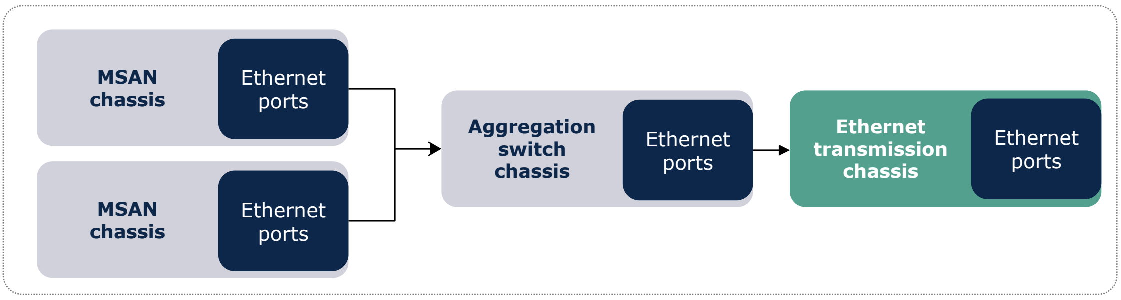

Exhibit 6.8: Architecture of the modelled Cabinets [Source: Axon Consulting]

As it has been described in section 1.1, the model includes the equipment above line cards. Please note that transmission equipment (i.e. backhaul) is dimensioned in section 6.4. Accordingly, the following equipment should be identified in cabinet nodes:

- **MSAN chassis:** This equipment is an evolution of the DSLAM described in previous section, with the difference that the MSAN provides also voice services (through VoIP)[13].
- **Aggregation switch chassis:** Element that aggregates the traffic of MSANs in the same location before sending it to the Edge router.
- **Cabinet Ethernet ports:** Cards to convey data traffic in NGN nodes. Please note that a number of bitrates is considered.

The algorithm for dimensioning the elements listed above is organised into four steps, as shown in the chart below:

Step 1. Number of MSAN chassis

Step 2. Number of MSAN Ethernet ports

Step 3. Number of aggregation switch chassis

Step 4. Number of aggregation Ethernet ports

Exhibit 6.9: Schematic Steps for the dimensioning of the Cabinets Nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of MSAN chassis

The number of MSAN chassis is calculated for each geotype according to the following algorithm:

[13] The cost of this equipment does not include the cost that would be associated to the access line cards, based on the average cards dedicated to access over the total cards in the chassis.

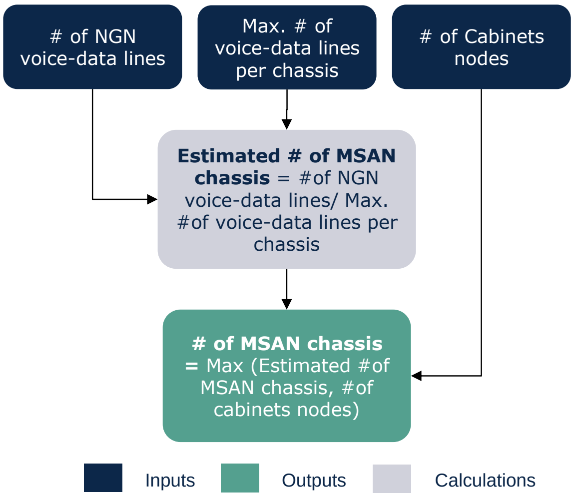

Exhibit 6.10: Algorithm for calculating the number of MSAN chassis [Source: Axon Consulting]

As shown above, at least one MSAN chassis is considered in each node. Additional chassis are calculated based on the maximum number of lines per chassis.

Step 2. Number of MSAN Ethernet ports

The algorithm used for dimensioning the MSAN Ethernet ports is equivalent to the one used for the DSLAM ports (previous section). The only difference is that the traffic, apart from broadband demand, includes voice channels[14].

Step 3. Number of aggregation switch chassis

The aggregation switch considered in the cabinets is equivalent to the one in the remote nodes. Therefore, the algorithm used is equivalent to the one described in section 6.1.1.

Step 4. Number of aggregation Ethernet ports

The aggregation switch considered in the cabinets is equivalent to the one in the remote nodes. Therefore, the algorithm used for the calculation of the ports is equivalent to the one described in section 6.1.1.

[14] Extracted from the Erlang Table based on the Erlangs per node and the maximum blocking probability and converted to Mbps based on the voice bitrate.

6.1.3. Sites and Energy

This section describes the algorithms used for the calculation of the access nodes supporting resources, namely:

- **Remotes site:** Represents the space used for the remote node equipment. It includes the space itself, air conditioning, power equipment (except the generator) and the maintenance of the previous elements[15].
- **Cabinet site:** Equivalent to the previous element for NGN access nodes[16].
- **Diesel generator:** Used for providing power to the node or for backup purposes.
- **Fuel**
- **Electricity**

The algorithm for dimensioning the elements listed above is structured as follows:

Step 1. Remotes and Cabinets sites

Step 2. Diesel generators

Step 3. Litres of fuel

Step 4. Electricity consumption

Exhibit 6.11: Schematic Steps for the dimensioning of the Access Sites and Energy [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Remotes and Cabinets sites

The calculation of the number of remote and cabinet nodes is described in section 5.2.1. One site per node is costed.

Step 2. Diesel generators

The number of diesel generator that are required in the remotes nodes and in the cabinets is calculated <u>for each geotype</u> based on the following methodology:

[15] The cost of this equipment does not include the cost that would be associated to the access line cards, based on the average cost of cards dedicated to access over the total cost per site.
[16] The cost of this equipment does not include the cost that would be associated to the access line cards, based on the average cost of cards dedicated to access over the total cost per site.

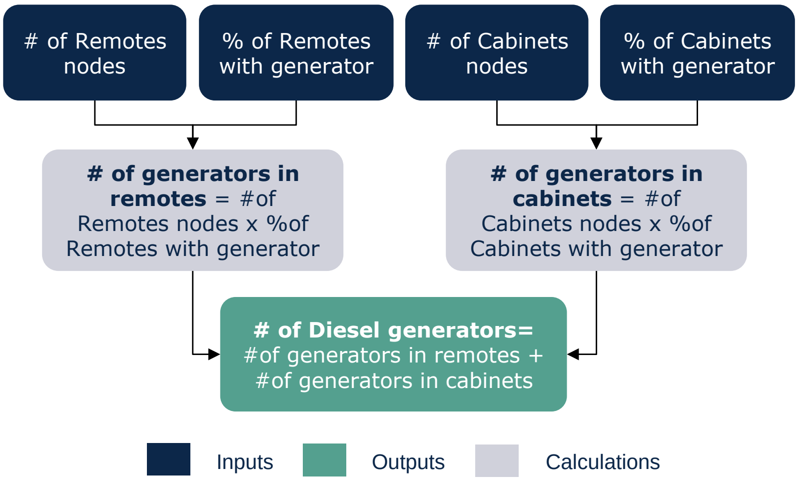

Exhibit 6.12: Algorithm for calculating the number of diesel generator in cabinets and remotes nodes [Source: Axon Consulting]

Step 3. Litres of fuel

The total litres of fuel consumed per year are calculated based on the following algorithm:

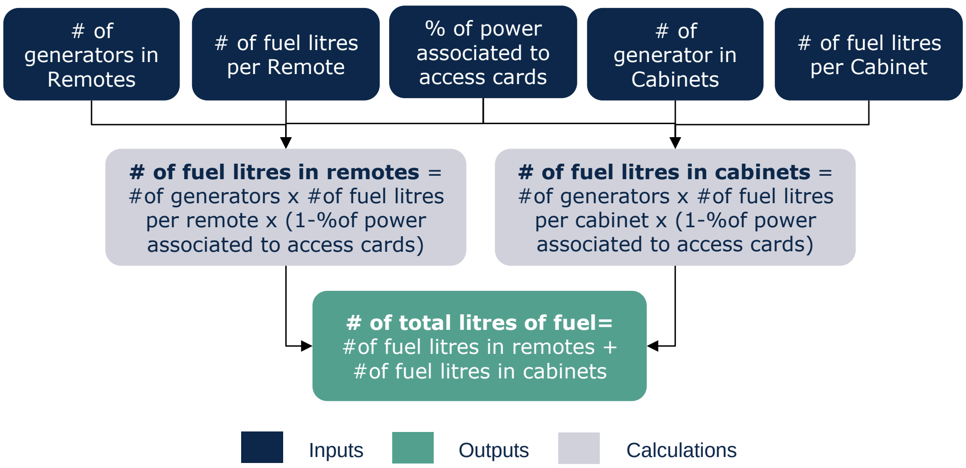

Exhibit 6.13: Algorithm for calculating the litres of fuel [Source: Axon Consulting]

Step 4. Electricity consumption

Yearly electricity consumption (kWh) is calculated based on the following algorithm:

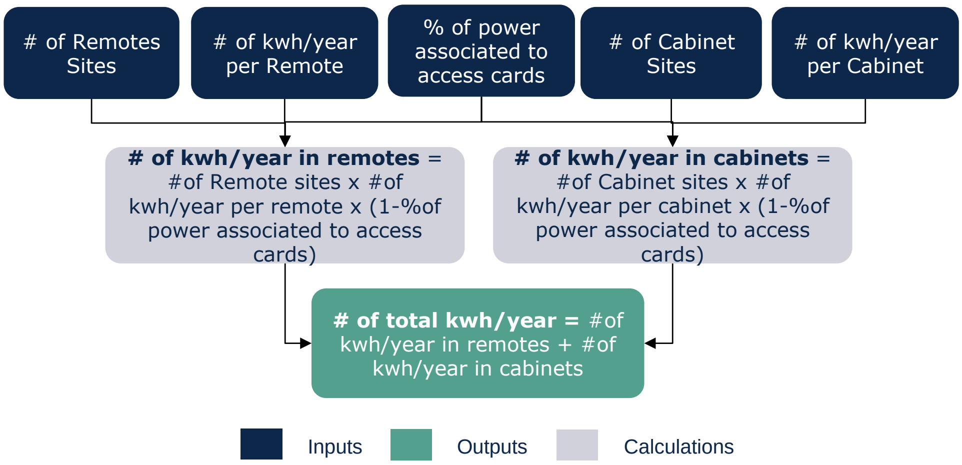

Exhibit 6.14: Algorithm for calculating the electricity consumption of the access nodes [Source: Axon Consulting]

6.2. Distribution Network Dimensioning

The dimensioning of the distribution network is performed through the following steps:

- Local nodes dimensioning
- Edge nodes dimensioning
- Distribution nodes dimensioning
- Sites and Energy

The dimensioning algorithms for the distribution network are implemented in the worksheet '6B CALC DIM DISTR' of the Model. The following sections provide further detail about the algorithm of each specific step.

6.2.1. Local nodes dimensioning

The following main elements are considered in the local exchange nodes:

- **Local exchange chassis:** Main unit used for switching voice calls between different remote nodes. The processor and ports are connected to this unit.
- **Local exchange CPU**: Processor installed in the local exchange chassis for traffic switching.
- **Local legacy ports**: Cards to convey the voice traffic in legacy nodes. Please note that a number of bitrates is considered.

The algorithm for dimensioning the elements listed above is structured as follows:

Exhibit 6.15: Schematic Steps for the dimensioning of the Local Nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of Local chassis and CPUs

The first step in the dimensioning of the Local Nodes consists in the calculation of the number of local exchange chassis. The quantity of elements required is calculated according to the algorithm outlined below <u>for each node type</u> (see section 5.2):

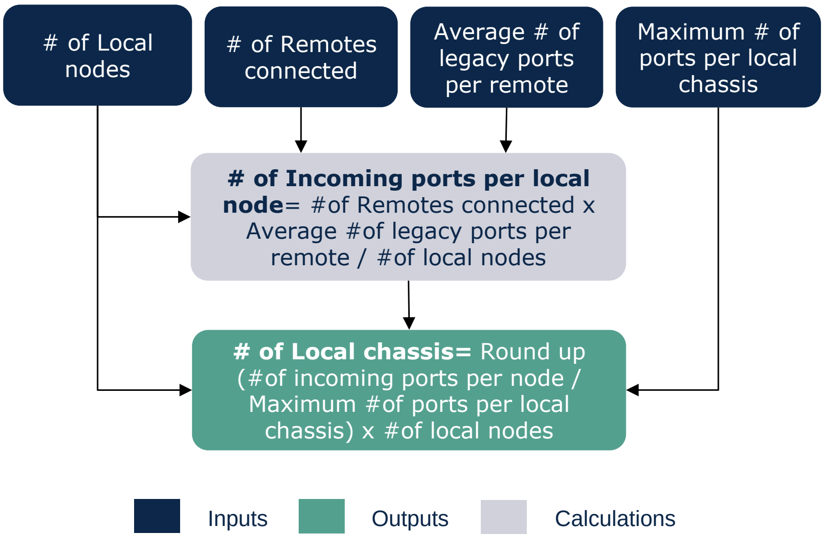

Exhibit 6.16: Algorithm for calculating the number of Local chassis [Source: Axon Consulting]

As shown above, at least one chassis is considered in each local node. Additional local chassis are calculated based on the maximum number of ports per chassis.

Additionally, the processing power required in the legacy network required is measured in Erlangs and calculated as follows:

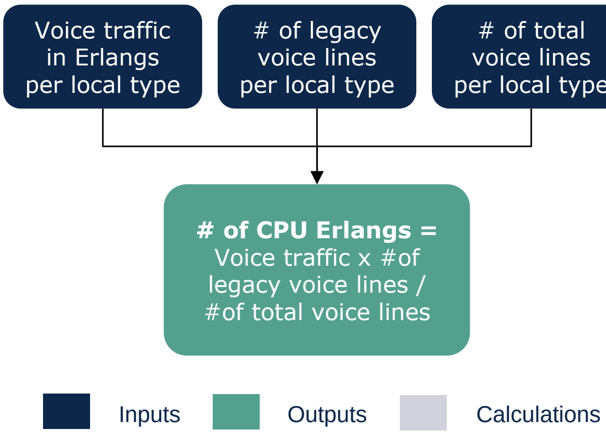

Exhibit 6.17: Algorithm for calculating the number of CPU Erlangs [Source: Axon Consulting]

Step 2. Number of local legacy ports

The second step in the dimensioning of the local exchange nodes consists in the calculation of the number of legacy ports, i.e. the ports required for legacy transmission of the voice traffic. It is calculated according to the algorithm outlined below for each node type (see section 5.2):

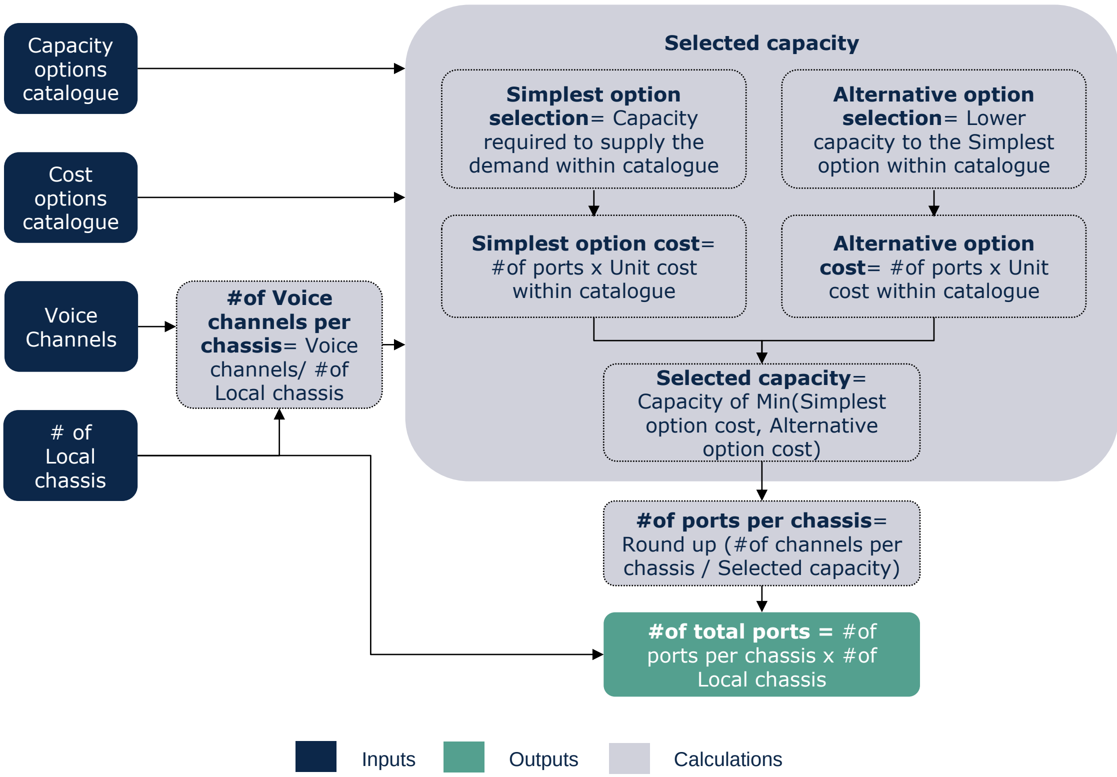

Exhibit 6.18: Algorithm for calculating the number of local legacy ports [Source: Axon Consulting]

As shown above, the calculation of the number of ports is based on a methodology equivalent to the one used for the calculation of remote legacy ports (see section 6.1.1 in the Step 2. Number of remote legacy ports).

