

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

*Description of the BULRIC Model for Fixed
networks*

29 May 2017



AXON

Contents

Contents.....	2
1. Introduction	5
1.1. Methodological choices	5
1.2. Structure of the document	7
2. General Architecture of the Model	9
3. Model inputs	11
4. Dimensioning Drivers	13
4.1. Dimensioning drivers concept	13
4.2. Mapping services to drivers	14
4.3. Conversion factors from services to drivers	15
5. Geographical Analysis	19
5.1. Introduction	19
5.2. Population centre characterisation.....	19
5.2.1. Breaking down the country into samples	20
5.2.2. Allocating population centres to samples	20
5.3. Node characterisation	21
5.3.1. Access nodes	22
5.3.2. Edge nodes	23
5.3.3. Distribution nodes	24
5.3.4. Core nodes	24
5.3.5. Core platform distribution.....	24
5.4. Backhaul transmission characterisation	25
5.4.1. Transmission technology and topology	25
5.4.2. Average link distance.....	26
5.5. Backbone transmission characterisation	28
5.5.1. Backbone fibre network.....	28
5.5.2. Backbone microwave network.....	29

6. Dimensioning Module	30
6.1. Access Network Dimensioning.....	30
6.2. Distribution Network Dimensioning.....	33
6.2.1. Edge node dimensioning	33
6.2.2. Distribution node dimensioning	35
6.2.3. Sites and energy	37
6.3. Core Network Dimensioning	38
6.3.1. Data core nodes dimensioning	39
6.3.2. Core platforms and equipment dimensioning	41
6.3.3. Sites and energy	48
6.4. Backhaul Transmission Network Dimensioning	49
6.4.1. Number of access nodes connected in the backhaul transmission network.....	50
6.4.2. Fibre transmission network of cabinet nodes.....	51
6.4.3. Microwave transmission network of cabinet nodes	53
6.5. Backbone Transmission Network Dimensioning	56
6.5.1. Fibre transmission network.....	56
6.5.2. Microwave transmission network	60
6.6. Direct Costs Dimensioning.....	62
6.6.1. Interconnection costs.....	63
6.6.2. Specific costs	63
7. Cost Calculation Module.....	65
7.1. Step 1. Determination of Resource Unit Costs and Cost Trends	65
7.2. Step 2. Calculation of GBV, OpEx and G&A.....	66
8. Depreciation Module	67
9. Cost Imputation to Services	68
9.1. Increment Definition.....	68
9.2. Incremental Cost Calculation	68
9.3. Common Cost Calculation	70
10. Cost overheads	71

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 Eastern Caribbean Telecommunications Authority (hereinafter, 'ECTEL' or the 'Authority') 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+ cost standard.
- ▶ It is based on engineering models that allow the consideration of multiple-year time frames (2015-2020)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 are decided in the document "*Final Principles Methodologies Guidelines*"² (hereinafter, 'the Methodology'), published on ECTEL's website³

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

² <https://s3.amazonaws.com/ectel-web/consultations/2016/determination-interconnection-rates+/Determination/Axon-Consulting-final-principles-methodologies-guidelines-20161227.pdf>

³ <https://www.ectel.int/principles-methodologies-and-guidelines-for-the-determination-of-new-interconnection-rates/>

Methodological Issue	Approach Adopted
Cost elements considered	<p>This model considers the following cost elements:</p> <ul style="list-style-type: none"> ▶ Network CapEx ▶ Network OpEx ▶ Licenses ▶ Frequency usage fees ▶ G&A costs ▶ Cost of capital
Treatment of OpEx	<p>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.</p>
Assets valuation method	<p>Use of a static Current Cost Accounting approach, by which all assets are valued every year based on their price that year. Assets will be substituted for a Modern Equivalent Asset when required.</p>
Annualisation method	<p>Tilted annuities method is used for all assets, which allows the consideration of the evolution of network prices, while avoiding potential deviation due to uncertainty of traffic forecasts.</p>
Cost Standard	<p>LRIC+ is used to obtain the cost of the services modelled.</p>
Network dimensioning optimisation	<p>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.</p>
Time period	<p>The model includes historical data (since 2015) as well as forecasted data (up to 2020) to represent the future network roll-out.</p>
Operator Modelled	<p>The model considers a reference operator which has similar characteristics (i.e. demand) to the incumbent, in each of the 5 modelled countries.</p>
List of services considered	<p>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.)</p>
Definition of the increments	<p>One increment that includes the entire traffic.</p>
Geotypes	<p>Geotypes are based on population and lines density.</p>

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 incumbent's current network.
Core network Technologies	The model considers an NGN core network
Transmission technologies	Incorporates the following mix of technologies: <ul style="list-style-type: none"> - Native Ethernet fibre transmission - WDM Fibre transmission - Microwaves

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

1.2. Structure of the document

The remainder 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.
- ▶ **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.
- ▶ **Cost 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 LRIC+ standard.

Additionally, it shows the calculation of demand scenarios used for allocating costs to services.

Please note that a user manual for the model has been provided as separate document.

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.

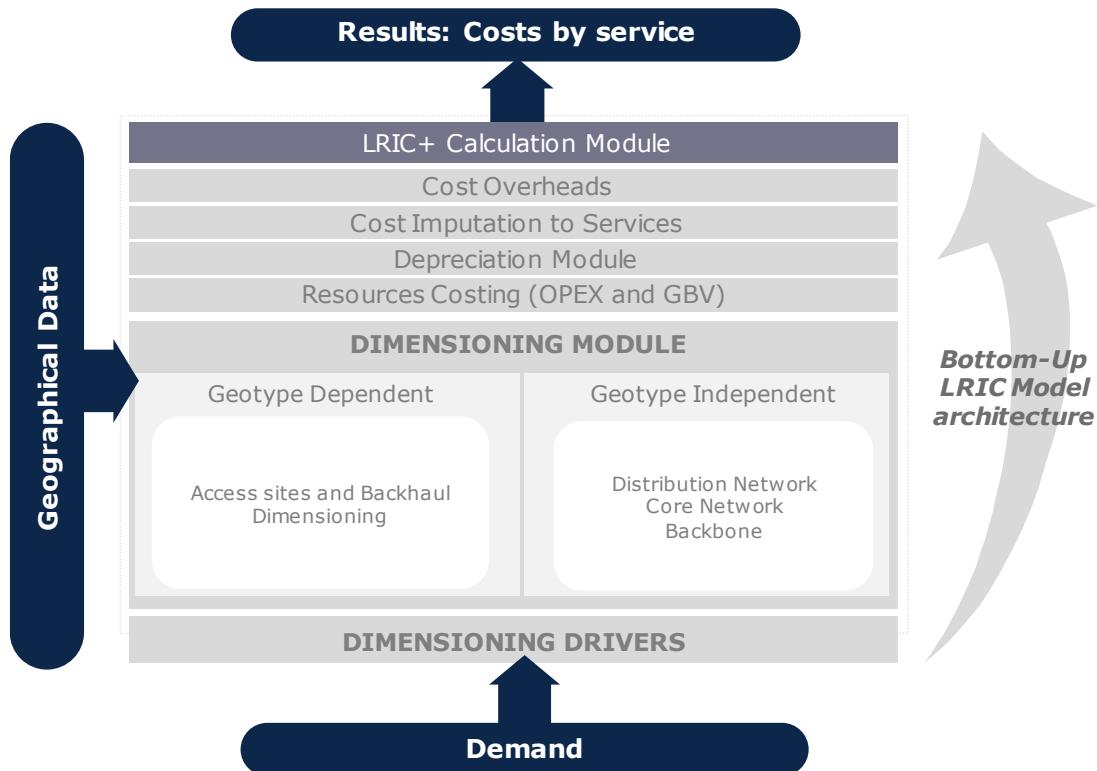


Exhibit 2.1: Structure of the model [Source: Axon Consulting]

Several calculation blocks can be identified above, namely:

- ▶ **Dimensioning drivers:** Converting traffic into dimensioning drivers, later assisting in dimensioning network resources.
- ▶ **Dimensioning module:** Modelling the number of resources required to satisfy the demand.
- ▶ **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 plus Common costs (LRIC+).
- ▶ **Cost overheads:** Calculating those cost categories as a mark-up (i.e. working capital).

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	<ul style="list-style-type: none"> ▶ The demand that must be supported by the network (e.g. voice traffic, data traffic) per country
1B INP NW STATISTICS	Network Statistics	<ul style="list-style-type: none"> ▶ Call and data statistics registered in the operator's network.
1C INP UNITARY COSTS	Unitary Costs Input	<ul style="list-style-type: none"> ▶ Unitary costs (differentiating CapEx and OpEx) for each resource/cost item.
1D INP COST TRENDS	Input: Cost Trends	<ul style="list-style-type: none"> ▶ Cost trends of the unitary costs by resource (differentiating CapEx and OpEx).
1E INP EXCHANGE RATES	Exchange Rates Input	<ul style="list-style-type: none"> ▶ Exchange rates between currencies considered in the model.
1F INP COST OVERHEADS	Overhead Costs Input	<ul style="list-style-type: none"> ▶ Overheads considered in the model (Working capital and G&A) per country.
2A INP NW	Network Input	<ul style="list-style-type: none"> ▶ Network parameters needed for the dimensioning of the network (e.g. equipment capacity, standard constants).
2B INP GEO ACCESS	Access Sites Geographical Inputs	<ul style="list-style-type: none"> ▶ Number of nodes per geotype per country. ▶ Number of voice lines and broadband lines per geotype per country.
2C INP GEO EDGE	Edge Sites Geographical Inputs	<ul style="list-style-type: none"> ▶ Number of edge nodes per type per country. ▶ Number of voice lines and broadband lines per edge type per country. ▶ Number of cabinet nodes connected under each edge type per country.
2D INP GEO DIST	Distribution Sites Geographical Inputs	<ul style="list-style-type: none"> ▶ Number of distribution nodes per type per country. ▶ Number of voice lines per local type per country. ▶ Number of distribution nodes per type per country. ▶ Number of voice lines and broadband lines per distribution type per country. ▶ Number of edge nodes connected under each distribution type per country.