6.2.2. **Edge nodes dimensioning**

The edge nodes handle the traffic coming from the aggregation switches (installed in both DSLAMs and MSANs nodes). Please note that edge nodes are common to the broadband legacy network and the NGN network. Therefore, they will handle both broadband and VoIP traffic. The following equipment is modelled:

- **Edge router chassis**: Unit where the Ethernet ports are connected.
- **Edge Ethernet ports**: Cards to convey data traffic. Please note that a number of bitrates is considered.

The algorithm for dimensioning the elements listed above is structured as follows:

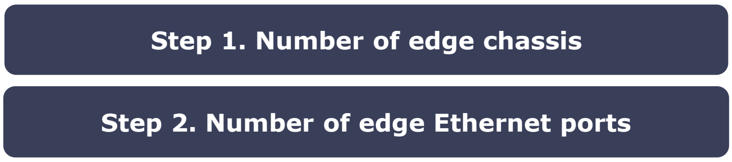

Exhibit 6.19: Schematic Steps for the dimensioning of the Edge Nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of Edge chassis

The first step in the dimensioning of the Edge Nodes consists in the calculation of the number of chassis. The quantity of elements required is calculated according to the algorithm outlined below for each node type (see section 5.2):

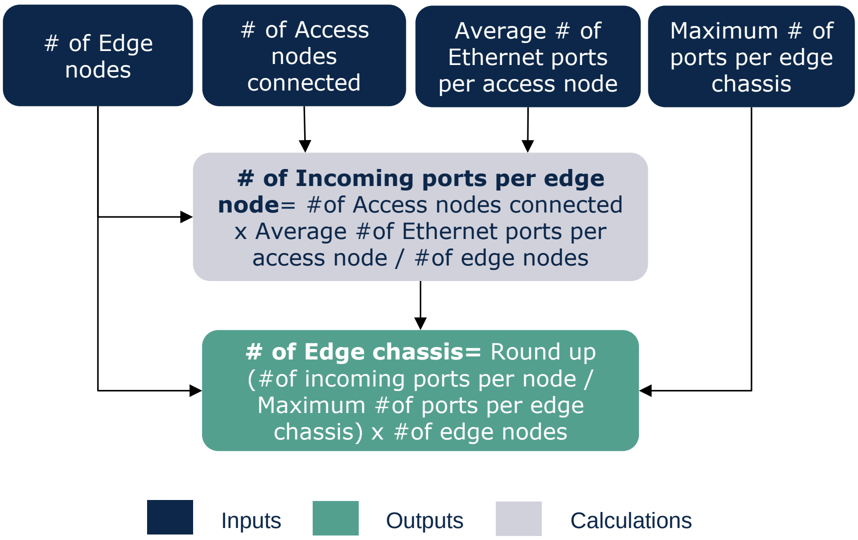

Exhibit 6.20: Algorithm for calculating the number of Edge chassis [Source: Axon Consulting]

As shown above, at least one router chassis is considered in each edge node. The need of more than one router chassis is based on the maximum number of ports per chassis.

Step 2. Number of edge Ethernet ports

The second step in the dimensioning of the edge nodes consists in the calculation of the number of ethernet ports, i.e. the ports required for transmission of broadband and VoIP traffic. It is calculated according to the algorithm outlined below <u>for each node type</u> (see section 5.2):

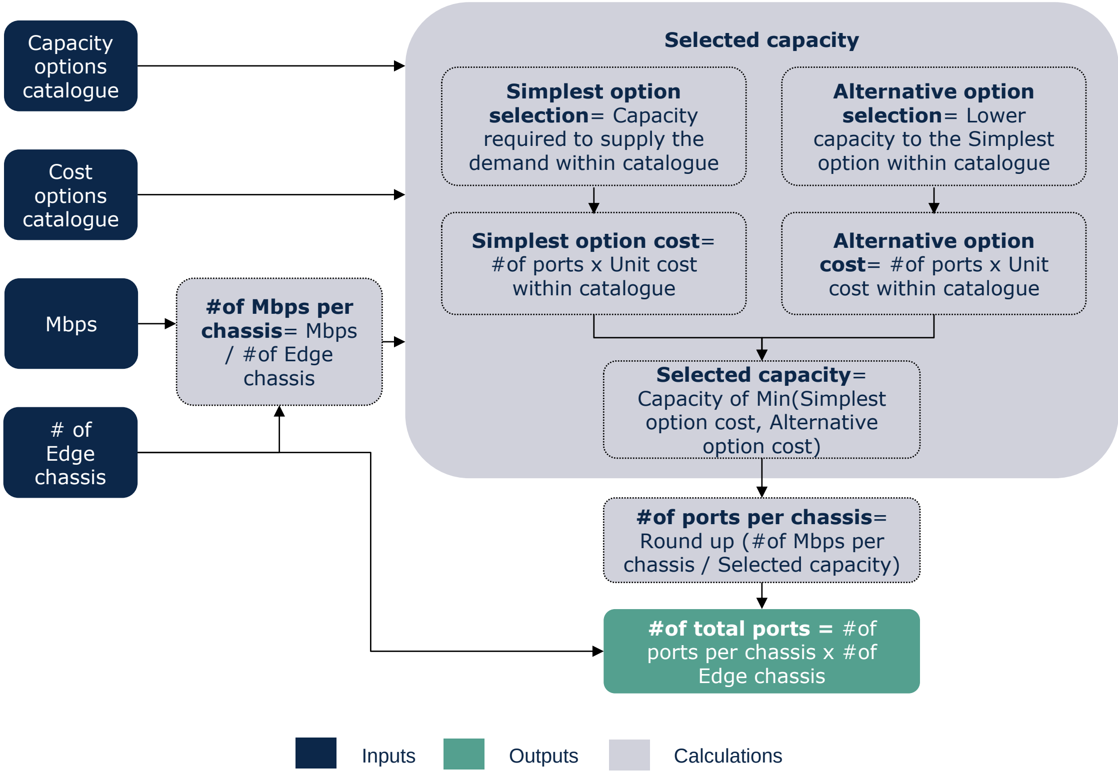

Exhibit 6.21: Algorithm for calculating the number of edge Ethernet ports [Source: Axon Consulting]

As shown above, the calculation of the number of ports is based on the same methodology used for the calculation of MSAN Ethernet ports (see section 6.1.2 in the Step 2. Number of MSAN Ethernet ports).

6.2.3. Distribution nodes dimensioning

The edge nodes handle the traffic coming from the edge nodes. Please note that distribution nodes are common to the broadband legacy network and the NGN network. Therefore, they will handle both broadband and VoIP traffic. The following equipment is modelled:

- **Distribution router chassis**: Unit where the Ethernet ports are connected.
- **Distribution Ethernet ports**: Cards to convey data traffic. Please note that a number of bitrates is considered.

The algorithm for dimensioning the elements listed above is structured as follows:

Exhibit 6.22: Schematic Steps for the dimensioning of the Distribution Nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of Distribution chassis

The first step in the dimensioning of the Distribution Nodes consists in the calculation of the number of chassis. The quantity of elements required is calculated according to the algorithm outlined below <u>for each node type</u> (see section 5.2):

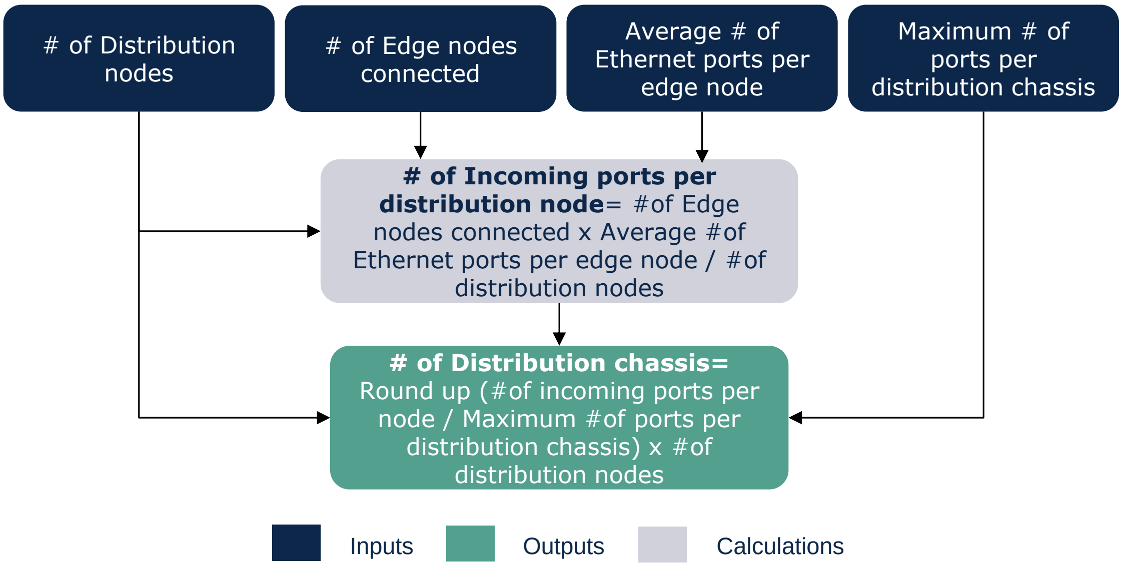

Exhibit 6.23: Algorithm for calculating the number of Distribution chassis [Source: Axon Consulting]

As shown above, at least one chassis is considered in each distribution node. The need of more than one chassis is based on the maximum number of ports that each chassis can support.

Step 2. Number of distribution Ethernet ports

The second step in the dimensioning of the distribution nodes consists in the calculation of the number of ethernet ports, i.e. the ports required for transmission of broadband and VoIP traffic. It is calculated according to the algorithm outlined below <u>for each node type</u> (see section 5.2):

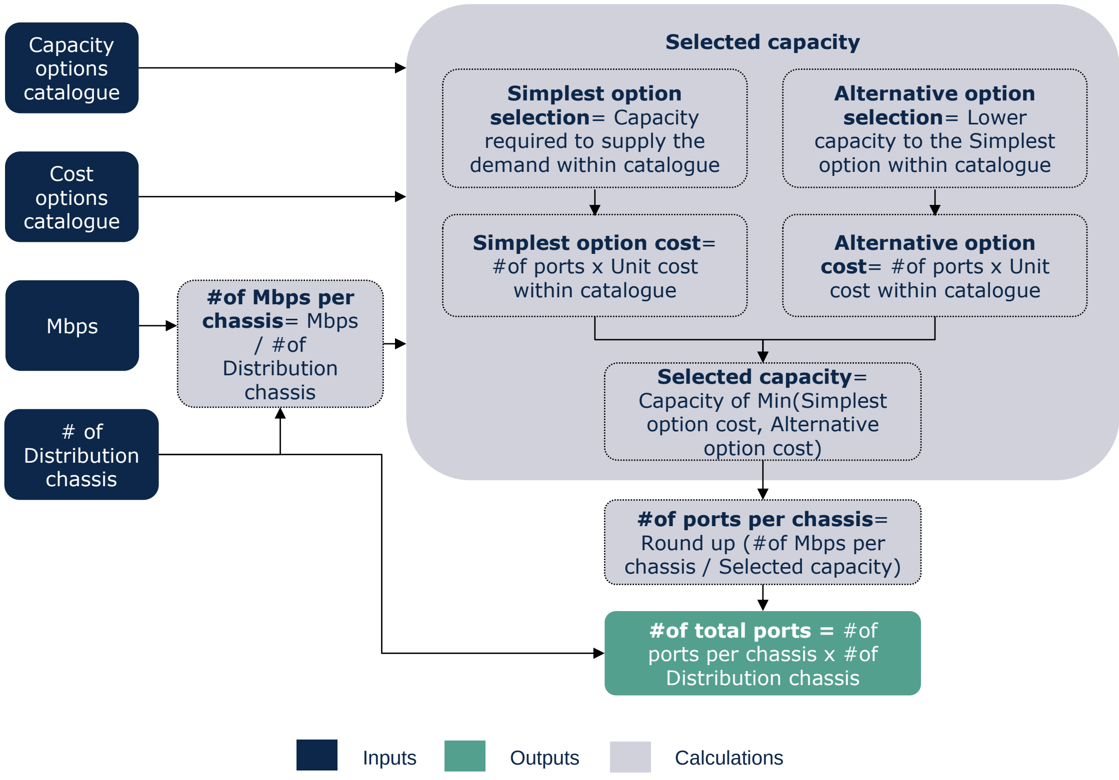

Exhibit 6.24: Algorithm for calculating the number of distribution Ethernet ports [Source: Axon Consulting]

As shown above, the calculation of the number of ports is based on the same methodology used for the calculation of MSAN Ethernet ports (see section 6.1.2 in the Step 2. Number of MSAN Ethernet ports).

6.2.4. **Sites and Energy**

This section describes the algorithms used for the calculation of the local, edge and distribution nodes supporting resources, namely:

- **Local site:** Represents the space used for the local node equipment. It includes the space itself, air conditioning, power equipment (including the generator for backup purposes) and the maintenance of the previous elements.
- **Edge site:** Represents the space used for the edge node equipment. It includes the space itself, air conditioning, power equipment (including the generator for backup purposes) and the maintenance of the previous elements.
- **Distribution site:** Represents the space used for the distribution node equipment. It includes the space itself, air conditioning, power equipment (including the generator for backup purposes) and the maintenance of the previous elements.

Electricity

Please note that the elements above only include the space (and other resources) requirements for the corresponding node equipment. In the case that a remote node or a cabinet node is collocated with a local, distribution or edge node, the space (and other resources) required for the remote or the cabinet are considered in the section 6.1.3.

The algorithm for dimensioning the elements listed above is structured as follows:

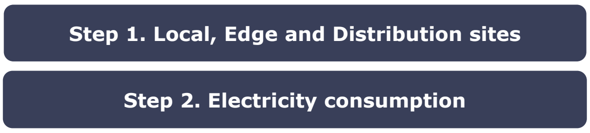

Exhibit 6.25: Schematic Steps for the dimensioning of the distribution Sites and Energy [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Local, Edge and Distribution sites

The calculation of the number of local, edge and distribution nodes is in sections 5.2.2, 5.2.3 and 5.2.4 respectively. One site per node is costed.

Step 2. Electricity consumption

Yearly electricity (kWh) consumed by local, edge and distribution nodes equipment is calculated based on the following algorithm:

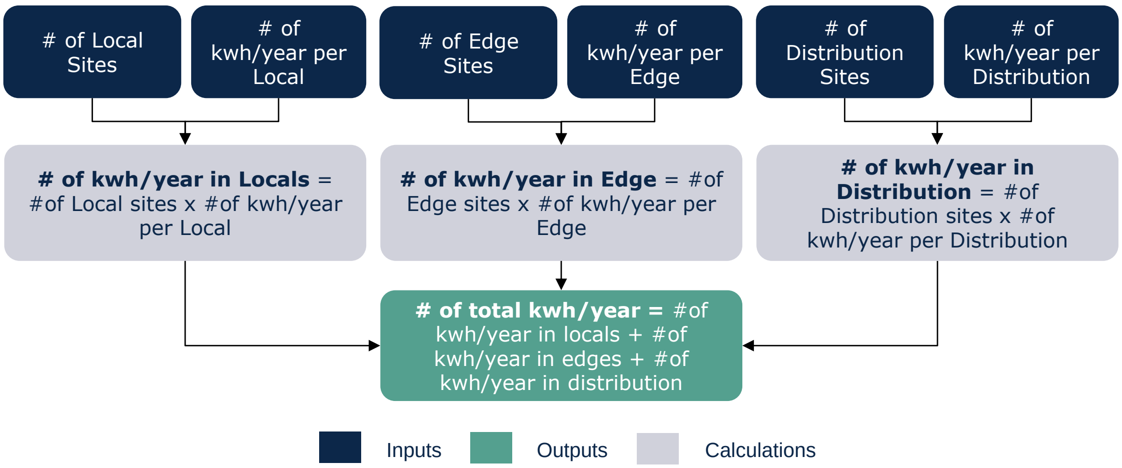

Exhibit 6.26: Algorithm for calculating the electricity consumption of the distribution nodes [Source: Axon Consulting]

6.3. Core Network Dimensioning

The dimensioning of the core network is performed through the following steps:

- Tandem exchanges dimensioning
- Data core nodes dimensioning
- Core platforms and equipment dimensioning
- Sites and Energy

The dimensioning algorithms for the core network are implemented in the worksheet '6C CALC DIM CORE' of the Model. The following sections provide further detail about the algorithm of each specific step.

6.3.1. Tandem exchanges dimensioning

The following main elements are considered in the tandem exchange nodes:

- **Tandem exchange chassis**: Main unit used for switching voice calls between different local nodes. The processor and ports are connected to this unit.
- **Tandem exchange CPU**: Processor installed in the tandem exchange chassis for traffic switching.
- **Tandem legacy ports**: Cards to convey the voice traffic in legacy nodes. Please note that a number of bitrates is considered.

The algorithm for dimensioning the elements listed above is structured as follows:

Step 1. Number of Tandem chassis and CPUs

Step 2. Number of tandem legacy ports

Exhibit 6.27: Schematic Steps for the dimensioning of the Tandem Nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of Tandem chassis and CPUs

The first step in the dimensioning of the Tandem Nodes consists in the calculation of the number of tandem exchange chassis and the processing power required. The quantity of elements required is calculated according to the algorithm outlined below <u>for each node type</u> (see section 5.2):

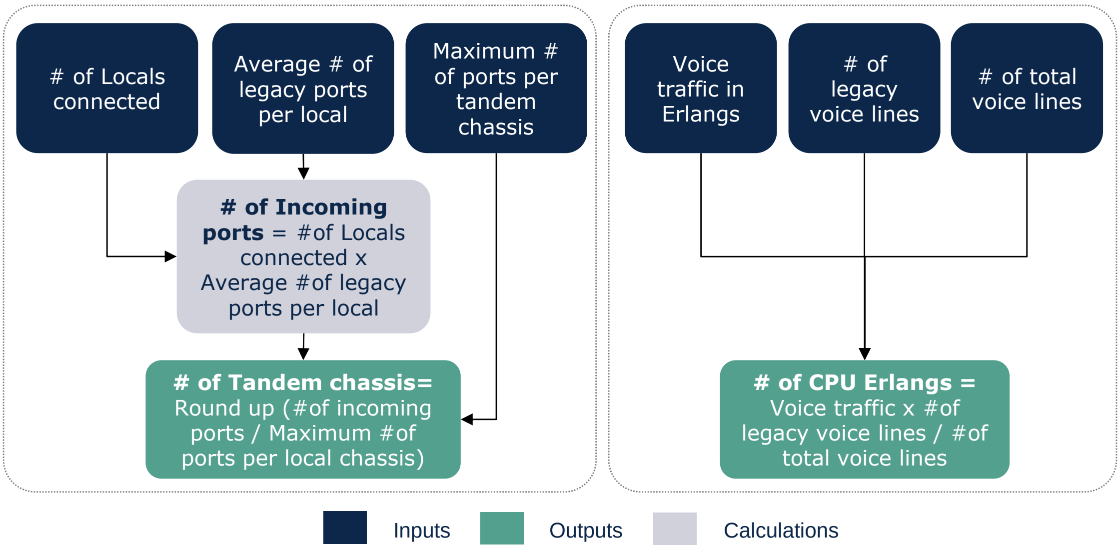

Exhibit 6.28: Algorithm for calculating the number of Tandem chassis and CPU Erlangs [Source: Axon Consulting]

As shown above, at least one chassis is considered in each tandem node. Additional tandem chassis are calculated based on the maximum number of ports per chassis.

Step 2. Number of tandem legacy ports

The second step in the dimensioning of the tandem exchange nodes consists in the calculation of the number of legacy ports, i.e. the ports required for legacy transmission of the voice traffic. It is calculated according to the algorithm outlined below <u>for each node type</u> (see section 5.2):

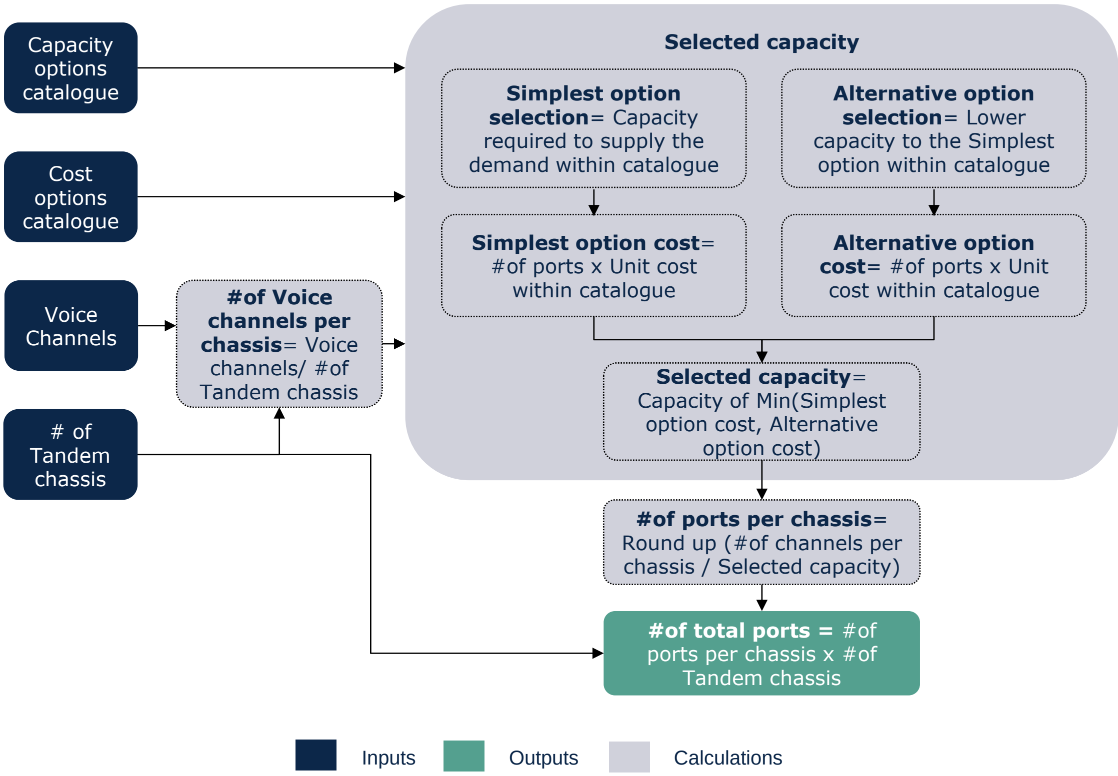

Exhibit 6.29: Algorithm for calculating the number of tandem legacy ports [Source: Axon Consulting]

As it is exposed above, the calculation of the number of ports is based on the same methodology used for the calculation of remote legacy ports (see section 6.1.1 in the Step 2. Number of remote legacy ports).

6.3.2. Data core nodes dimensioning

The data core nodes handle the traffic coming from the distribution switches. Please note that core nodes are common to the broadband legacy network and the NGN network. Therefore, they will handle both broadband and VoIP traffic. The following equipment is modelled:

- **NGN core router chassis**: Unit where the Ethernet ports are connected.
- **NGN core Ethernet ports**: Cards to convey data traffic. Please note that a number of bitrates is considered.

The algorithm for dimensioning the elements listed above is structured as follows:

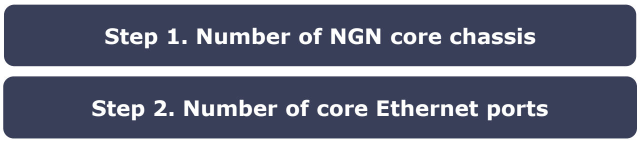

Exhibit 6.30: Schematic Steps for the dimensioning of the NGN Core Nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of NGN core chassis

The first step in the dimensioning of the Core Nodes consists in the calculation of the number of chassis. The quantity of elements required is calculated according to the algorithm outlined below <u>for each node type</u> (see section 5.2):

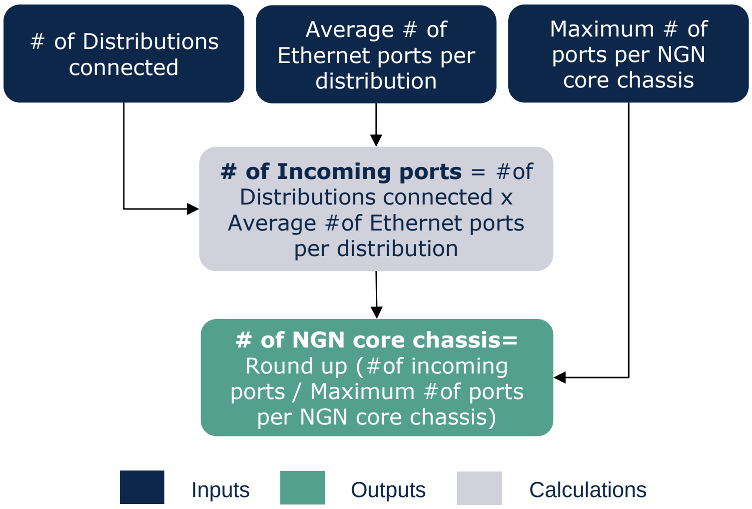

Exhibit 6.31: Algorithm for calculating the number of NGN core chassis [Source: Axon Consulting]

As shown above, at least one router chassis is considered in each node. The need of more than one chassis is based on the maximum number of ports per chassis.

Step 2. Number of core Ethernet ports

The second step in the dimensioning of the core nodes consists in the calculation of the number of ethernet ports, i.e. the ports required for transmission of broadband and VoIP traffic. It is calculated according to the algorithm outlined below <u>for each node type</u> (see section 5.2):

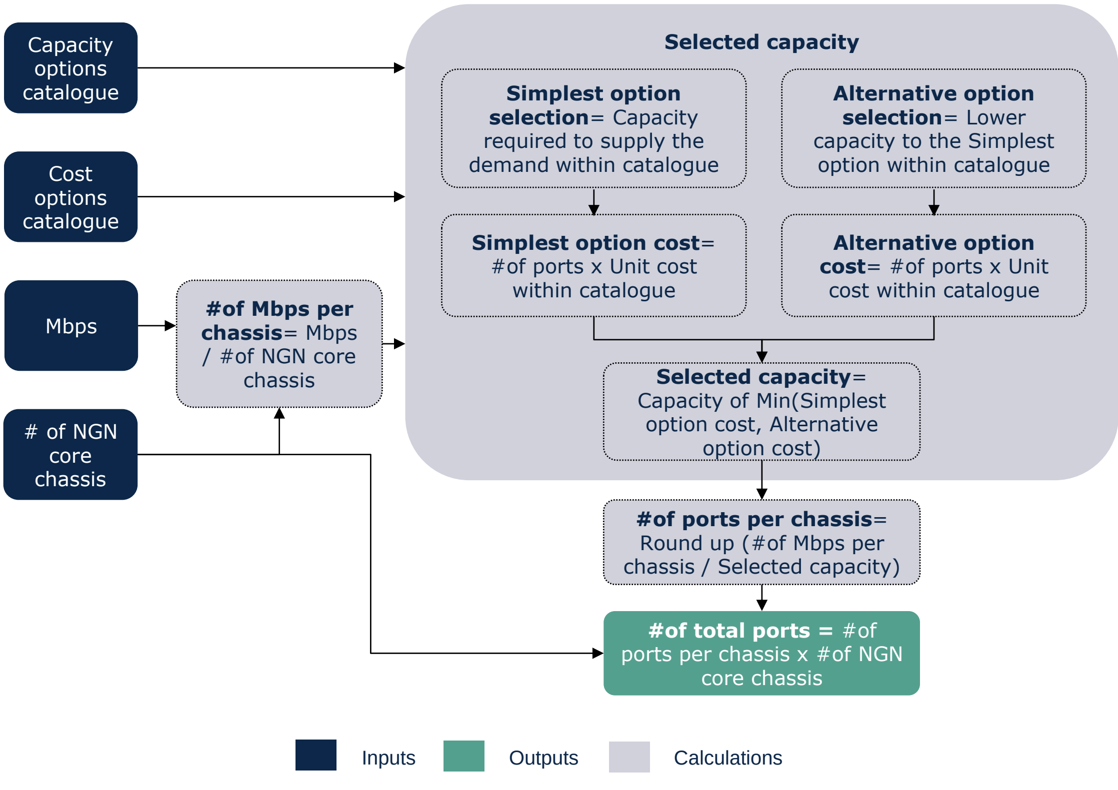

Exhibit 6.32: Algorithm for calculating the number of NGN core Ethernet ports [Source: Axon Consulting]

As it is exposed above, the calculation of the number of ports is based on the same methodology used for the calculation of MSAN Ethernet ports (see section 6.1.2 in the Step 2. Number of MSAN Ethernet ports).

6.3.3. Core platforms and equipment dimensioning

The Core Network Dimensioning module is responsible for the dimensioning of the Core Equipment, dealing with the central network management. The main equipment constituting the modelled Core Network is:

- **AS (Application Server)**: Provides voice and multimedia services over and above basic session setup.
- **BS (Billing System)**: Responsible for collecting and correlating chargeable event details for billing and charging purposes.
- **VMS (Voicemail System)**: The equipment that manages the mailboxes of subscribers.
- **CSCF (Call Service Control Function)**: The CSCF is generally comprise of three different network elements: the S-CSCF (Serving CSCF), the I-CSCF (Interrogating CSCF) and the P-CSCF (Proxy CSCF).

- **AGCF (Access Gateway Control Function):** Supports SIP signalling. The AGCF emulates the role of a P-CSCF for TDM networks.
- **Softswitch:** Responsible for controlling (signalization and management) and processing calls, and other services.
- **MGCF (Media Gateway Control Function)**: Responsible for controlling tandem to IP converters used for interconnecting IMS networks with the PSTN.
- **NMS (Network Management System)**: The NMS is responsible for the maintenance of the network and its equipment.
- **HSS (Home Subscriber Server)**: Responsible for storage of various kinds of subscriber-related data, including authentication credentials, details of services subscribed, and identity of currently assigned S-CSCF.
- **Tandem to IP Converter:** Supports physical connectivity from TDM-based legacy access technologies such as PSTN or ISDN. That is, it is the network element that allows the reception and emission of data between TDM-based networks and IP networks.
- **International Exchange:** Supports international TDM-based connectivity.

The algorithm for dimensioning the elements listed above is structured as follows:

Step 1. Traffic distribution per core location

Step 2. Application layer platforms

Step 3. Control layer platforms

Step 4. User layer equipment

Exhibit 6.33: Schematic Steps for the dimensioning of the core platforms and equipment [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Traffic distribution per core location

For dimensioning different platforms and equipment is necessary to calculate the traffic per core node, differentiating NGN and legacy traffic based in the migration of lines. Accordingly to the Methodology (see section 1.1), at 2020 all the voice lines will be NGN lines, then the migration percentage will reach the 100% in that year.