Name	Title	Input Information
2E INP GEO CORE	Core Sites Geographical Input	<ul style="list-style-type: none"> ▶ Number of distribution nodes connected under each core location per country. ▶ Number of voice and data lines connected under each core location per country. ▶ Distribution of core platforms and equipment per core location per country.
2F INP GEO LINKS	Transmission Links Geographical Input	<ul style="list-style-type: none"> ▶ Percentage of access nodes connected with fibre per geotype per country. ▶ Percentage of access nodes connected with microwave per geotype per country. ▶ Average distance between nodes connected in ring per geotype per country. ▶ Number of access nodes connected in ring per geotype per country. ▶ Average distance between nodes connected in tree per geotype per country. ▶ Daisy chain factor per geotype per country. ▶ Fibre link types for backbone transmission per country. ▶ Microwave link types for backbone transmission per country. ▶ Percentage of capacity for carried traffic per link type per country. ▶ Number of fibre and microwave links per type per country. ▶ Average length of fibre and microwave links per type per country.
2G INP BUSY HOUR	Busy Hour Input	<ul style="list-style-type: none"> ▶ The percentage of traffic in the busy hour per service category.
2H INP IDLE	Idle Traffic Input	<ul style="list-style-type: none"> ▶ 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	<ul style="list-style-type: none"> ▶ Useful lives for the annualisation of resources costs.
2J INP ERLANG	Input: Erlang Tables	<ul style="list-style-type: none"> ▶ Erlang tables to be used when dimensioning the equipment required to satisfy the demand.
2K INP HORIZON	Planning Horizon and Dimensioning Overcapacity Input	<ul style="list-style-type: none"> ▶ 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 NGN network.
- ▶ 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.EDGE.Traffic.Voice traffic
DRIV.EDGE.Traffic.Data traffic
DRIV.DISTRIBUTION.Traffic.Voice traffic
DRIV.DISTRIBUTION.Traffic.Data traffic
DRIV.CORE.Traffic.Voice traffic
DRIV.CORE.Traffic.Incoming Voice traffic
DRIV.CORE.Traffic.Outgoing to off-net Voice traffic

VARIABLE
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.COSTS SPECIFIC.Traffic.Emergency services and DQ specific costs
DRIV.COSTS SPECIFIC.Traffic.Wholesale billing
DRIV.COSTS SPECIFIC.Traffic.Terminating from international fee

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 cabinet 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 fixed	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.Off-net to mobile	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.Off-net to international	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.Calls to emergency services	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.Calls to national DQ service	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Outgoing.Retail.Calls to international DQ service	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Outgoing.Wholesale.Originating to international	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Incoming.Wholesale.Termination from national	DRIV.ACCESS.Traffic.Voice traffic
Voice Traffic.Incoming.Wholesale.Termination from international	DRIV.ACCESS.Traffic.Voice traffic

Exhibit 4.2: Excerpt from the Mapping of Services into Drivers (Sheet '3A MAP SERV2DRV')

[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 calculated representing the number of driver units generated by each demand service unit. In general, conversion factor calculation consists of four subfactors, in compliance with the following structure:

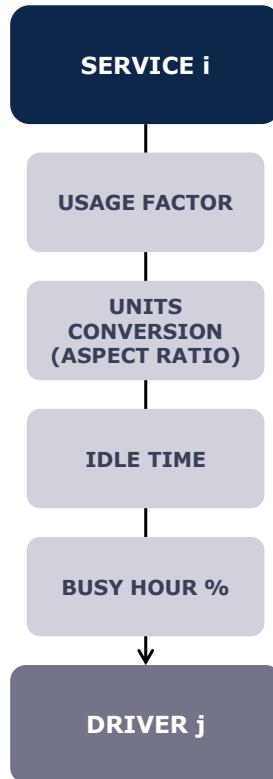


Exhibit 4.3: Conversion Process from Services to Drivers [Source: Axon Consulting]

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 using the following formula:

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

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 the units of services (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 in which 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 network's required resource consumption.

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 time of service.

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

$$\text{Idle time (connection)} = ART/ACD$$

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

2. Missed calls: non-attended calls, due to general recipient unavailability.

This factor even takes into consideration communications to notify the impossibility of completing the call.

This is the formula used:

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

Where PNRC represents the percentage of non-answered calls, PO the percentage of calls where the recipient is busy, ART the average ringing time and AT the duration time of the message indicating the failure 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 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 objectives of the Geographical Analysis are the following:

- ▶ Aggregate access node locations into geotypes.
- ▶ Aggregate distribution and core node locations into different categories.
- ▶ Characterise the backhaul links under each geotype in terms of distances between network elements and capacity for carried traffic.
- ▶ Characterise 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:

- ▶ Population centre characterisation
- ▶ Node characterisation
- ▶ Backhaul transmission characterisation
- ▶ Backbone transmission characterisation

5.2. Population centre characterisation

The main purpose of this analysis is to aggregate the areas with similar characteristics (e.g. population density) into geotypes.

The steps below have been followed in the geographical analysis:

1. Breaking down of the country into samples
2. Allocating population centres to samples

The steps are completed 5 times, one for each Member States.

5.2.1. Breaking down the country into samples

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

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



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

5.2.2. Allocating population centres to samples

Once the grid is defined, the population centres⁴ are allocated to the sample that contains them. The following exhibit illustrates the process of allocation:

⁴ The names, coordinates and populations of the population centres have been extracted from www.geonames.org

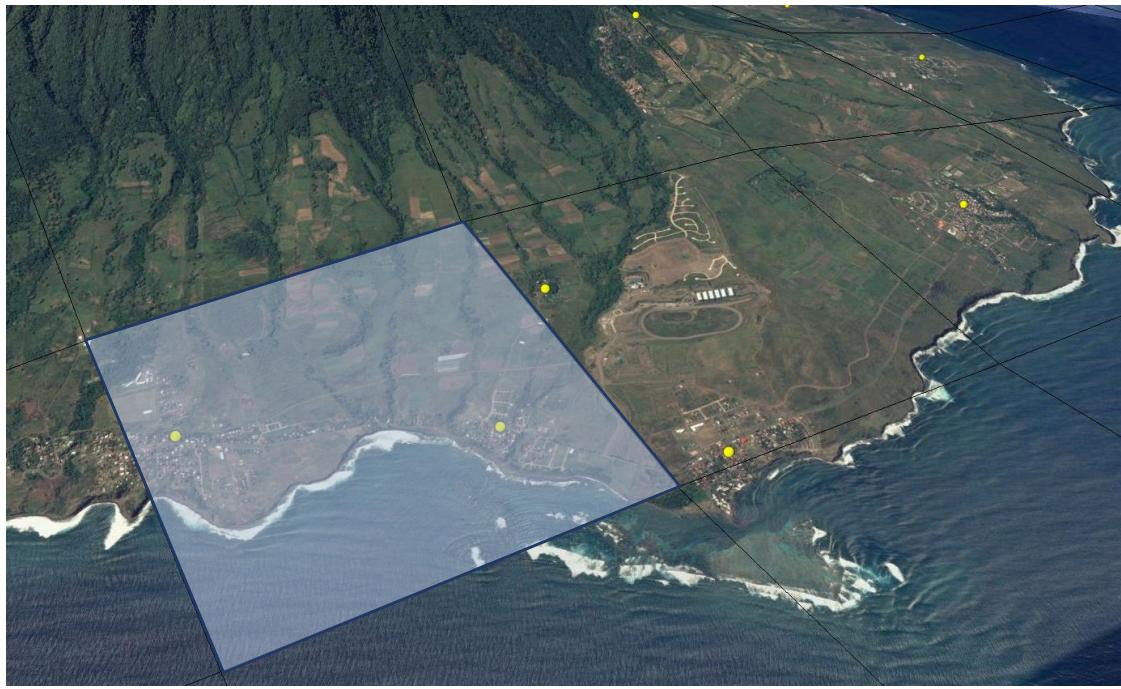


Exhibit 5.2: Illustrative example of aggregation of population centres (yellow circles) into samples (blue square) [Source: Axon Consulting]

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

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

5.3. Node characterisation

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

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

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

5.3.1. Access nodes

Based on the available information on the number and distribution of the access node locations, we have aggregated them into geotypes, which have been used to dimension the Operator's network of each of the Member States.