Step 2. Application Layer Platforms

The algorithm designed for each element is described in the following subsections. Please note that hardware and software is calculated separately to be able to apply different useful lives.

AS Dimensioning

Application Servers are responsible for providing voice and multimedia services over and above basic session setup.

The AS software licenses are measured in BHCA (NGN) and calculated as follows:

$$AS\ software = Total\ \ BH\ Call\ Attempts\ (BHCA) * \%of\ voice\ lines\ migration$$

The number of AS hardware units is calculated based on the demand in BHCA and the capacity per unit:

$$AS\ hardware \geq \frac{Total\ \ BH\ Call\ Attempts\ (BHCA) * \%of\ voice\ lines\ migration}{Maximum\ Capacity\ (BHCA)}$$

BS Dimensioning

The Billing System (BS) is responsible for collecting and correlating chargeable event details for billing purposes. The core network elements involved in session control and call services (e.g. CSCF and Application Servers) report significant events to the BS. These events typically include the calls, and the invocation of chargeable services provided by Application Servers. The event details may then be correlated and turned into call detail records for billing purposes.

The BS software license is measured in billing events per busy hour:

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

The number of BS hardware units is calculated based on the demand in billing events and the capacity per unit:

$$BS\ hardware \geq \frac{Billing\ \ events\ in\ the\ busy\ hour\ \ (\#BE)}{Maximum\ Capacity\ (\#BE)}$$

VMS Dimensioning

The Voicemail Server (VMS) is the automatic recording, storing and delivery system for voice messages. The VMS software license is measured in the number of erlangs managed in the busy hour:

$$VMS\ software = Voicemail\ traffic\ in\ the\ busy\ hour\ (\#Erlangs)$$

The number of VMS hardware units is calculated based on the demand in Erlangs and the capacity per unit:

$$VMS\ hardware \geq \frac{Voicemail\ traffic\ in\ the\ busy\ hour\ (\#Erlangs)}{Maximum\ Capacity\ (\#Erlangs)}$$

Step 3. Control Layer Platforms

The algorithm designed for each element is described in the following subsections. Please note that hardware and software is calculated separately to be able to apply different useful lives.

CSCF Dimensioning

The CSCF comprises three different network elements that are considered altogether in the BULRIC Model. The S-CSCF (Serving CSCF), responsible for directing signalling requests to Application Servers so as to invoke services for subscribers on the network, the I-CSCF (Interrogating CSCF) which is responsible for querying the HSS to obtain the identity of the S-CSCF to which signalling requests addressed to particular destination should be sent, and the P-CSCF (Proxy CSCF) which is responsible for providing a secure edge between the access network and the core network.

The CSCF software licenses are measured in the number of busy hour call attempts:

$$CSCF\ software = Total\ \ BH\ Call\ Attempts\ (BHCA) * \%of\ voice\ lines\ migration$$

The number of CSCF hardware units is calculated based on the demand in BHCA and the capacity per unit:

$$CSCF\ hardware \geq \frac{Total\ \ BH\ Call\ Attempts\ (BHCA) * \%of\ voice\ lines\ migration}{Maximum\ Capacity\ (BHCA)}$$

AGCF Dimensioning

The Access Gateway Control Function (AGCF) controls the Converters used for interconnecting TDM to NGN networks, and supports SIP signalling towards the NGN network.

The AGCF software license is measured in the number of outgoing busy hour call attempts handled for this element:

$$AGCF\ software = \ Outgoing\ BHCA * (1 - \%of\ voice\ lines\ migration)^2$$

The number of AGCF hardware units is calculated based on the demand in BHCA and the capacity per unit:

$$AGCF\ hardware \geq \frac{Outgoing\ BHCA * (1 - \%of\ voice\ lines\ migration)^2}{Maximum\ Capacity\ (BHCA)}$$

Softswitch

The softswitch manages VoIP calls signalling. The Softswitch software license is measured in busy hour call attempts:

$$Softswitch\ software = \ Total\ \ BH\ Call\ Attempts\ (BHCA) * \%of\ voice\ lines\ migration$$

The number of softswitch hardware units is calculated based on the demand in BHCA and the capacity per unit:

$$Softswitch\ hardware \geq \frac{Total\ \ BH\ Call\ Attempts\ (BHCA) * \%of\ voice\ lines\ migration}{Maximum\ Capacity\ (BHCA)}$$

MGCF Dimensioning

The Media Gateway Control Function (MGCF) controls interconnection between NGN networks with the PSTN. The MGCF software license is measured in number of BHCA:

$$MGCF\ software = (Outgoing\ BHCA\ to\ TDM + \ Incoming\ BHCA\ from\ TDM) * \%of\ voice\ lines\ migration$$

The number of MGCF hardware units is calculated based on the demand in BHCA and the capacity per unit:

$$MGCF\ hardware \geq (Outgoing\ BHCA\ to\ TDM + Incoming\ BHCA\ from\ TDM) * \%of\ voice\ lines\ migration\ /\ Maximum\ Capacity\ (BHCA)$$

NMS Dimensioning

The Network Management System (NMS) is responsible of monitoring constantly the network elements and equipment for failures, and notifying for reparations. The NMS software license is assumed to be measured in total erlangs in the busy hour:

$$NMS\ software = Voice\ traffic\ in\ the\ busy\ hour\ (\#Erlangs)$$

The number of NMS units is calculated based on the demand in Erlangs and the capacity per unit:

$$NMS\ hardware \geq \frac{Voice\ traffic\ in\ the\ busy\ hour\ (\#Erlangs)}{Maximum\ Capacity\ (\#Erlangs)}$$

HSS Dimensioning

The Home Subscriber Server (HSS) is the central users' data register and is centralised in the Core Network Each S-CSCF instance (at registration time) provides details about which Application Servers to apply to originating and terminating calls for each registered endpoint, and it also answers queries about S-CSCF is currently serving a given endpoint.

The HSS software license is measured in busy hour call attempts:

$$HSS\ software = Outgoing\ BH\ Call\ Attempts\ (BHCA) * \%of\ voice\ lines\ migration$$

The number of HSS hardware units is calculated based on the demand in BHCA and the capacity per unit:

$$HSS\ hardware \geq \frac{Outgoing\ BH\ Call\ Attempts\ (BHCA) * \%of\ voice\ lines\ migration}{Technical\ Constraint\ (BHCA)}$$

Step 4. User Layer Equipment

The algorithm designed for each element is described in the following subsections. Please note that hardware and software is calculated separately to be able to apply different useful lives.

Tandem to IP Converter Dimensioning

The TDM to IP Converter allows the physical interconnection of voice traffic between TDM-based networks and NGN networks. The algorithm for dimensioning this equipment is organised into three steps, as shown below:

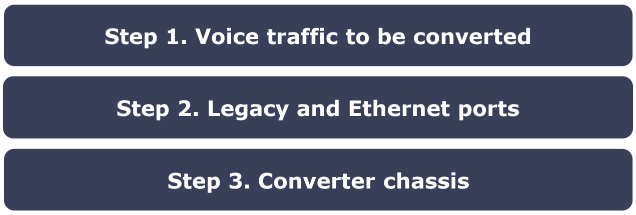

Exhibit 6.34: Schematic Steps for the dimensioning of TDM to IP Converters [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Voice traffic to be converted

The first step for dimensioning the TDM to IP converters consists in the calculation of the voice traffic that should be converted. The following voice traffic categories have been calculated based on the demand and the percentage of voice lines migration:

- On-net calls between legacy lines and NGN lines.
- Off-net calls originated on NGN lines and terminated in traditional networks.
- Off-net calls originated on legacy lines and terminated in NGN networks.
- Incoming to legacy lines from NGN networks.
- Incoming to NGN lines from traditional networks.

Legacy and Ethernet ports

The second step consists in the calculation of the number of legacy an Ethernet ports required to handle the traffic to be converted. The algorithm to calculate the number of converter ports is similar to the algorithm used to dimensioning the remote legacy ports (see section 6.1.1 in the Step 2. Number of remote legacy ports) or the MSAN Ethernet ports (see section 6.1.2 in the Step 2. Number of MSAN Ethernet ports), and it is outlined below:

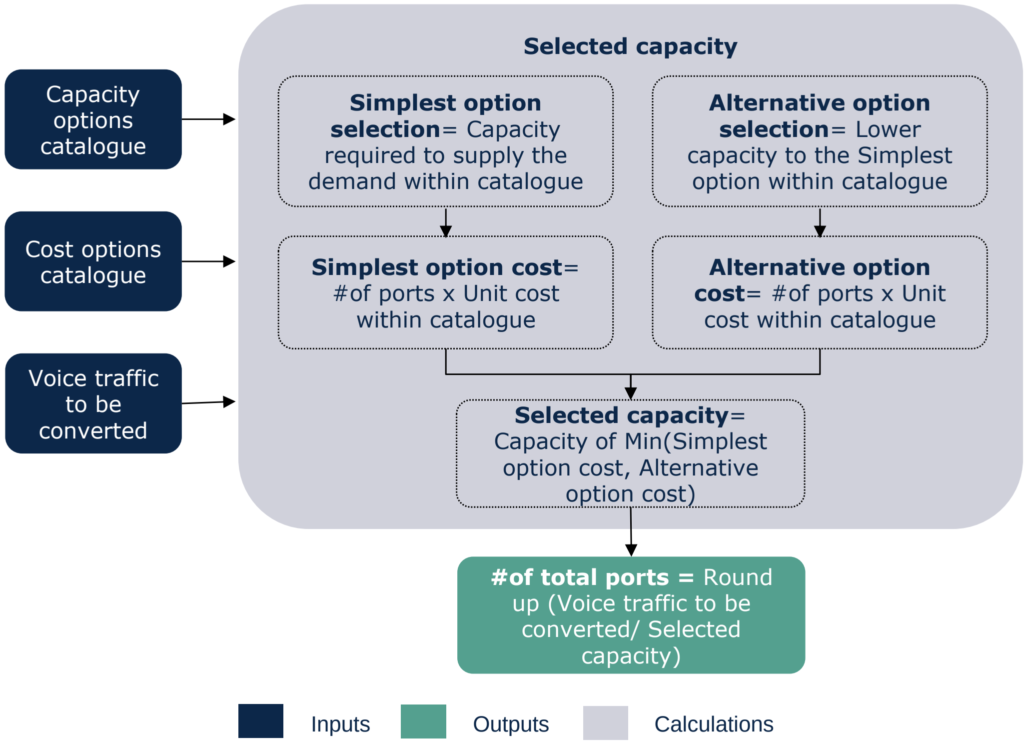

Exhibit 6.35: Algorithm for calculating the number of Converter ports [Source: Axon Consulting]

Converter chassis

Finally, the number of converter chassis can be calculated based on the total number of ports and the maximum number of ports permitted by chassis. The algorithm is shown in the exhibit below:

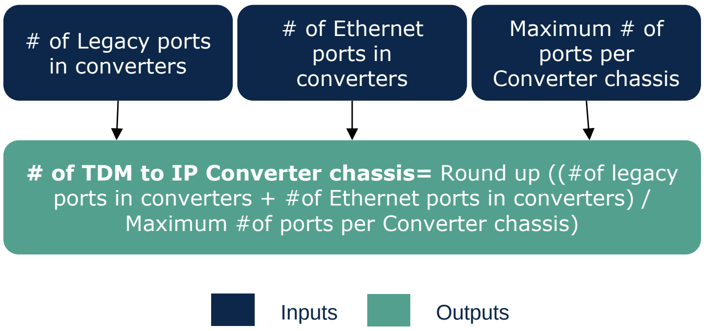

Exhibit 6.36: Algorithm for calculating the number of Converters chassis [Source: Axon Consulting]

International Exchange Dimensioning

The international exchange allows the transmission of voice traffic to international networks. The algorithm for dimensioning this equipment is organised into two steps, as shown in the chart below:

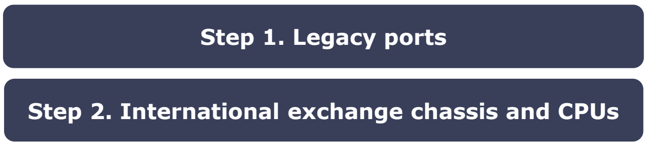

Exhibit 6.37: Schematic Steps for the dimensioning of International exchanges [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Legacy ports

The first step for dimensioning international exchanges consists in the calculation of the number of legacy ports required to handle the international voice traffic. The algorithm to calculate the number of international legacy ports is similar to the algorithm used to dimensioning the remote legacy ports (see section 6.1.1 in the Step 2. Number of remote legacy ports), and it is outlined below:

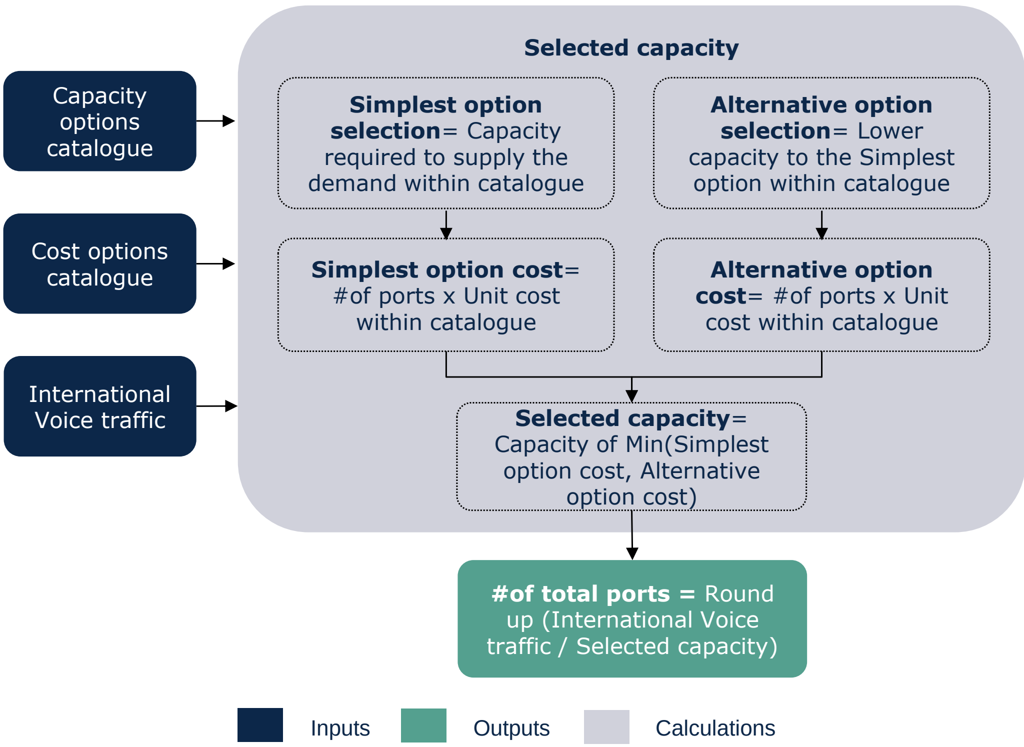

Exhibit 6.38: Algorithm for calculating the number of Converter ports [Source: Axon Consulting]

International exchange chassis and CPUs

The second step consists in calculating the number of international exchange chassis and the processing power requirements for routing the international voice traffic. The number of such elements is calculated according to the algorithm outlined below:

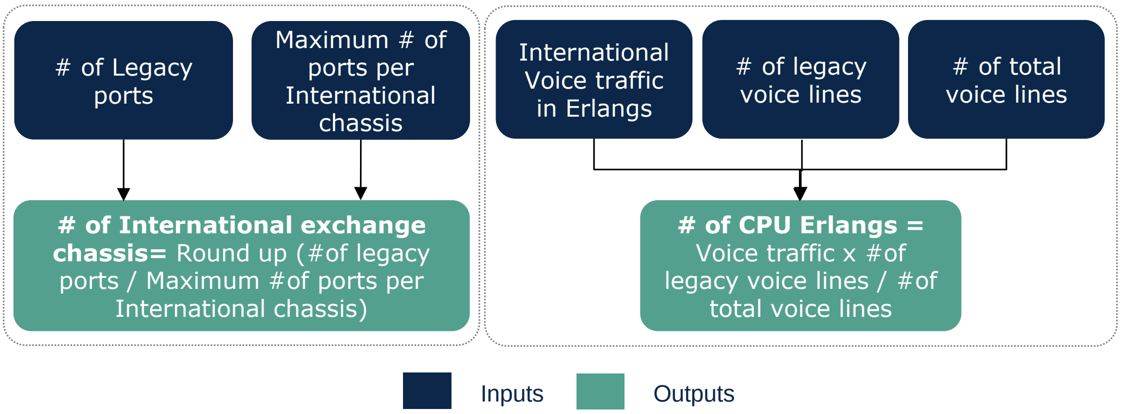

Exhibit 6.39: Algorithm for calculating the number of International exchange chassis and CPU Erlangs [Source: Axon Consulting]

6.3.4. **Sites and Energy**

This section describes the algorithms used for the calculation of core nodes supporting resources, namely:

- **Tandem site:** Represents the space used for the tandem node equipment. It includes the space itself, air conditioning, power equipment (including the generator for backup purposes) and the maintenance of the previous elements.
- **Data core site:** Represents the space used for the core node equipment. It includes the space itself, air conditioning, power equipment (including the generator for backup purposes) and the maintenance of the previous elements.
- **Electricity**

Please note that the elements above only include the space (and other resources) requirements for the corresponding node equipment. In the case that a remote node or a cabinet node is collocated with a tandem or core, the space (and other resources) required for the remote or the cabinet are considered in the section 6.1.3.

The algorithm for dimensioning the elements listed above is structured as follows:

Exhibit 6.40: Schematic Steps for the dimensioning of the Core Sites and Energy [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Tandem and core sites

The calculation of the number of tandem and core nodes is in sections 5.2.5 and 5.2.6 respectively. One site per node is costed.

Step 2. Electricity consumption

Yearly electricity (kWh) consumed by tandem and core nodes equipment is calculated based on the following algorithm:

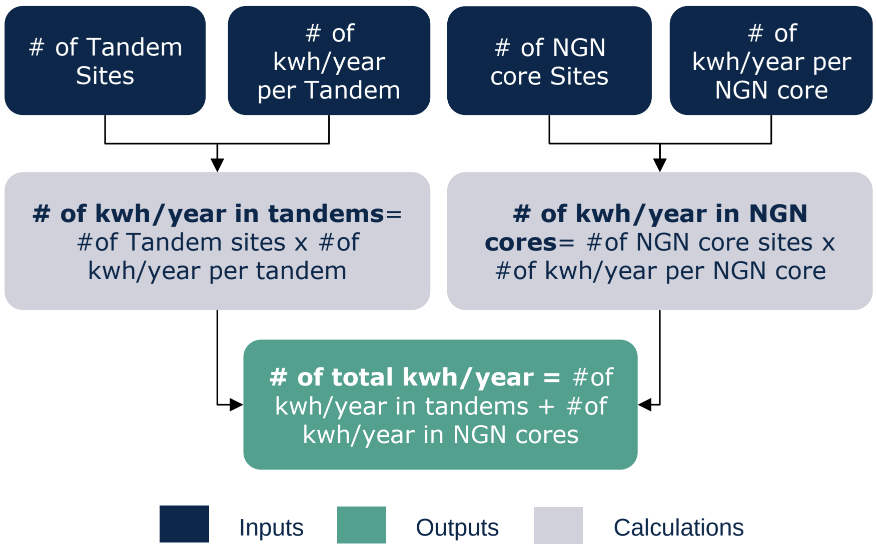

Exhibit 6.41: Algorithm for calculating the electricity consumption of the core nodes [Source: Axon Consulting]

6.4. Backhaul Transmission Network Dimensioning

The dimensioning of the backhaul transmission network is performed through the following steps:

- Number of access nodes connected in the backhaul transmission network
- Fibre transmission network of remotes nodes

- Fibre transmission network of cabinets nodes
- Microwave transmission network of remotes nodes
- Microwave transmission network of cabinets nodes

The dimensioning algorithms for the backhaul transmission network are implemented in the worksheet '6D CALC DIM TX BACKHAUL' of the Model. The following sections provide further detail about the algorithm of each specific step.

6.4.1. Number of access nodes connected in the backhaul transmission network

In order to dimension the backhaul transmission network properly, it is required to identify and exclude those access nodes (remotes and cabinets) which are collocated with backbone nodes. The transmission of these access nodes will be then considered in the backbone and it should not be considered in the backhaul to avoid double counting.

In the model it is assumed that the number of access nodes connected in the backbone network does no change in the time, i.e. additional access nodes installed due to the migration to NGN will connected through backhaul.

The algorithm is organised into two steps:

Step 1. Number of remote nodes

Step 2. Number of cabinet nodes

Exhibit 6.42: Schematic Steps for the calculation of access nodes connected in the backhaul transmission network [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of remote nodes

The first step consists in the calculation of the number of remotes nodes which are connected in the backhaul network. This calculation is developed according to the algorithm outlined below for each geotype (see section 5.2):

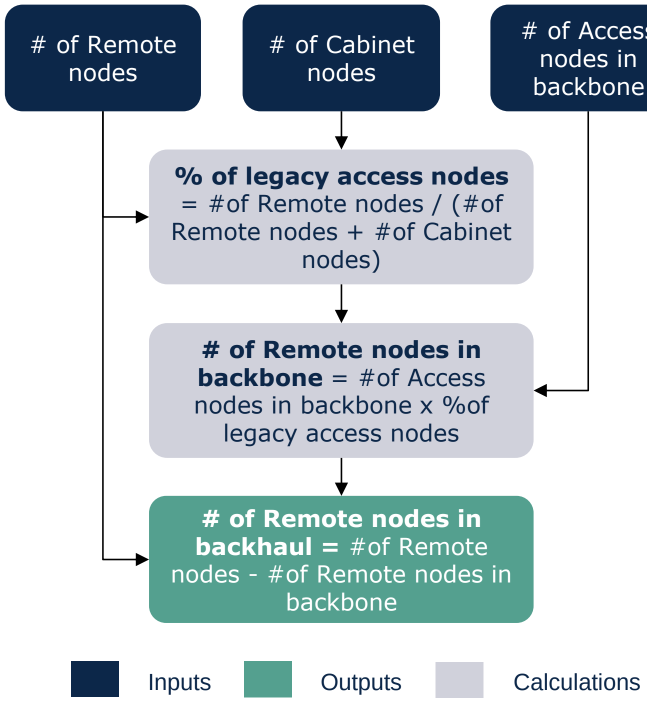

Exhibit 6.43: Algorithm for calculating the remotes nodes connected in backhaul network [Source: Axon Consulting]

Step 2. Number of cabinet nodes

As a second step, the number of cabinets connected in the backhaul network is calculated. The following exhibit shows the algorithm used to calculate that number of nodes, which is equivalent to the one used in the previous step for calculating the remote nodes for each geotype (see section 5.2):

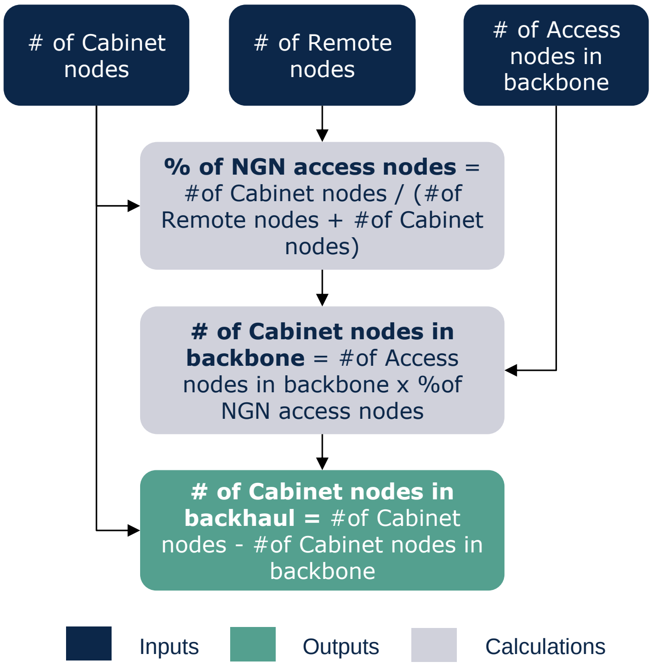

Exhibit 6.44: Algorithm for calculating the cabinets connected in backhaul network [Source: Axon Consulting]

6.4.2. Fibre transmission network of remotes nodes

As it was outlined in the section 5.3, two topologies of connection are considered for the calculation of the fibre network: ring and minimum distance tree. The following parameters will be used for the calculation of the fibre network and vary depending on the topology and the geotype (see section 5.2):

- Number of fibre links
- Average distance per link
- Capacity factor for carried traffic

The algorithm for dimensioning the fibre network to connect the remotes nodes is structured as follows:

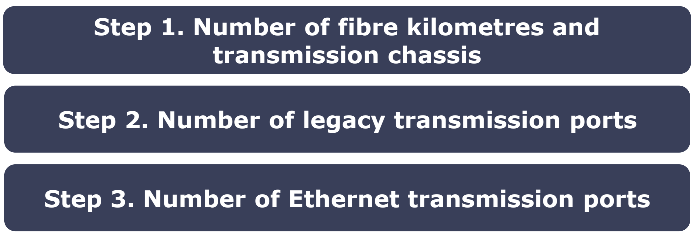

Exhibit 6.45: Schematic Steps for dimensioning the fibre transmission network of remotes nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of fibre kilometres and transmission chassis

The first step in the dimensioning of fibre transmission network is to calculate the number of fibre kilometres and the number of transmission chassis.

Please note that the fibre cable will be shared between the legacy (TDM) and the NGN (Ethernet) transmission networks. The transmission chassis are separated according to the technology of transmission (legacy transmission chassis and ethernet transmission chassis). These elements are calculated as follows <u>for each geotype</u> (see section 5.2):

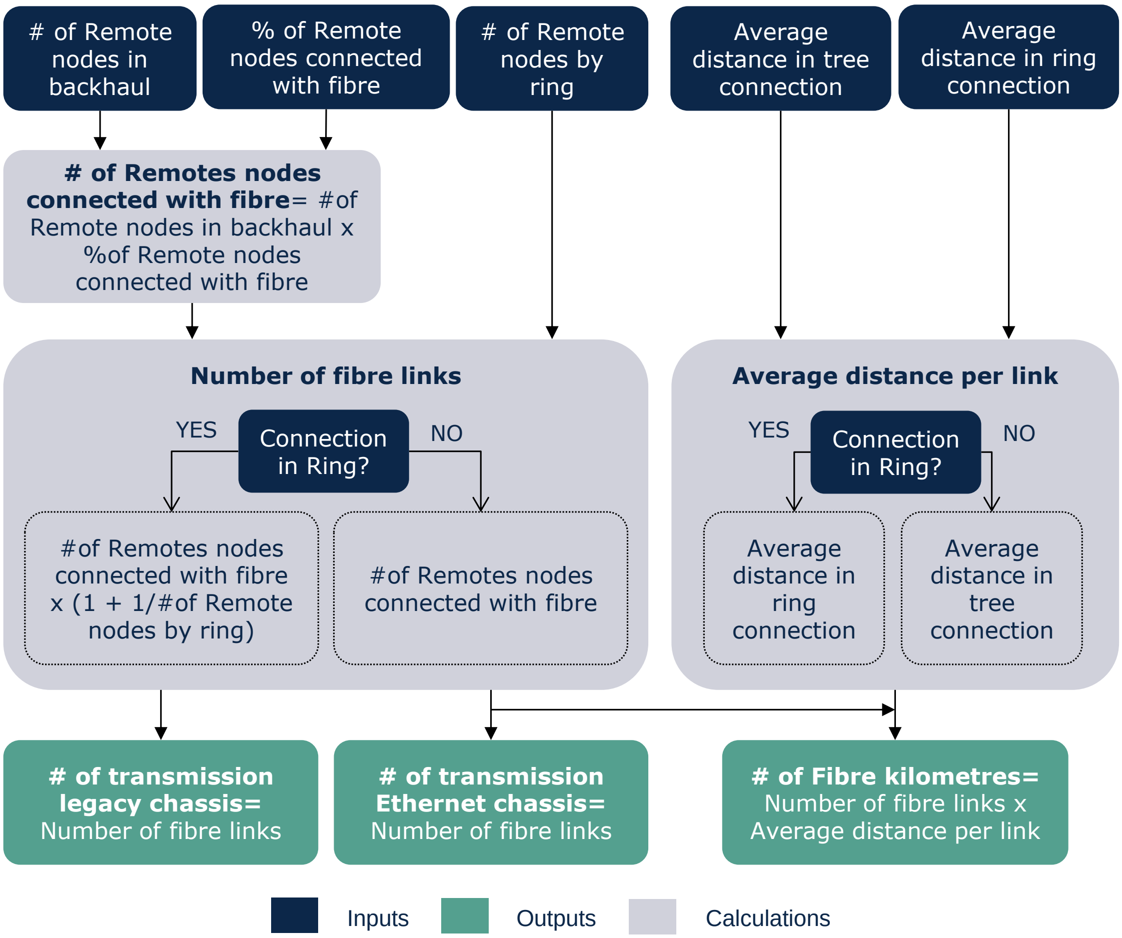

Exhibit 6.46: Algorithm for calculating the fibre kilometres and transmission chassis in remotes nodes [Source: Axon Consulting]

As it is shown in the exhibit above, the number of transmission chassis and fibre kilometres depends on the topology of connection as follows:

- **Ring topology:** The number of transmission chassis is equal to the number of remotes connected plus an additional chassis per each ring (corresponding to the next level node connected in each ring), and the number of fibre kilometres is equal to multiplication the number of fibre links by the average distance in ring connection.

- **Minimum tree topology:** The number of transmission chassis is equal to the number of remotes connected, and the number of fibre kilometres is equal to multiply the number of fibre links by the average distance in tree connection.

Step 2. Number of legacy transmission ports

The second step consists in the calculation of the number of backhaul legacy ports, i.e. the ports required for transmission of the voice traffic.

The legacy voice traffic per link is calculated according to the algorithm outlined below <u>for each geotype</u> (see section 5.2):

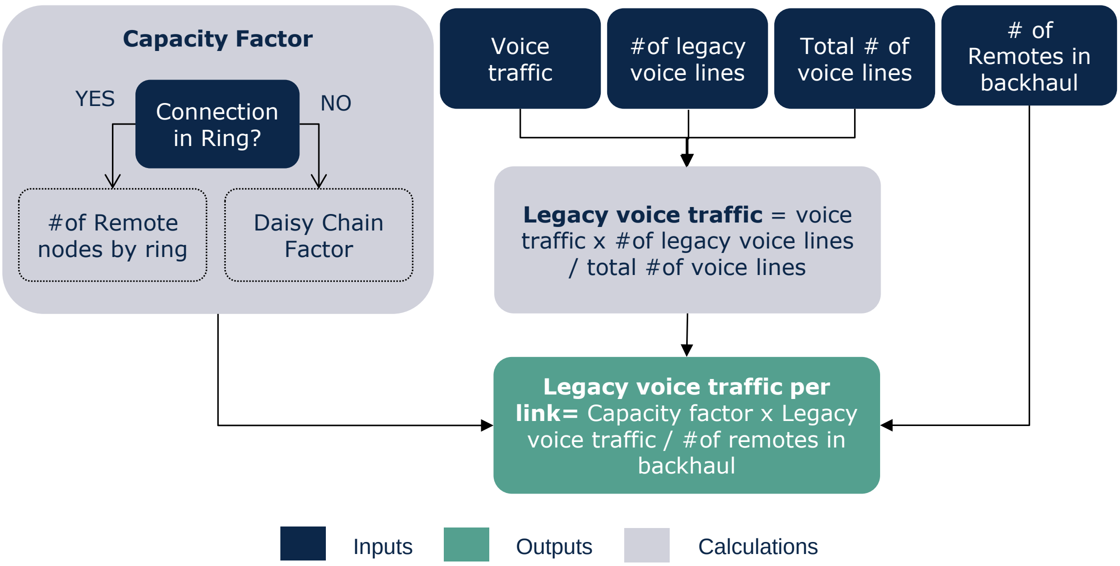

Exhibit 6.47: Algorithm for calculating the legacy voice traffic per backhaul fibre link [Source: Axon Consulting]

In the exhibit above is shown that the capacity factor depends on the topology o as follow:

- **Ring topology:** The capacity factor is equal to the number of remote nodes connected in one singular ring; i.e., all of the links in that ring should be able to carry the traffic of all the nodes.