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

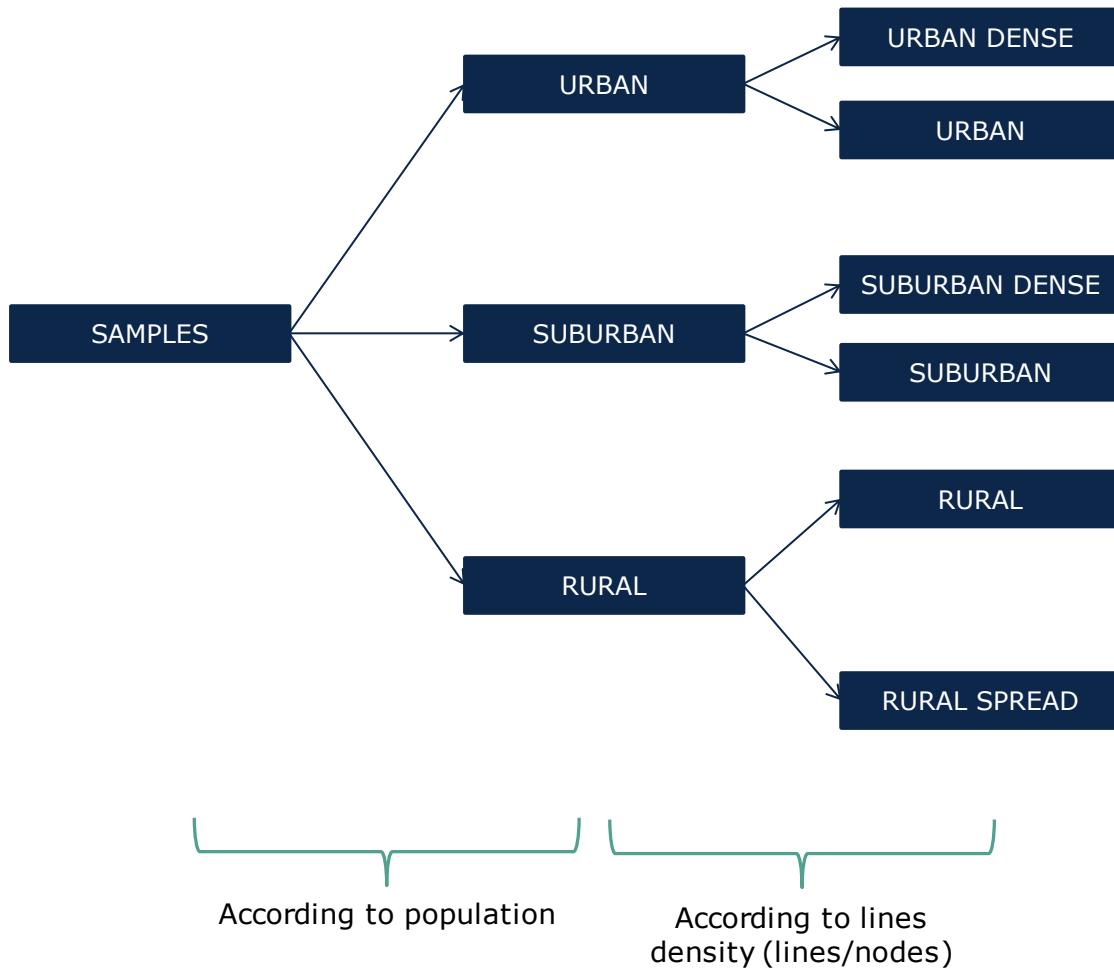


Exhibit 5.3: Classification of samples into geotypes. [Source: Axon Consulting]

Geotypes considered in the model are defined as follows:

GEOTYPE	Description
URBAN_DENSE	► Samples with a population higher than 5000 per sample and an access line density higher than 900 lines/nodes
URBAN	► Samples with a population higher than 5000 per sample and an access line density lower than 900 lines/nodes
SUBURBAN_DENSE	► Samples with a population between 2500 and 5000 per sample and an access line density higher than 900 lines/nodes
SUBURBAN	► Samples with a population between 2500 and 5000 per sample and an access line density lower than 900 lines/nodes
RURAL_DENSE	► Samples with a population lower than 2500 per sample and an access line density higher than 900 lines/nodes
RURAL	► Samples with a population lower than 2500 per sample and an access line density lower than 900 lines/nodes

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

Following this approach, the genotype 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 genotype definitions, the geographical characterisation of the access nodes locations is obtained.

5.3.2. Edge nodes

Based on the available information on the number of access nodes connected to each edge node location, we have aggregated them into four different and independent categories for each node type (Small, Medium, Large and Extra-large nodes), which have been used to dimension the Operator's network for each of the member States.

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

Edge Node Type	Description
Extra large	► Nodes under which more than 6000 lines are connected
Large	► Nodes under which between 4000 and 6000 lines are connected
Medium	► Nodes under which between 2000 and 4000 lines are connected
Small	► Nodes under which fewer than 2000 lines are connected

Table 5.2: Characterisation of Edge node types [Source: Axon Consulting]

When for a certain node there is no defined 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.

5.3.3. Distribution nodes

Based on the available information on the number of edge nodes connected to each distribution node, we have aggregated them into four different categories (Small, Medium, Large and 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 15000 lines are connected
Large	► Nodes under which between 10000 and 15000 lines are connected
Medium	► Nodes under which between 5000 and 10000 lines are connected
Small	► Nodes under which fewer than 5000 lines are connected

Table 5.3: Characterisation of Distribution node types [Source: Axon Consulting]

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

5.3.4. Core nodes

There is not necessarily a categorization for the IP core node locations. Based on the available information there are 1 or 2 NGN core locations depending on the Member State.

5.3.5. Core platform distribution

In addition 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 must be defined. This definition has been used to dimension the Operator's core network.

5.4. 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 subsections.

5.4.1. Transmission technology and topology

Based on the available data about access node locations, the specific transmission technology used in each location, the geographical distribution of those access nodes and their categorisation into geotypes, we have calculated 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. edge sites). 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. edge nodes) in such a way that 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 typically handle 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 differences between the topologies:

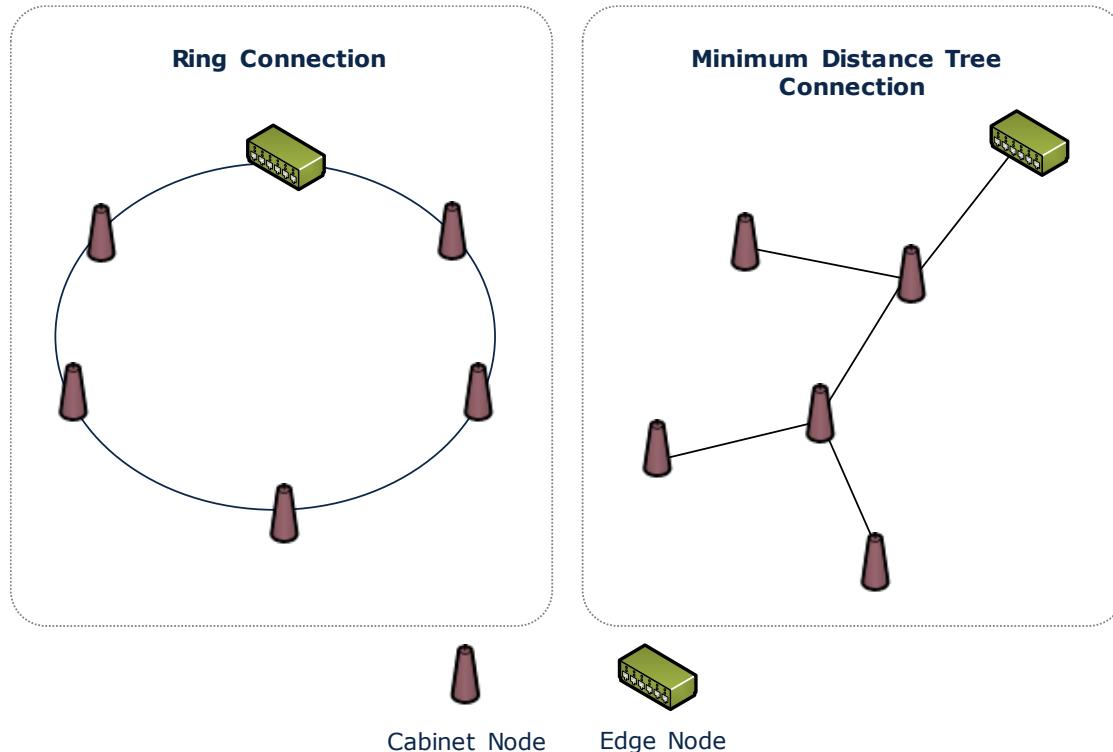


Exhibit 5.4: Topologies used for dimensioning the backhaul network [Source: Axon Consulting]

5.4.2. Average link distance

As indicated in the previous section, one of two topologies is used to dimension the backhaul network, depending on the geotype (ring or minimum distance tree). The following sections describe the methodologies used to calculate the average distance per link and other relevant factors.

Calculation of average link distance for ring topology

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

1. The starting node "a₁" 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."

1. The next access node "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 other access node that have not been connected, the process from step 2 is repeated
3. The last point connected is also connected to a_1 to close the ring topology

After obtaining the initial route, the Cabinets 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-Kernighan). Several iterations of this swapping process are calculated and the one that minimises the total distance is selected.

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 node not yet connected to the node 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 from step 2 is repeated.

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

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 node is not handled only by the ports of the node because the traffic will also be transmitted through other node ports.

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

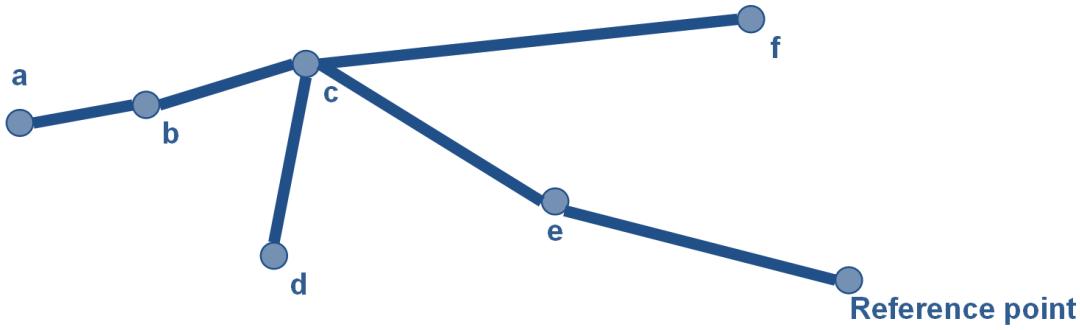


Exhibit 5.5: Example of the Daisy Chain effect [Source: Axon Consulting]

As shown in the previous exhibit, the traffic generated by node "a" must be transmitted four times (by nodes "a", "b", "c" and "e") to reach the reference point. The reference point is the point the traffic is aimed at. In the analysis, the reference point is the starting node " 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.