- **Minimum tree topology:** The capacity factor is equal to the daisy chain factor[17].

Once the legacy voice traffic per link is obtained, the number of legacy ports is calculated according to the following algorithm for each geotype (see section 5.2):

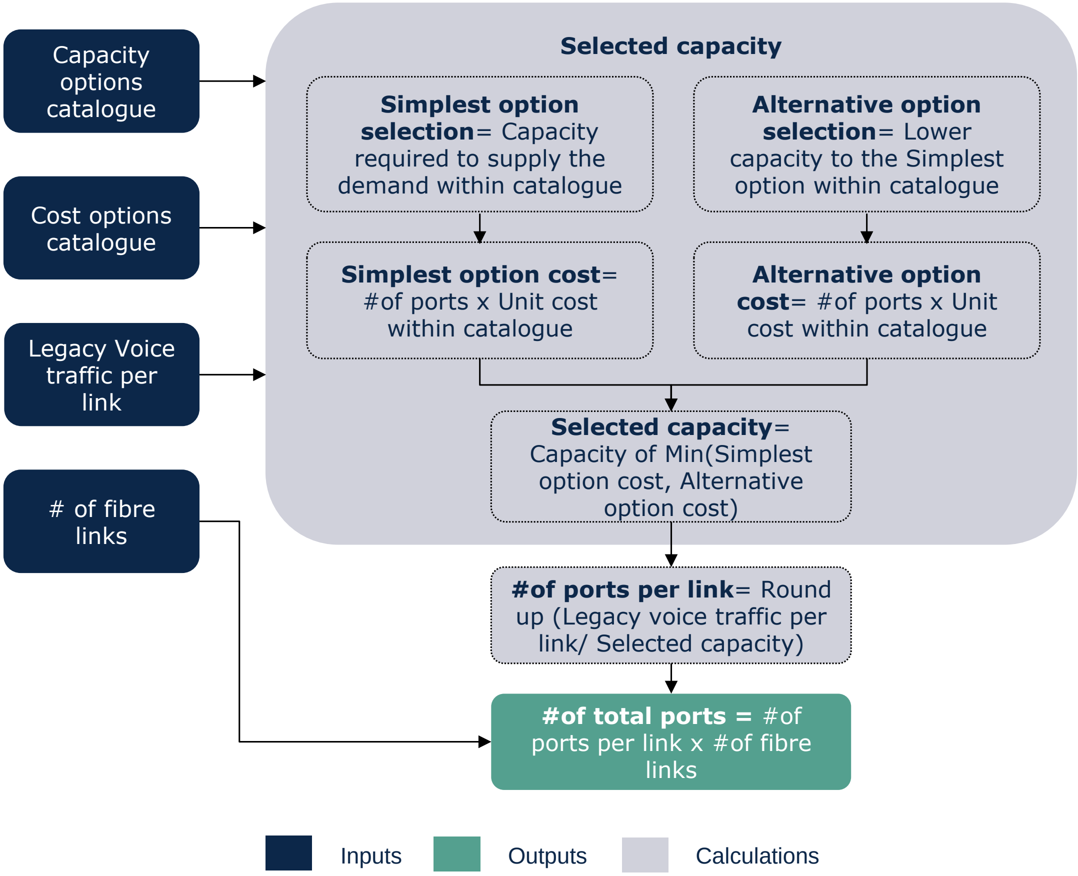

Exhibit 6.48: Algorithm for calculating the number of backhaul legacy ports in remotes [Source: Axon Consulting]

As shown above, the calculation of the number of ports is based on a methodology equivalent to the one described in section 6.1.1 (Step 2. Number of remote legacy ports).

Step 3. Number of Ethernet transmission ports

The dimensioning of the backhaul Ethernet ports in remotes, i.e. the ports required for transmission data, is similar to the one used for legacy ports:

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[17] Daisy chain factor represents that some links would handle the traffic of more than one access node. It is calculated as the total capacity required divided by the traffic generated by the access nodes.

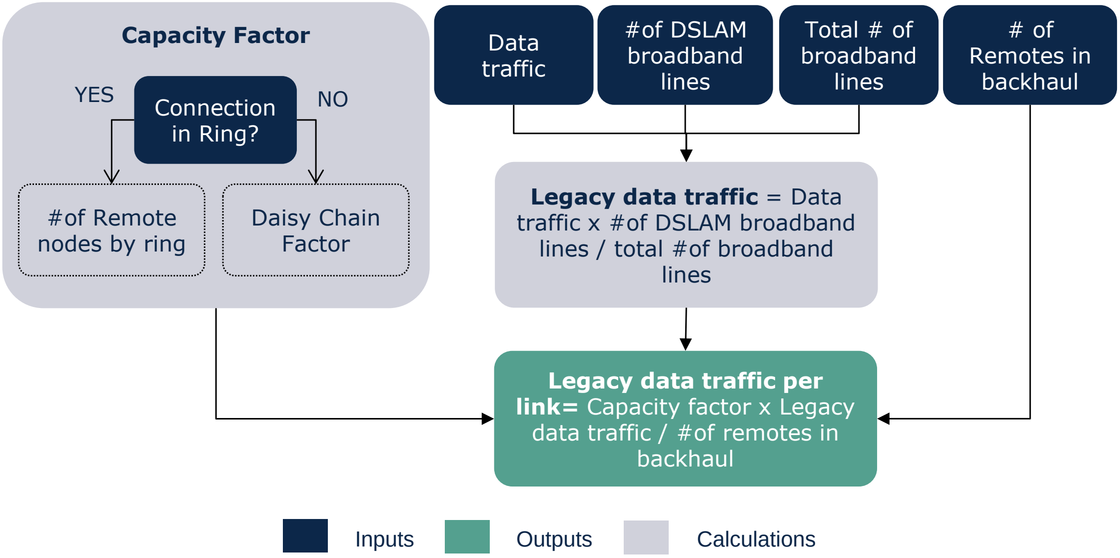

Exhibit 6.49: Algorithm for calculating the legacy data traffic per backhaul fibre link [Source: Axon Consulting]

Please note that the capacity factor for carried traffic depends on the topology of connection as it is described in the Step 2. Number of legacy transmission ports.

The number of Ethernet ports is calculated according to the following algorithm <u>for each geotype</u> (see section 5.2):

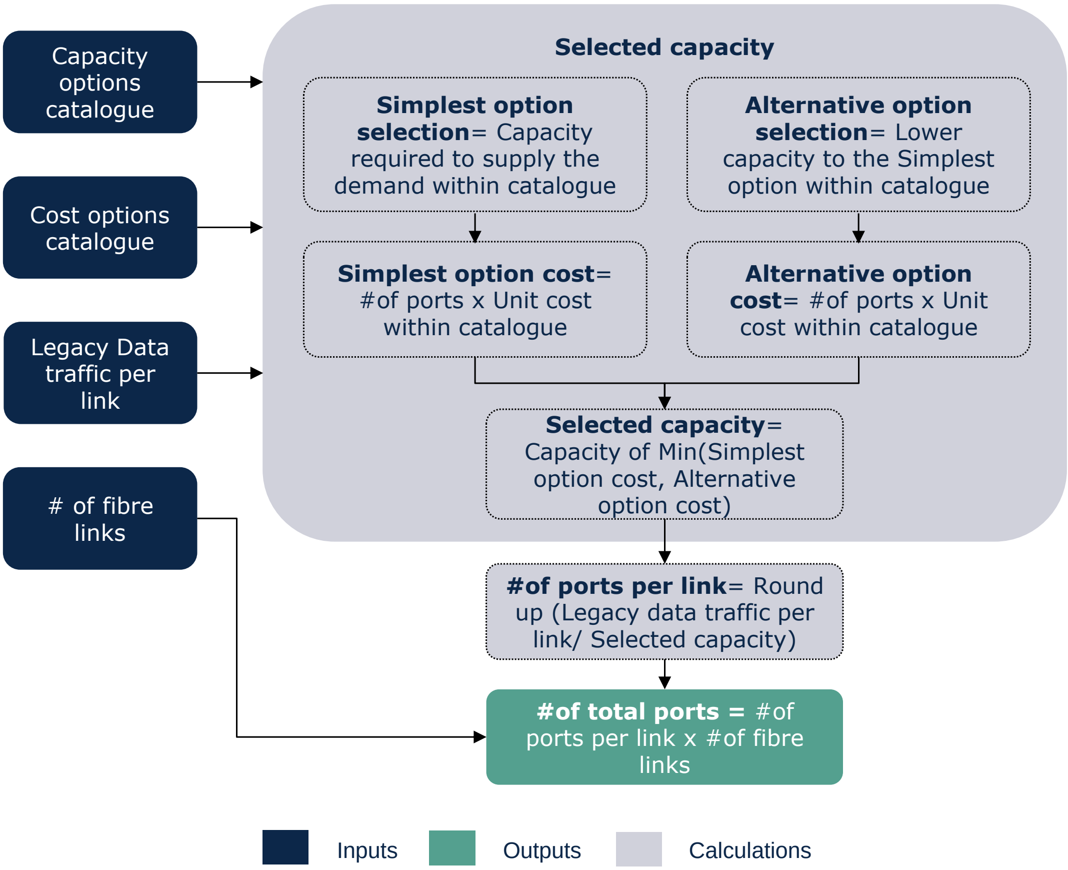

Exhibit 6.50: Algorithm for calculating the number of backhaul Ethernet ports in remotes [Source: Axon Consulting]

As shown above, the calculation of the number of ports is based on a methodology equivalent to the one described in section 6.1.1.

6.4.3. **Fibre transmission network of cabinets nodes**

The algorithms used for calculating the fibre requirements for cabinets backhaul is equivalent to the one applied for the remote nodes with the exception that only ethernet network is deployed for both voice and data traffic.

6.4.4. **Microwave transmission network of remotes nodes**

The next stage in the dimensioning of the backhaul network is calculating the backhaul transmission through microwave (MW) technologies. MW transmission dimensioning has two main differences compared to the fibre transmission:

- It is assumed that all connection are point to point; i.e. only minimum distance tree topology is considered.

- There is no different technologies for transmission of voice and data traffic; i.e. there is only one type of transmission technology modelled[18].

The algorithm for dimensioning the microwave transmission network to connect the remotes nodes is structured as follows:

Step 1. Number of towers

Step 2. Number of transmission hops

Exhibit 6.51: Schematic Steps for dimensioning the MW transmission network of remotes nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of towers

The first step consist in calculating the number of towers required, including:

- Towers in the access nodes.
- Towers required for repeaters in those cases that the links are longer than the maximum MW hop distance.

The number of towers is calculated according to the algorithm outlined below <u>for each geotype</u> (see section 5.2):

[18] It is assumed that the data traffic will be aggregated through the same link instead of installing two microwave links.

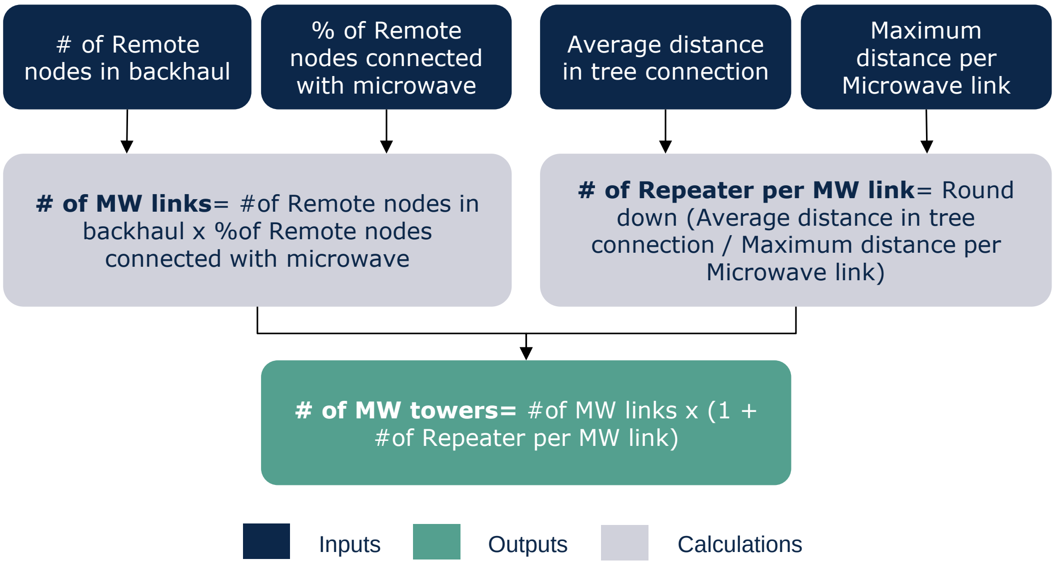

Exhibit 6.52: Algorithm for calculating the number towers in remotes [Source: Axon Consulting]

Step 2. Number of transmission hops

The second step consists in the calculation of the transmission units required. Please bear in mind that in the model the resource is measured in number of hops. This means that each hop would include the elements required in both ends of the hop (e.g. transmission unit, cables, antennas).

To obtain the number of hops it is necessary to calculate the legacy traffic (voice traffic and data traffic from DSLAMs) that should be transport by each one of the links. The legacy traffic per link is calculated according to the algorithm outlined below <u>for each geotype</u> (see section 5.2):

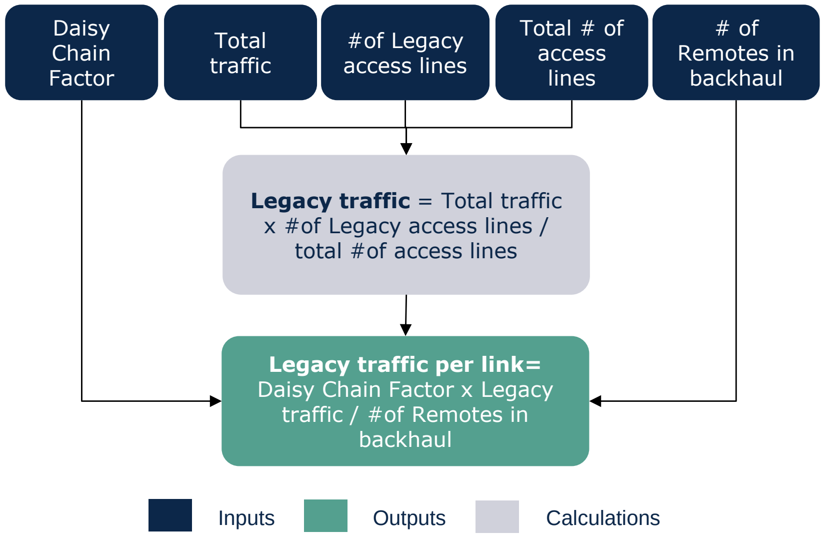

Exhibit 6.53: Algorithm for calculating the legacy traffic per backhaul MW link [Source: Axon Consulting]

The algorithm in the exhibit above has to be applied twice:

- For calculating the voice traffic
- For calculating the data traffic

Once the total legacy traffic per link is obtained (voice plus data traffic), the number of microwave hops is calculated according to the following algorithm <u>for each geotype</u> (see section 5.2):

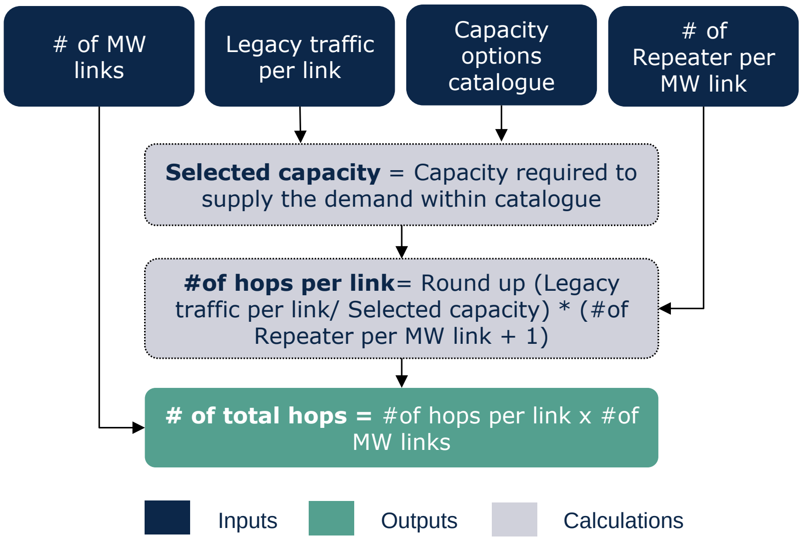

Exhibit 6.54: Algorithm for calculating the number of backhaul MW hops in remotes [Source: Axon Consulting]

6.4.5. **Microwave transmission network of cabinets nodes**

The algorithms used for calculating the fibre requirements for cabinets backhaul is equivalent to the one applied for the remote nodes with the exception that ethernet technologies are used (instead of TDM).

6.5. Backbone Transmission Network Dimensioning

The dimensioning of the backbone transmission network is performed through the following steps:

- Fibre transmission network
- Microwave transmission network

The dimensioning algorithms for the backbone transmission network are implemented in the worksheet '6E CALC DIM TX BACKBONE' of the Model. The following sections provide further detail about the algorithm of each specific step.

6.5.1. **Fibre transmission network**

The following parameters have been defined for each link type (see section 5.4.1):

  - Percentage of capacity over total traffic
  - Number of links
  - Average link length

The algorithm for dimensioning the backbone transmission network by fibre is structured as follows:

Step 1. Number of fibre kilometres and transmission chassis

Step 2. Legacy and NGN traffic per link

Step 3. Number of legacy transmission ports

Step 4. Number of Ethernet transmission ports

Step 5. Number of DWDM chassis and lambdas

Step 6. Determination of the low cost scenario

Exhibit 6.55: Schematic Steps for dimensioning the backbone transmission network by fibre [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of fibre kilometres and transmission chassis

The first step is to calculate the number of fibre kilometres and the number of transmission units. Please note that the fibre cable will be shared between the legacy (TDM) and the NGN (Ethernet) transmission networks. The transmission chassis are separated according to the technology of transmission (legacy transmission chassis and ethernet transmission chassis). These elements are calculated as follows for each link type:

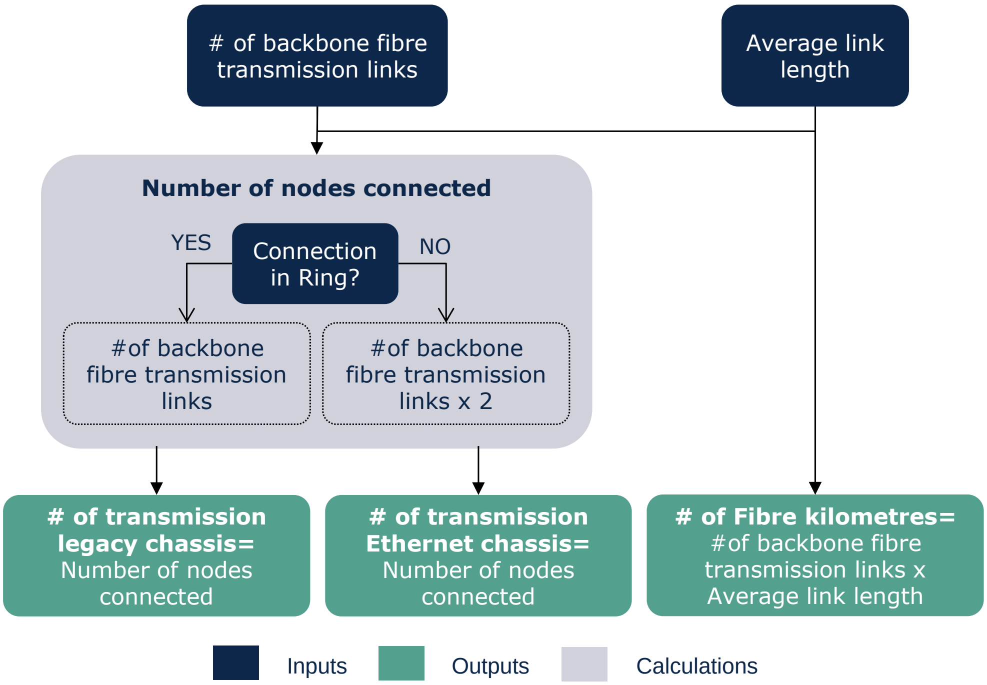

Exhibit 6.56: Algorithm for calculating the fibre kilometres and transmission chassis in backbone network [Source: Axon Consulting]

Step 2. Legacy and NGN traffic per link

The second step consists in the calculation of the legacy traffic and the NGN traffic that should be transport by each one of the links. The legacy voice traffic per link is calculated according to the algorithm outlined below for each one of the link types:

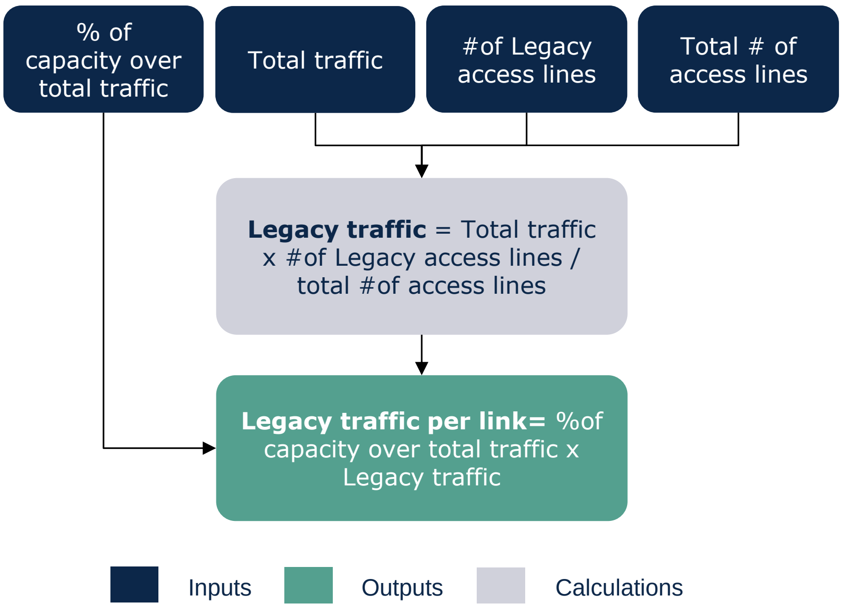

Exhibit 6.57: Algorithm for calculating the legacy voice traffic per backbone fibre link [Source: Axon Consulting]

The NGN traffic per link is calculated in similar way that legacy traffic, and according to the algorithm outlined below for each one of the link types:

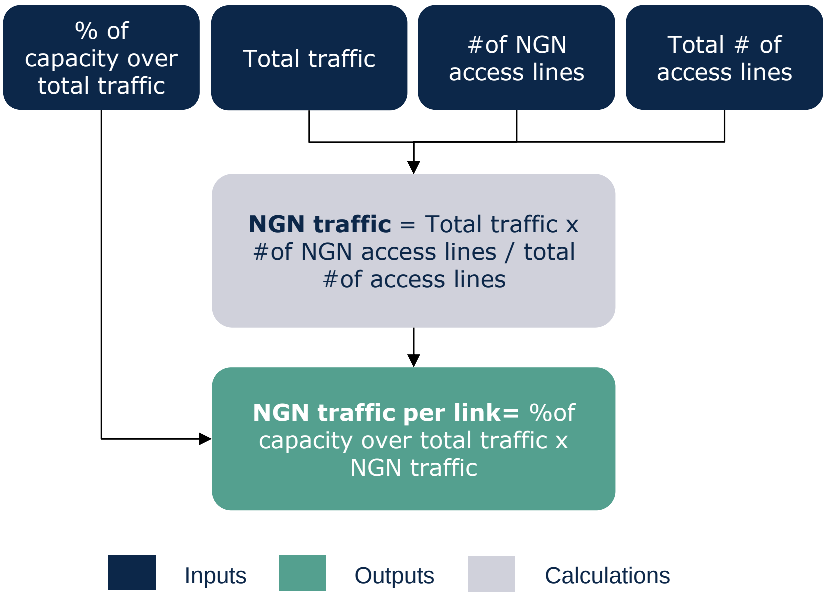

Exhibit 6.58: Algorithm for calculating the NGN traffic per backbone fibre link [Source: Axon Consulting]

Please note that the algorithm in the exhibit above includes both broadband traffic and VoIP traffic.

Step 3. Number of legacy transmission ports

The following step consists in calculating the number of legacy transmission ports. This number of ports is calculated according to the following algorithm for each link type:

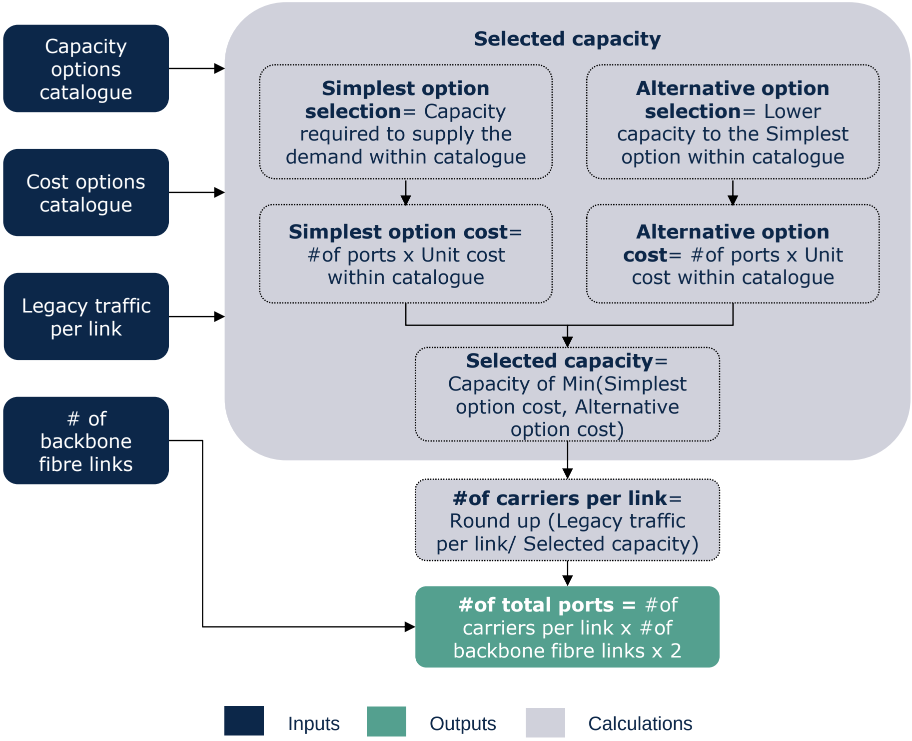

Exhibit 6.59: Algorithm for calculating the number of backbone legacy ports [Source: Axon Consulting]

As shown above, the calculation of the number of ports is based on a methodology equivalent to the one described in section 6.1.1 (Step 2. Number of remote legacy ports).

Step 4. Number of Ethernet transmission ports

The number of Ethernet ports is calculated as follows:

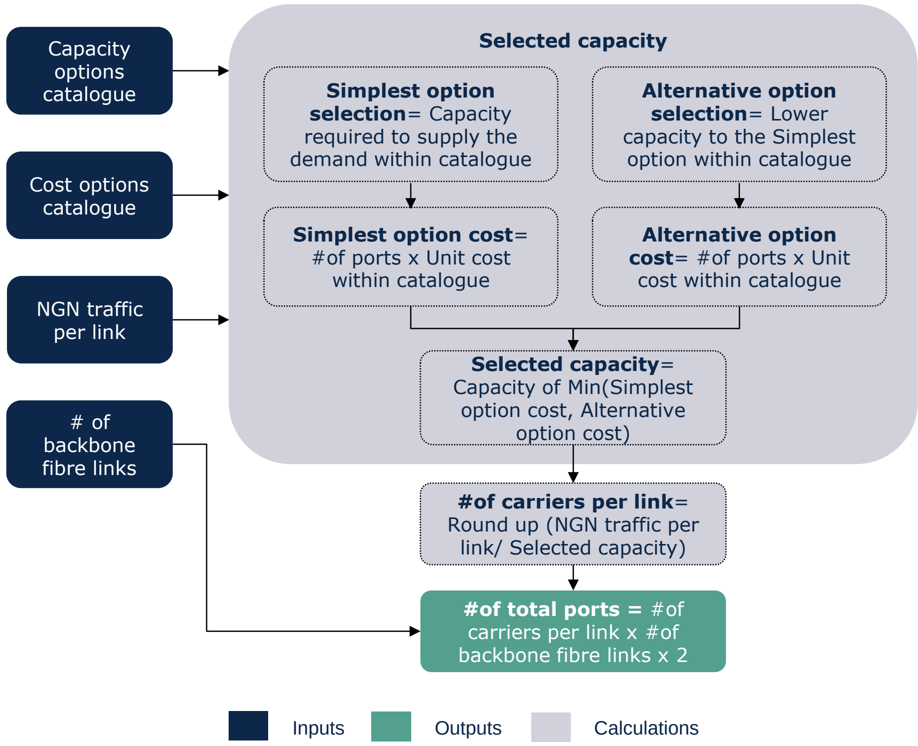

Exhibit 6.60: Algorithm for calculating the number of backbone NGN ports [Source: Axon Consulting]

The number of Ethernet ports is calculated according to the following algorithm for each geotype (see section 5.2):

Step 5. Number of DWDM chassis and lambdas

DWDM technology is considered when several transmission links should be aggregated in the same cable. The maximum number of carriers per link is defined as a parameter. In those cases that the number of carriers required is bigger than the maximum, part of them would be aggregated through DWDM. The number of DWDM chassis and lambdas is calculated according to the following algorithm for each link type:

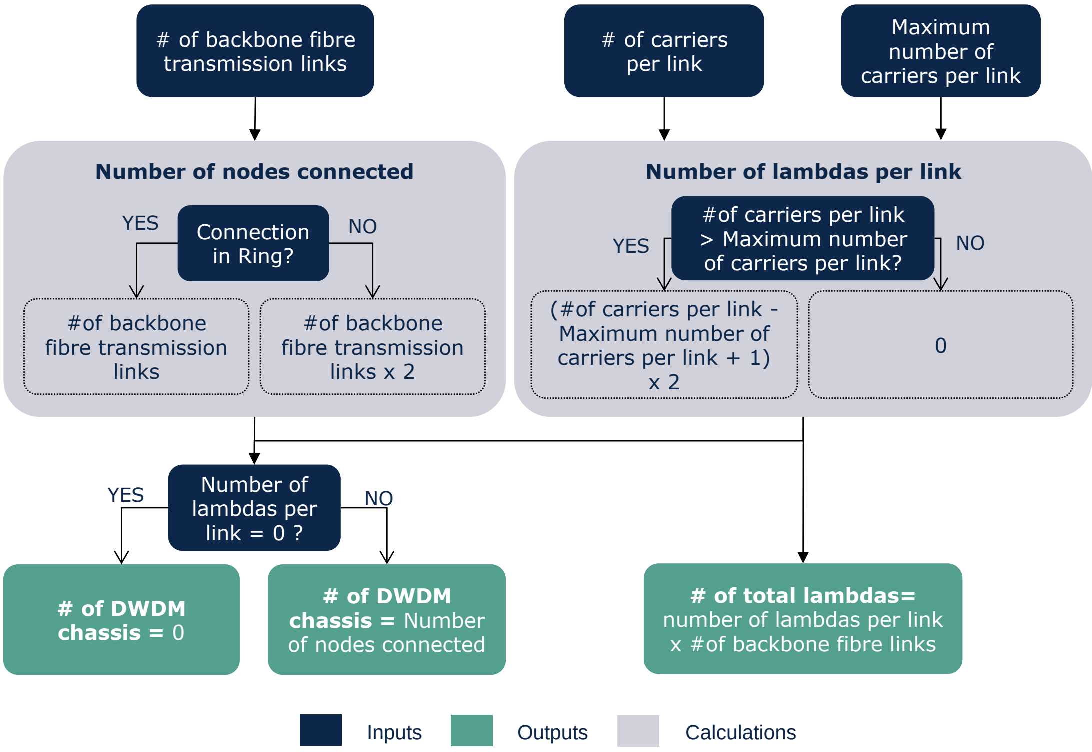

Exhibit 6.61: Algorithm for calculating the number of DWDM chassis and lambdas [Source: Axon Consulting]

Step 6. Determination of the low cost scenario

Despite that the calculation of legacy ports and NGN ports is based on the principle of minimum cost, it is necessary evaluated different scenarios including the DWDM equipment with the legacy and NGN ports. Therefore a number of scenarios are calculated to identify the most cost efficient option.