5.5. Backbone transmission characterisation

Unlike in the case of the backhaul network, the backbone is heterogeneous and, therefore, the routes are difficult to estimate based on general theoretical methodologies. Therefore, the existing networks in the Member States 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.

5.5.1. Backbone fibre network

Based on the available information from the fibre transmission network the reference backbone has been defined.

All the link connections have been classified into types according to topology, the nature of the link and the geographic locations. Additionally, according to the information about the 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.

5.5.2. Backbone microwave network

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

All link connections have been classified into types according to topology, the nature of the link, and the geographic locations. Additionally, according to the information about the 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 summarises all the factors by link type, which have been used to dimension the Operator's microwave transmission network.

6. Dimensioning Module

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

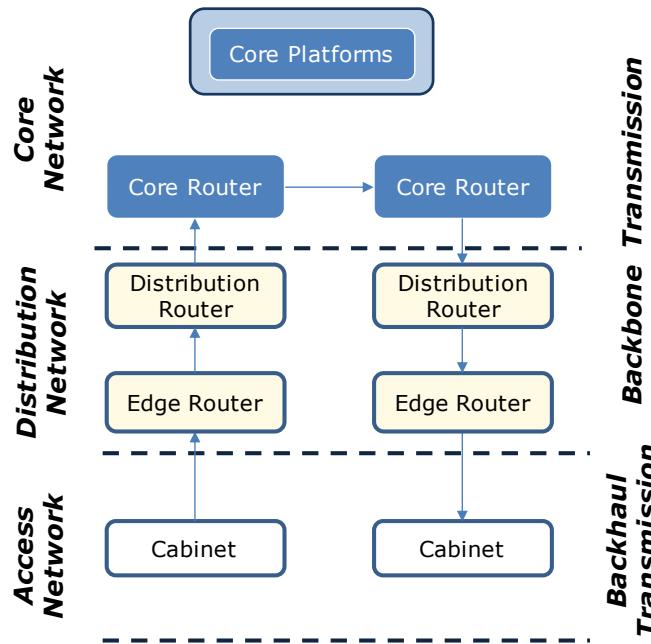


Exhibit 6.1: Schematic diagram of the network structure modelled for legacy and NGN technology [Source: Axon Consulting]

The following sections describe each network block:

- ▶ Access Network Dimensioning
- ▶ Distribution Network Dimensioning
- ▶ Core Network Dimensioning
- ▶ Backhaul Transmission Network Dimensioning
- ▶ Backbone Transmission Network Dimensioning
- ▶ Direct Costs Dimensioning

6.1. Access Network Dimensioning

The access network dimensioning algorithms are implemented in the worksheet '6A CALC DIM ACCESS' of the Model.

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

- ▶ **Cabinet site:** represents the space used for the cabinet node equipment. It includes the space itself, air conditioning, power equipment (except the generator) and the maintenance of the previous elements.
- ▶ **Diesel generator:** used to provide power to the node or for backup purposes.
- ▶ **Fuel**
- ▶ **Electricity**

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

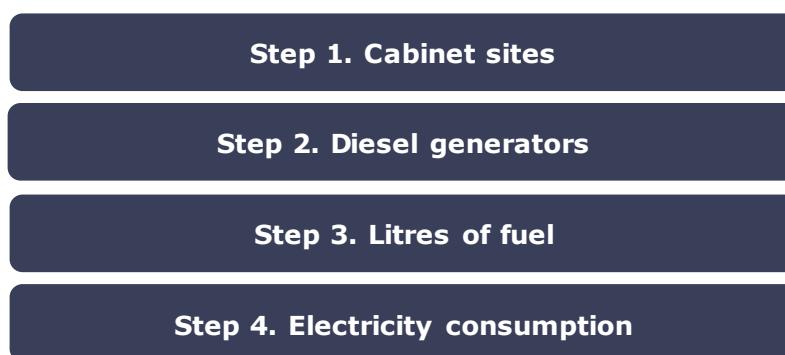


Exhibit 6.2: Schematic Steps for the dimensioning of the Access Sites and Energy [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Cabinet sites

The calculation of the number of cabinet nodes is described in section 5.3.1. One site per node is costed.

Step 2. Diesel generators

The number of diesel generators required in the cabinet nodes is calculated for each geotype based on the following methodology:

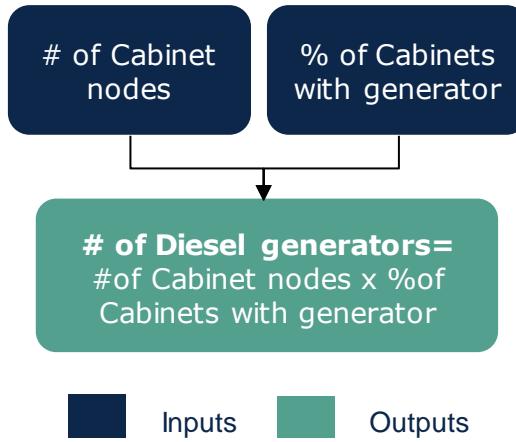


Exhibit 6.3: Algorithm for calculating the number of diesel generators in cabinet nodes
[Source: Axon Consulting]

Step 3. Litres of fuel

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

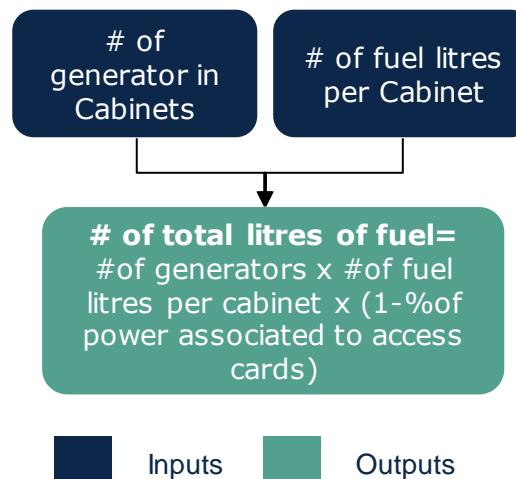


Exhibit 6.4: Algorithm for calculating the litres of fuel [Source: Axon Consulting]

Step 4. Electricity consumption

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

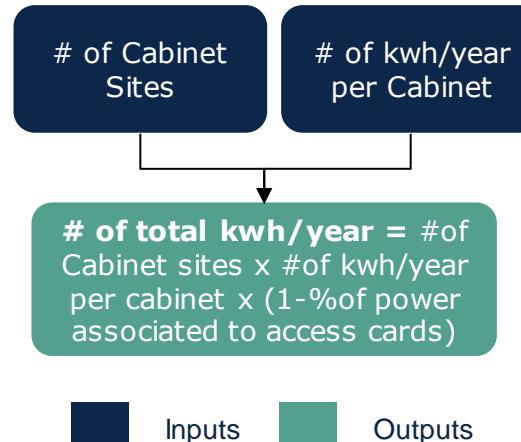


Exhibit 6.5: Algorithm for calculating the electricity consumption of the access nodes
[Source: Axon Consulting]

6.2. Distribution Network Dimensioning

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

- ▶ Edge node dimensioning
 - ▶ Distribution node 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. Edge node dimensioning

The edge nodes handle the traffic coming from the access nodes. Please note that edge nodes 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:

Step 1. Number of edge chassis

Step 2. Number of edge Ethernet ports

Exhibit 6.6: 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 5.3):

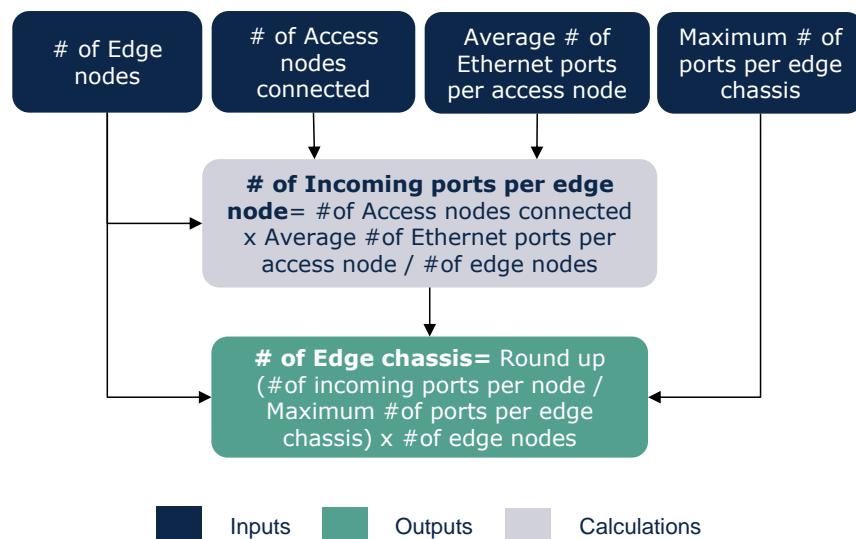


Exhibit 6.7: Algorithm for calculating the number of edge chassis [Source: Axon Consulting]