6.5.2. **Microwave transmission network**

The following parameters have been defined for each link type (see section 5.4.2):

- Percentage of capacity over total traffic
- Number of links
- Average link length
- The algorithm for dimensioning the backbone transmission network by fibre is structured as follows:

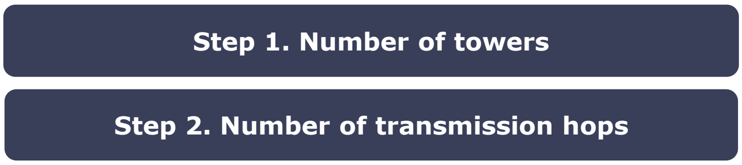

Exhibit 6.62: Schematic Steps for dimensioning the backbone transmission network by microwave [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of towers

As a first step in the dimensioning of backbone transmission network by microwave, it is necessary to calculate the number of towers installed in the nodes and in the repeaters locations. The number of towers is calculated according to the following algorithm for each link type:

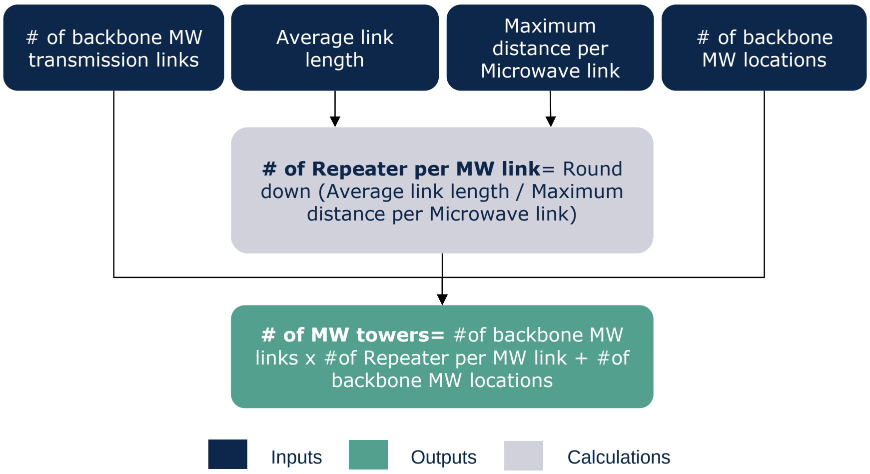

Exhibit 6.63: Algorithm for calculating the number towers in backbone [Source: Axon Consulting]

Step 2. Number of transmission hops

The second step consists in the calculation of the transmission units required. Please bear in mind that in the model the resource is measured in number of hops. This means that each hop would include the elements required in both ends of the hop (e.g. transmission unit, cables, antennas).

The second step consists in the calculation of the total traffic (voice and data traffic). The total traffic per link is calculated as follows for each link type:

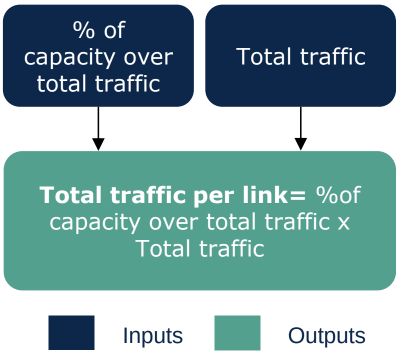

Exhibit 6.64: Algorithm for calculating the total traffic per backbone MW link [Source: Axon Consulting]

The algorithm in the exhibit above has to be applied twice, for calculating the voice traffic and for calculating the data traffic. Once the total traffic per link is obtained (voice plus data traffic), the number of microwave hops is calculated according to the following algorithm for each one of the link types:

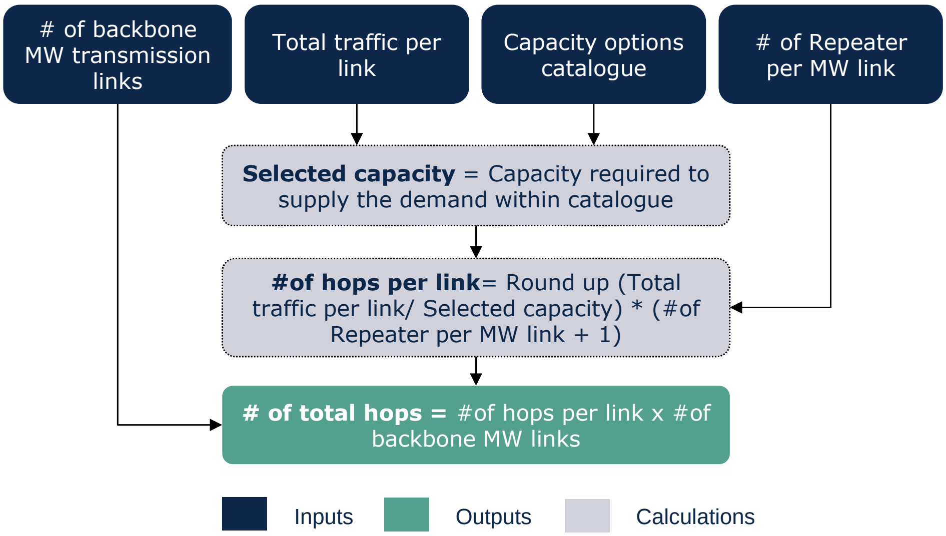

Exhibit 6.65: Algorithm for calculating the number of backbone MW hops [Source: Axon Consulting]

6.6. Direct Costs Dimensioning

Additionally to the elements dimensioned in the previous section, the model also considers the calculation of certain direct costs associated to some specific services. The dimensioning of those direct costs is performed through the following steps:

- Interconnection costs
- Specific costs

The dimensioning algorithms for the direct costs are implemented in the worksheet '6F CALC DIM DIRECT COSTS' of the Model. The following sections provide further detail about the algorithm of each specific step.

6.6.1. **Interconnection costs**

The interconnection costs are defined as a fixed tariff per minute, then dimensioning these resources is really simple.

Those resources are measured in minutes, and in consequence those are equal to the traffic for each one of the following concepts:

- Fixed termination
- Mobile termination
- International Termination
- National freephone termination
- International freephone termination
- Home Country Interconnection

6.6.2. **Specific costs**

The specific costs are defined as a fixed tariff per minute, then dimensioning these resources is really simple.

Those resources are measured in minutes, and in consequence those are equal to the traffic for each one of the following concepts:

- Emergency services specific costs
- National DQ specific costs
- International DQ specific costs
- Own freephone specific costs
- Wholesale billing

7. Costs Calculation Module

The purpose of this module is to calculate the expenditures 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.

Step 1. Determination of Resources' Unit Costs and Cost Trends

Step 2. Calculation of GBV and OpEx

Exhibit 7.1: Resources Costing [Source: Axon Consulting]

The following sections explain each step in detail.

7.1. Step 1. Determination of Resources' 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 cost**: Separated in CAPEX and OPEX (for those resources where applicable). Unitary costs can be introduced in the local currency (i.e. Jamaican Dollars) or in USD, which will be used throughout the model.
- **Cost trends**: For each resource a cost trend can be introduced, outlining the expected evolution of its prices (both CapEx and OpEx separately).

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

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

This calculation is performed in the worksheets '4A OPEX COST CONSOL' and '4B CAPEX COST CONSOL' of the model.

7.2. Step 2. Calculation of GBV and OpEx

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

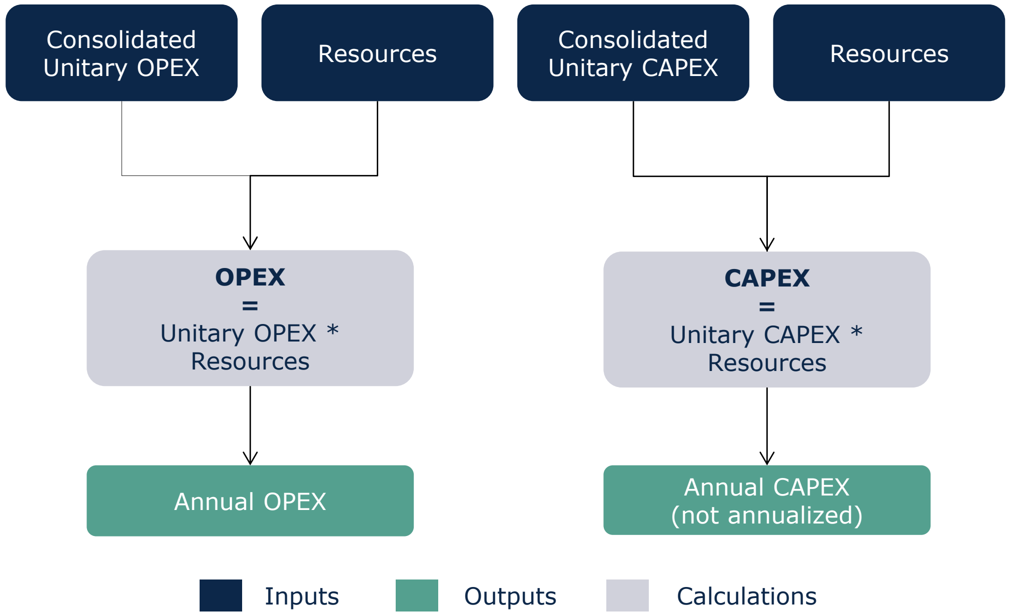

Exhibit 7.2: Algorithm for the Calculation of GBV and OPEX [Source: Axon Consulting]

8. Depreciation Module

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

Tilted annuities adapt the profile of the costs recovery with the objective of recognising the variations in asset prices. For example, in case 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, in case prices decrease, a higher proportion of the asset is recovered during the initial periods so the same cost will be recognized 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 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 it 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. Cost imputation to services

According to the methodology, the LRIC model should produce results under the following methodologies:

- **Pure Long Run Incremental Costs (Pure LRIC):** this methodology calculates the costs that would be saved if certain services, group of services or activities (defined as an increment) were not provided (avoidable costs). These incremental costs are aligned with the variable costs in the long run. Using this approach, neither common costs, nor joint costs are allocated to the services.
- **Long Run Incremental Costs plus Common Costs (LRIC+):** unlike the pure LRIC approach, this allows the recovery of common and joint costs that are not incremental to any given service. This approach corresponds to the TLRIC standard defined in the Act. For the allocation of the common costs, a Shapley-Shubik methodology is applied. This methodology is based on a combination of the incremental costs for each possible order of arrival of the services provided (further detail in section 9.2).
- **Stand Alone Costs (SAC):** it calculates the costs of a network developed to provide only a group of services (increment).

As can be extracted, the three methodologies are based on what are the costs of the network required for providing different combination of services. For instance, the Pure LRIC costs are based on the cost difference if the network offers the entire services portfolio or if a group of services is not provided.

Due to the economies of scale of telecommunication networks, the network structure is not sensitive enough to respond to small variations of demand. Therefore, in order to analyse the costs variations for the different combinations of services, they are grouped into "increments". As defined in the methodology and principles set by the OUR, the following increments are used in the LRIC model:

- **Voice termination (increment 1):** including the voice traffic originated in third parties' networks and terminated in the reference operator's network.
- **Other voice services (increment 2):** such as retail voice on-net, voice off-net, calls to voice-mail, etc.
- **Non-voice services (increment 3):** broadband and leased lines services.

The network (resources and corresponding costs) is calculated for the different combinations of increments using the same methodology and algorithms described in the sections above, with the only change of the demand that is input in the calculation of the dimensioning drivers. Specifically, the following scenarios are calculated:

Scenario	Description	Increments provided		
		Increment 1	Increment 2	Increment 3
FAC	This scenario is calculated as a reference of the real network of the operator.	✓	✓	✓
INC(1)	A network that satisfies the demand of all the increments, but the Increment 1 (voice termination)		✓	✓
INC(2)	A network that satisfies the demand of all the increments, but the Increment 2 (other voice services)	✓		✓
INC(3)	A network that satisfies the demand of all the increments, but the Increment 3 (non-voice services)	✓	✓	
SAC(1)	A network to only offer the Increment 1 (voice termination)	✓		
SAC(2)	A network to only offer the Increment 2 (other voice services)		✓	
SAC(3)	A network to only offer the Increment 3 (non-voice services)			✓

Table 9.1: Summary of network scenarios calculated [Source: Axon Consulting]

The following subsections describe the methodology applied for the calculation of services' costs under each of the standards.

9.1. Pure LRIC calculations

As defined above, the Pure LRIC standard is calculated as the avoidable cost of stopping the provision of one increment. Therefore, the formula is as follows:

$$Pure\ LRIC\ (i) = FAC - INC(i)$$

Once the LRIC of each increment is obtained, it is required to allocate the costs to the services included in that increment. Such allocation is performed through the use of Routing Factors, as defined in the worksheet '3B MAP ROUTING FACTORS'.

Please note that certain resources are allocated only based on NGN or Legacy traffic. This options are set up in the worksheet '0B PAR RESOURCES' (column "Demand type for allocation to services").

9.2. LRIC+ calculations

LRIC+ standard is calculated as the Pure LRIC cost plus network common and joint costs. The common costs are calculated as follows:

$$Common\ Costs = FAC - PureLRIC(1) - PureLRIC(2) - PureLRIC(3)$$

According to the methodology and principles defined by the OUR, the allocation of common costs to the different increments is performed through a Shapley Shubik methodology.

This methodology allocates the common costs based on the average incremental costs obtained as per all the combinations of increments arrival to the network. In the case of having three increments, the combinations are the following (example for increment 1):

Combination #	Description	Formula[19]
1	The increment 1 arrives to a network where increment 2 and increment 3 were already provided.	$C(1) = FAC - INC(1)$
2	The increment 1 arrives to a network that only provides increment 2.	$C(2) = INC(3) - SAC(2)$
3	The increment 1 arrives to a network that only provides increment 3.	$C(3) = INC(2) - SAC(3)$
4	The increment 1 is the only one provided in the network	$C(4) = SAC(1)$

Table 9.2: Calculation combinations for the application of Shapley Shubik methodology for a system of 3 increments (example for increment 1) [Source: Axon Consulting]

The driver used for the allocation of the common costs to each increment is calculated as the average of the combinations 1 to 4.

Then, the common costs associated to each increment are allocated among the services included in such increment as a mark-up of Pure LRIC.

Please note that for the calculation of the drivers and for the allocation of common costs to services the direct costs (such as interconnection and specific costs) are not included. The resources considered for the allocation of common costs are

[19] The scenarios are defined in the Table 9.1.

defined in the worksheet '0B PAR RESOURCES' (column "To be considered for common costs allocation").

9.3. SAC calculations

In the case of SAC standard, the cost associated to each increment is the one corresponding to a network that only provides such increment. In this case, the cost corresponds directly to the scenarios SAC(i) defined in the Table 9.1.

10. Cost overheads

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

Additionally, during the public consultation of the methodology, the operators commented the complexity of calculating the part of retail and G&A costs associated to fixed network traffic (i.e. discounting the costs associated to the mobile network and to the fixed access network that is not included in the LRIC model). 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, Retail Costs and G&A Costs are calculated as follows:

- Network OpEx Working Capital:

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

- Retail Costs

$$Retail\ Costs = RetailOverhead * (Network\ OpEx + Network\ Depreciation)$$

- General and Administrative costs (G&A)

$$G\&A = G\&AOverhead * (Network\ OpEx + Network\ Depreciation + Retail\ Costs)$$

Please note that the overhead percentages are calculated based on operators' overall financial statements consistently with the formulas above.