As shown above, at least one router chassis is considered in each edge node. The need for 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 for each node type (see section 5.3):

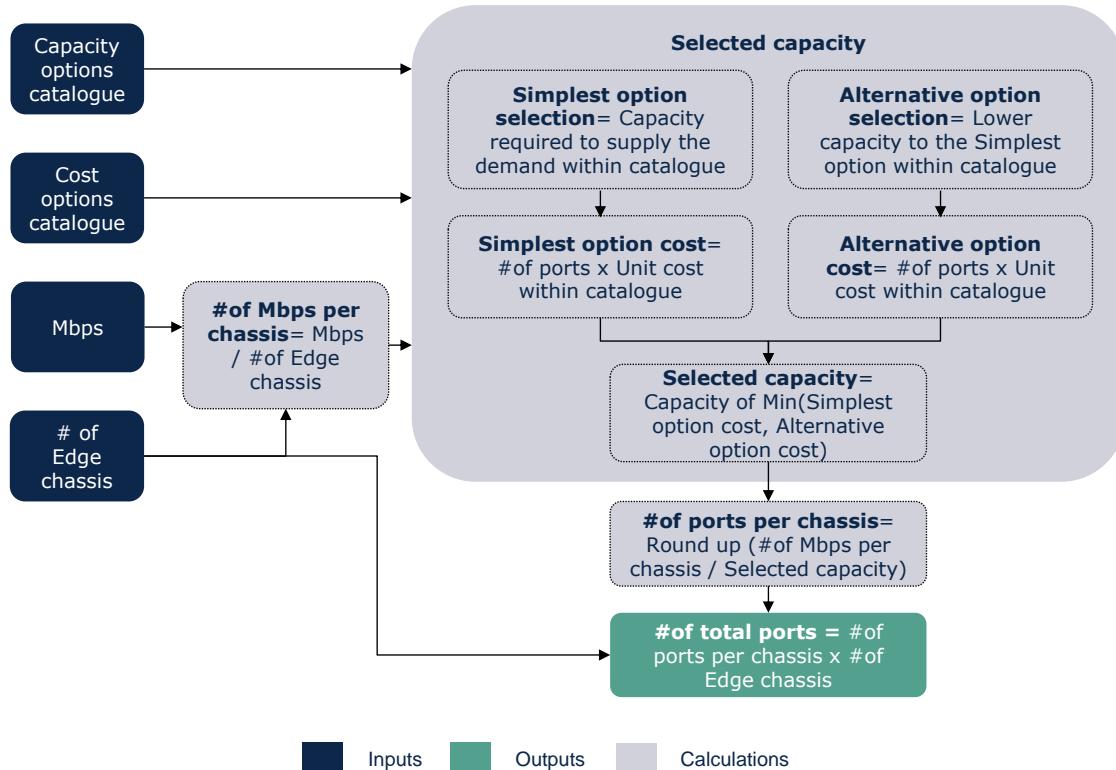


Exhibit 6.8: Algorithm for calculating the number of edge Ethernet ports [Source: Axon Consulting]

6.2.2. Distribution node dimensioning

The edge nodes handle the traffic coming from the edge nodes. Please note that distribution nodes 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 6.9: 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 for each node type (see section 5.3):

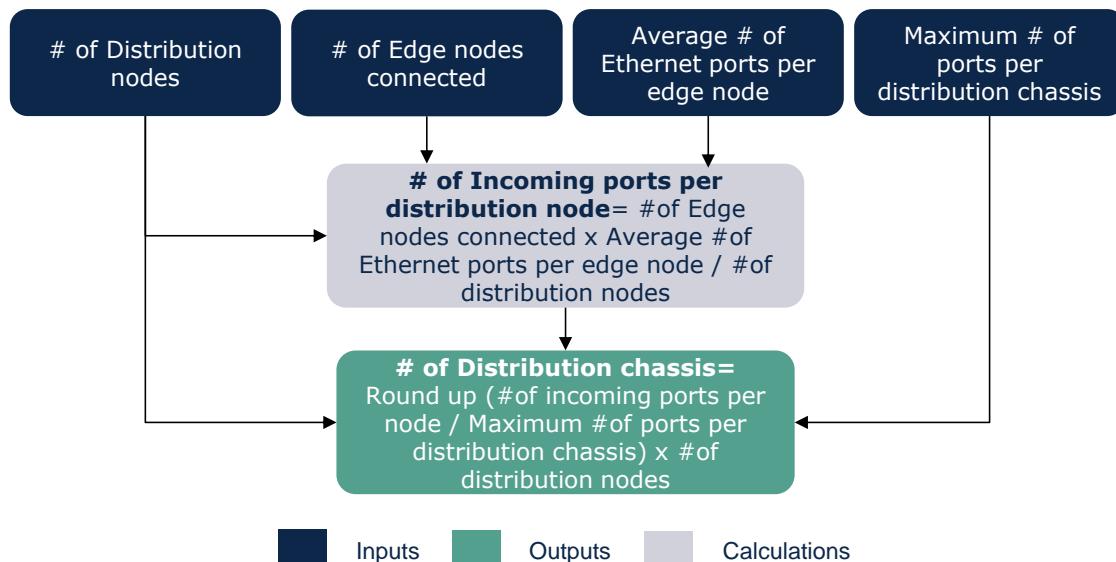


Exhibit 6.10: Algorithm for calculating the number of distribution chassis [Source: Axon Consulting]

As shown above, at least one chassis is considered in each distribution node. The need for 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 for each node type (see section 5.3):

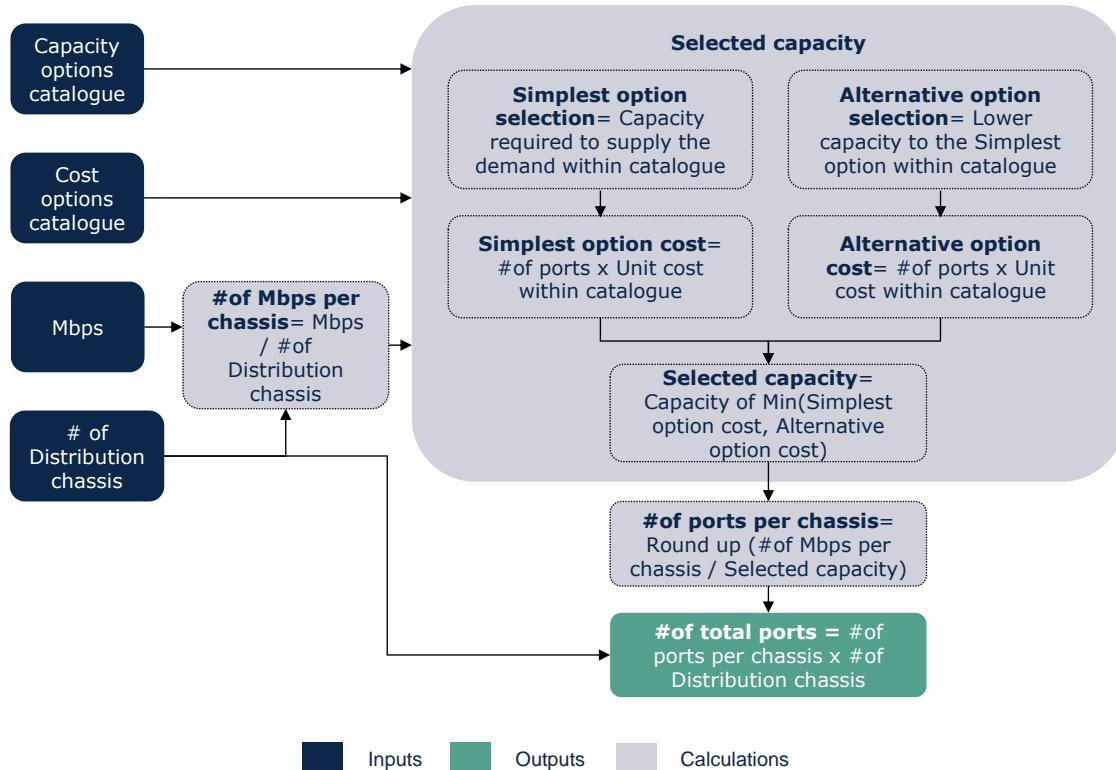


Exhibit 6.11: Algorithm for calculating the number of distribution Ethernet ports [Source: Axon Consulting]

6.2.3. Sites and energy

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

- ▶ **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 cabinet node is collocated with a distribution or edge node, the space (and other resources) required for the cabinet is considered in section 6.1.

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



Exhibit 6.12: 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. Edge and distribution sites

The calculation of the number of edge and distribution nodes is in sections 5.3.1, 5.3.2 and 5.3.3 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:

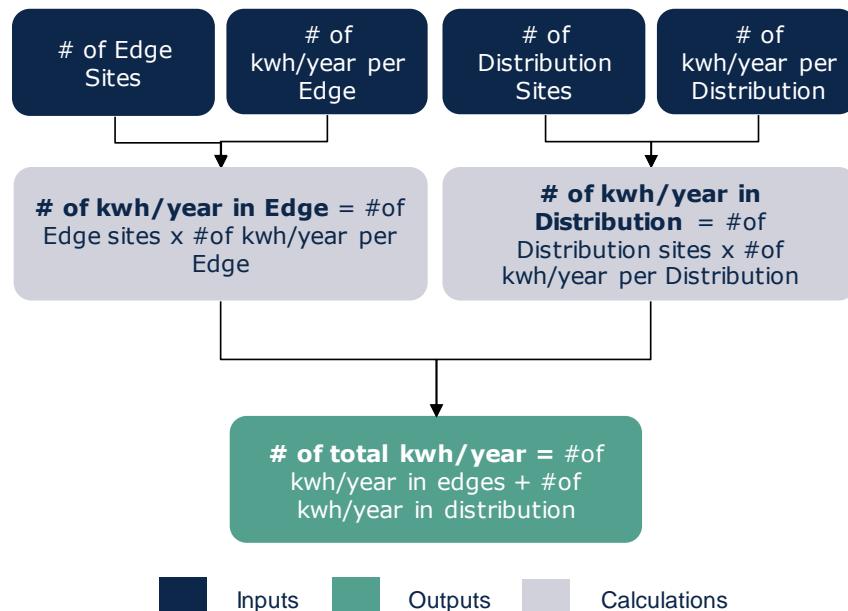


Exhibit 6.13: Algorithm for calculating the electricity consumption of the distribution nodes
 [Source: Axon Consulting]

6.3. Core Network Dimensioning

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

- ▶ 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. 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:

Step 1. Number of NGN core chassis

Step 2. Number of core Ethernet ports

Exhibit 6.14: 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 for each node type (see section 5.3):

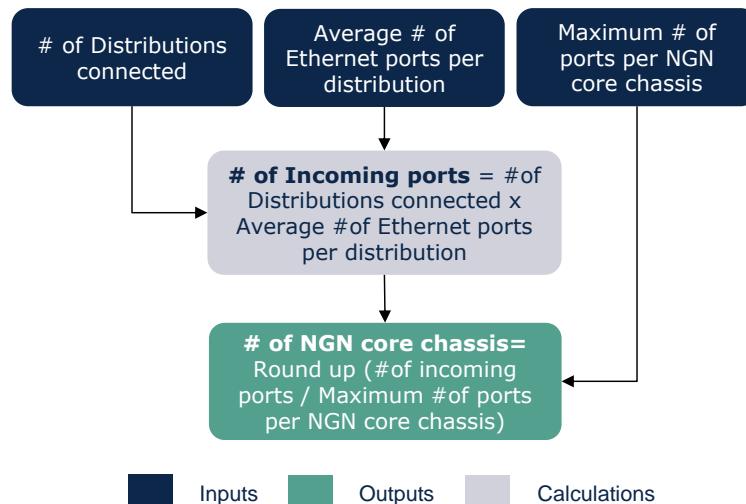


Exhibit 6.15: Algorithm for calculating the number of NGN core chassis [Source: Axon Consulting]

As shown above, at least one router chassis is considered in each node. The need for 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 for each node type (see section 5.3):

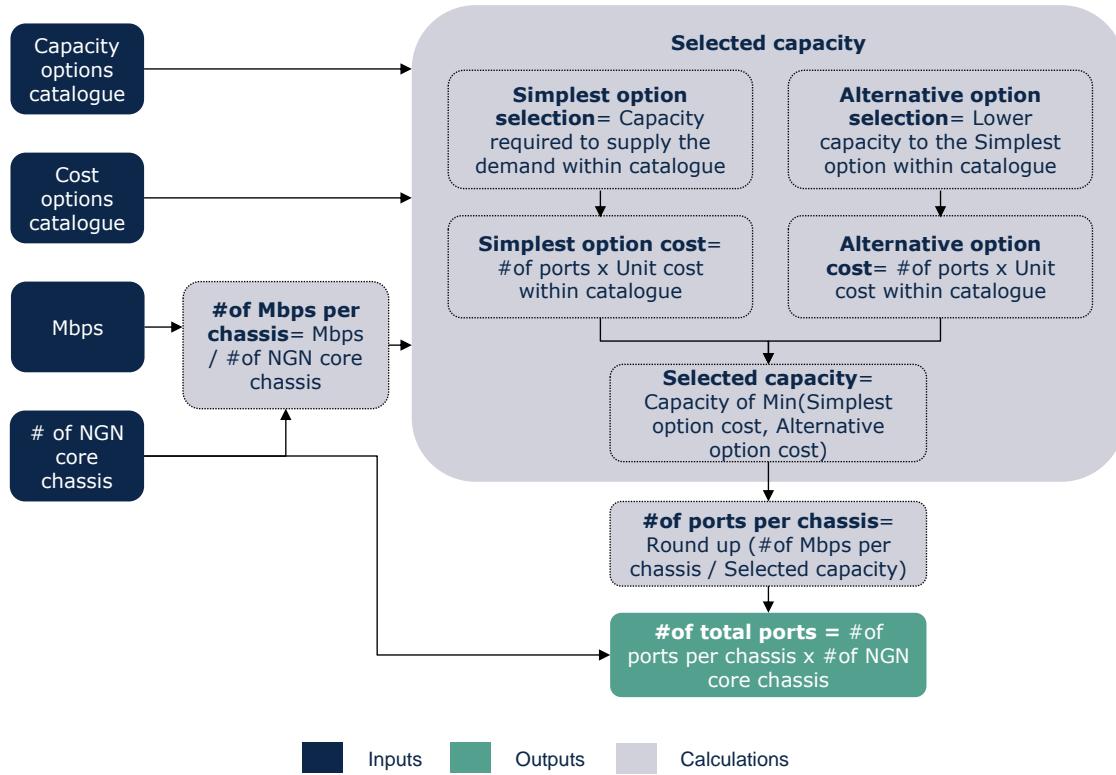


Exhibit 6.16: Algorithm for calculating the number of NGN core Ethernet ports [Source: Axon Consulting]

6.3.2. 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 subscriber mailboxes.
- ▶ **CSCF (Call Session Control Function):** the CSCF is generally composed 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 (signalisation 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:



Exhibit 6.17: 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.

Step 2. Application layer platforms

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

AS Dimensioning

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

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

$$AS\ HW\ and\ SW = Total\ BH\ Call\ Attempts\ (BHCA)$$

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 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 licence is measured in billing events per busy hour:

$$BS\ HW\ and\ SW = Billing\ events\ in\ the\ busy\ hour\ (#BE)$$

VMS Dimensioning

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

$$VMS\ HW\ and\ SW = Voicemail\ traffic\ in\ the\ busy\ hour\ (#Erlangs)$$

Step 3. Control Layer Platforms

The algorithm designed for each element is described in the following subsections. Please note that hardware and software are calculated separately in order 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 in order 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 licenses are measured in the number of busy-hour call attempts:

$$\text{CSCF HW and SW} = \text{Total BH Call Attempts (BHCA)}$$

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

$$\text{AGCF HW and SW} = \text{Outgoing BHCA}$$

Softswitch

The softswitch manages VoIP calls signalling. The Softswitch HW and SW license is measured in busy-hour call attempts:

$$\text{Softswitch HW and SW} = \text{Total BH Call Attempts (BHCA)}$$

MGCF Dimensioning

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

$$\text{MGCF HW and SW} = (\text{Outgoing BHCA to TDM} + \text{Incoming BHCA from TDM})$$

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 HW and SW license is assumed to be measured in total Erlangs in the busy hour:

$$\text{NMS HW and SW} = \text{Voice traffic in the busy hour (#Erlangs)}$$

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 license is measured in busy-hour call attempts:

$$HSS\ HW\ and\ SW = Outgoing\ BH\ Call\ Attempts\ (BHCA)$$

Step 4. User Layer Equipment

The algorithm designed for each element is described in the following subsections. Please note that hardware and software are 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:

Step 1. Voice traffic to be converted

Step 2. Legacy and Ethernet ports

Step 3. Converter chassis

Exhibit 6.18: 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. It is assumed that the interconnection traffic is delivered based on TDM technology (to ensure compatibility with the non-price terms of current reference offers). Therefore, the following voice traffic categories have been calculated based on the demand:

- ▶ Off-net calls
- ▶ Incoming calls

Legacy and Ethernet ports

The second step consists in the calculation of the number of legacy and Ethernet ports required to handle the traffic to be converted. It is outlined below:

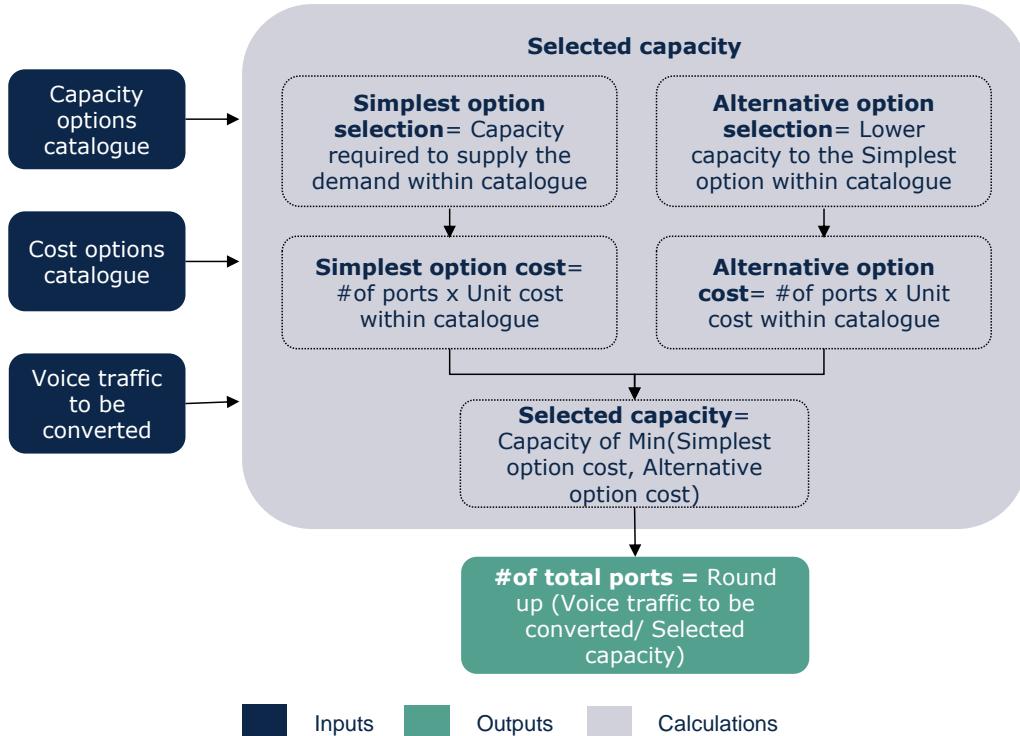


Exhibit 6.19: Algorithm for calculating the number of converter ports [Source: Axon Consulting]

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 per chassis. The algorithm is shown in the exhibit below:

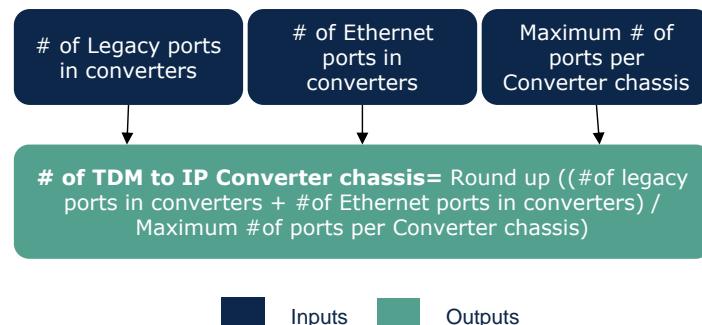


Exhibit 6.20: Algorithm for calculating the number of converter chassis [Source: Axon Consulting]

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 6.21: Schematic steps for the dimensioning of international exchanges [Source: Axon Consulting]

The following subsections provide further detail about these steps.

NGN ports

The first step for dimensioning international exchanges consists in the calculation of the number of ports required to handle the international voice traffic. The algorithm to calculate the number of international NGN ports is outlined below:

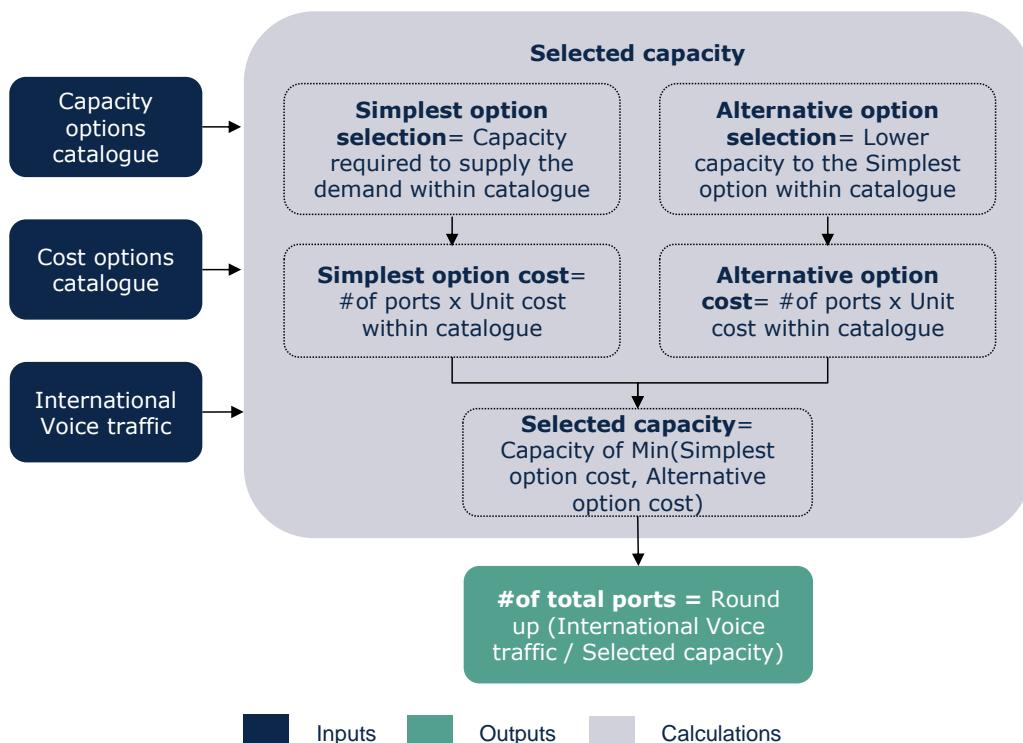


Exhibit 6.22: Algorithm for calculating the number of converter ports [Source: Axon Consulting]

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:

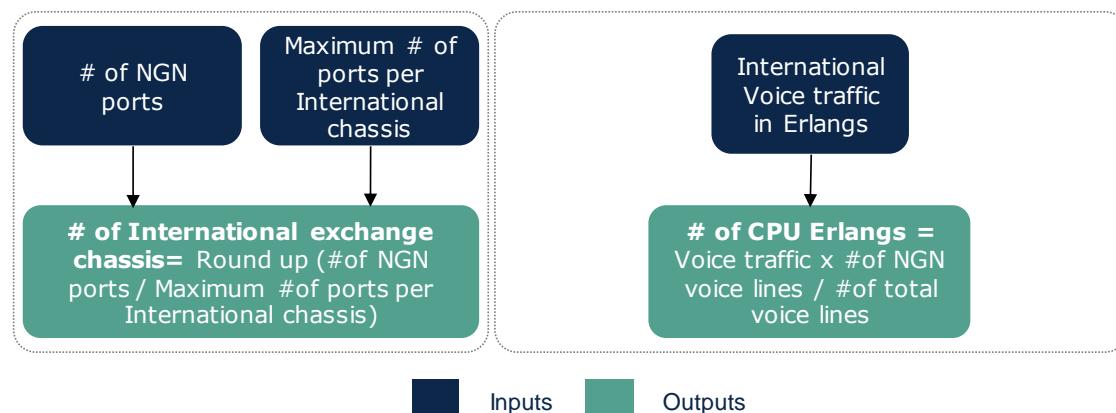


Exhibit 6.23: Algorithm for calculating the number of international exchange chassis and CPU Erlangs [Source: Axon Consulting]

6.3.3. Sites and energy

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

- ▶ **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 cabinet node is collocated with a core, the space (and other resources) required for the cabinet are considered in section 6.1.

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

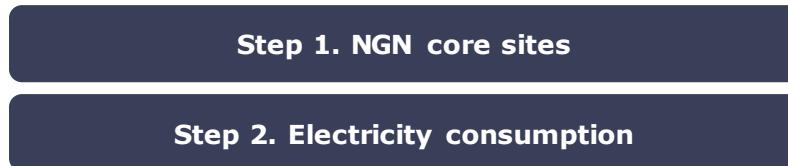


Exhibit 6.24: Schematic steps for the dimensioning of the core sites and energy [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Core sites

The calculation of the number of core nodes is based on the geographical analysis (section 5.3.1). One site per node is costed.

Step 2. Electricity consumption

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

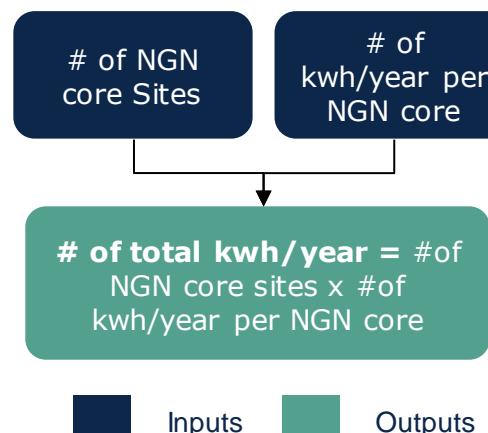


Exhibit 6.25: Algorithm for calculating the electricity consumption of the core nodes [Source: Axon Consulting]

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 cabinet nodes
- ▶ Microwave transmission network of cabinet 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 for each specific step.

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

To dimension the backhaul transmission network properly, it is necessary to identify and exclude those access nodes (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.

The number of access nodes connected in the backbone network is calculated after the backbone transmission characterisation is completed (see section 5.5). This number includes all access nodes that are collocated with upper-level nodes or connected through backbone links.

In the model, it is assumed that the number of access nodes connected in the backbone network does not change over time.

The algorithm takes the form of the following step.

Step 1. Number of cabinet nodes

The number of cabinets connected in the backhaul network is calculated. The following exhibit shows the algorithm used to calculate the number of nodes:

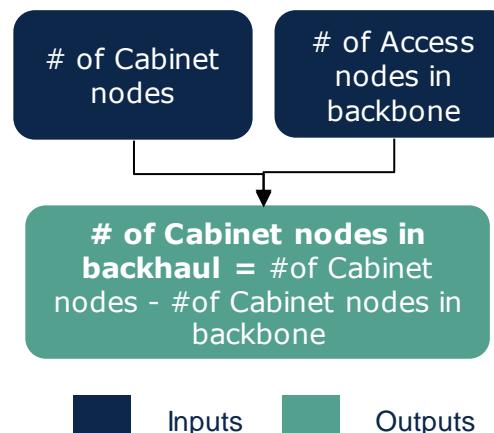


Exhibit 6.26: Algorithm for calculating the cabinets connected in backhaul network [Source: Axon Consulting]

6.4.2. Fibre transmission network of cabinet nodes

As outlined in the section 5.4, two connection topologies 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 geotype (see section 5.3):

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

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

Step 1. Number of fibre kilometres and transmission chassis

Step 2. Number of Ethernet transmission ports

Exhibit 6.27: Schematic steps for dimensioning the fibre transmission network of cabinet nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of Ethernet transmission ports

The algorithm for dimensioning the backhaul Ethernet ports in cabinets, i.e. the ports required for transmission data, is as follows:

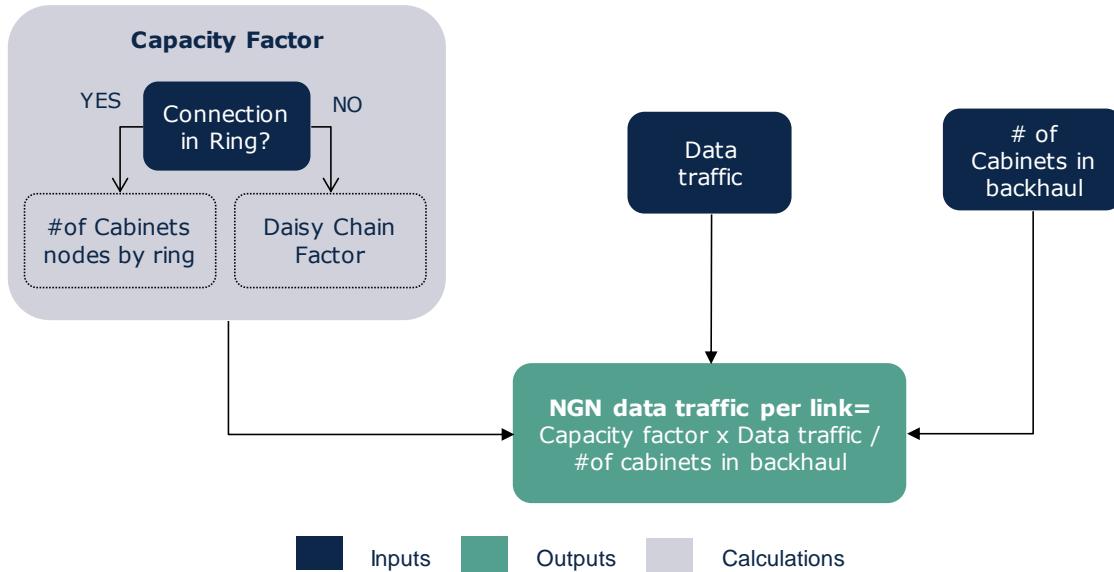
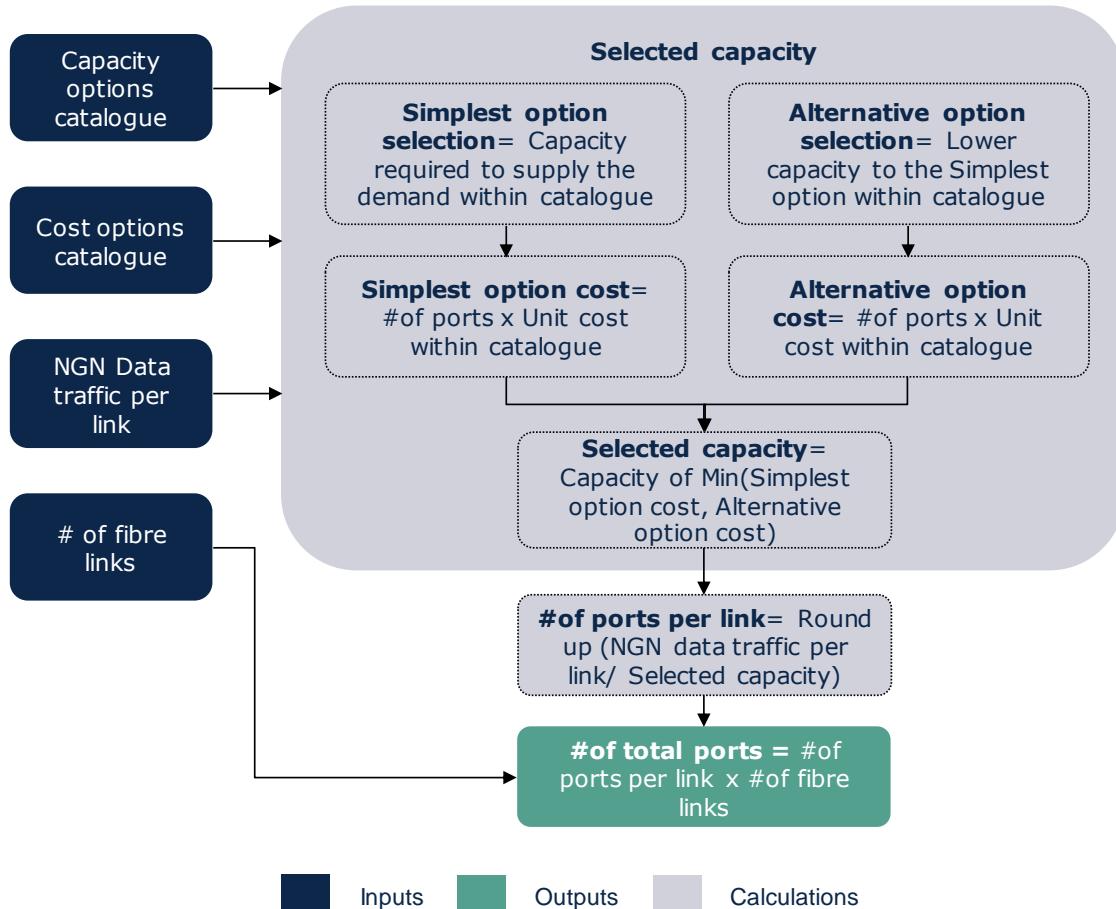


Exhibit 6.28: Algorithm for calculating the data traffic per backhaul fibre link [Source: Axon Consulting]

The exhibit above shows that the capacity factor depends on the topology:

- ▶ **Ring topology:** the capacity factor is equal to the number of cabinet nodes connected in a ring; i.e., all 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.

The number of Ethernet ports is calculated according to the following algorithm for each geotype (see section 5.3):

**Exhibit 6.29: Algorithm for calculating the number of backhaul Ethernet ports in cabinets**

[Source: Axon Consulting]

6.4.3. Microwave transmission network of cabinet 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 connections are point to point; i.e. only minimum distance tree topology is considered.
- ▶ The technology for the transmission of voice and data traffic is the same; i.e. there is only one type of transmission technology modelled⁵.

⁵ It is assumed that the data traffic will be aggregated through the same link instead of installing two microwave links.

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

Step 1. Number of towers
Step 2. Number of transmission hops

Exhibit 6.30: Schematic Steps for dimensioning the MW transmission network of cabinet nodes [Source: Axon Consulting]

The following subsections provide further detail about these steps.

Step 1. Number of towers

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

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

The number of towers is calculated according to the algorithm outlined below for each geotype (see section 5.3):

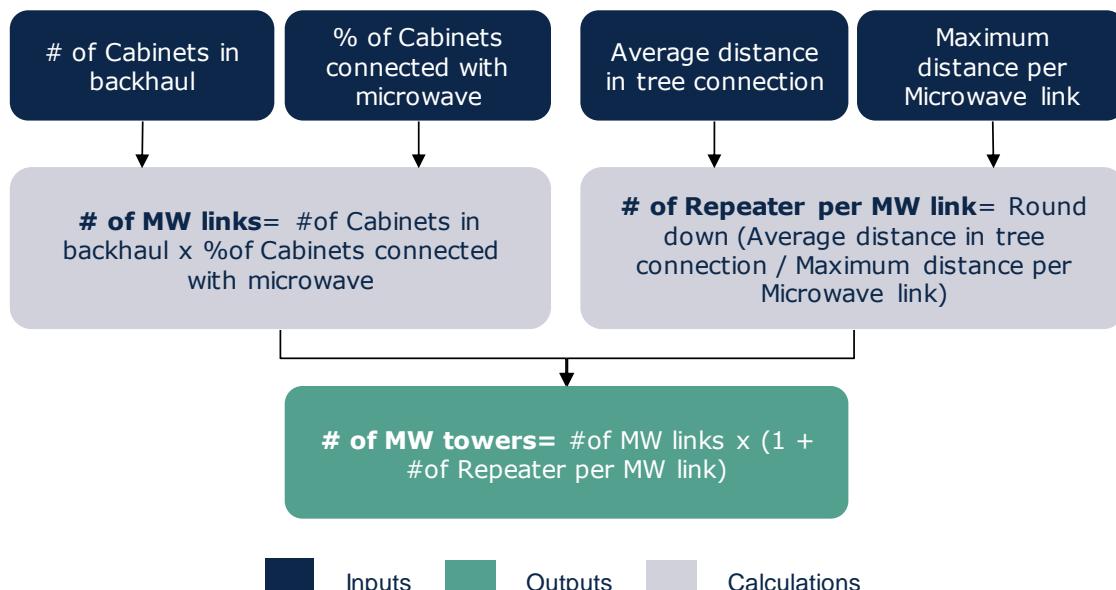


Exhibit 6.31: Algorithm for calculating the number of towers in cabinets [Source: Axon Consulting]

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 at both ends of the hop (e.g. transmission unit, cables, antennas).

To obtain the number of hops it is necessary to calculate the traffic that should be transported by each one of the links. The traffic per link is calculated according to the algorithm outlined below for each geotype (see section 5.3):

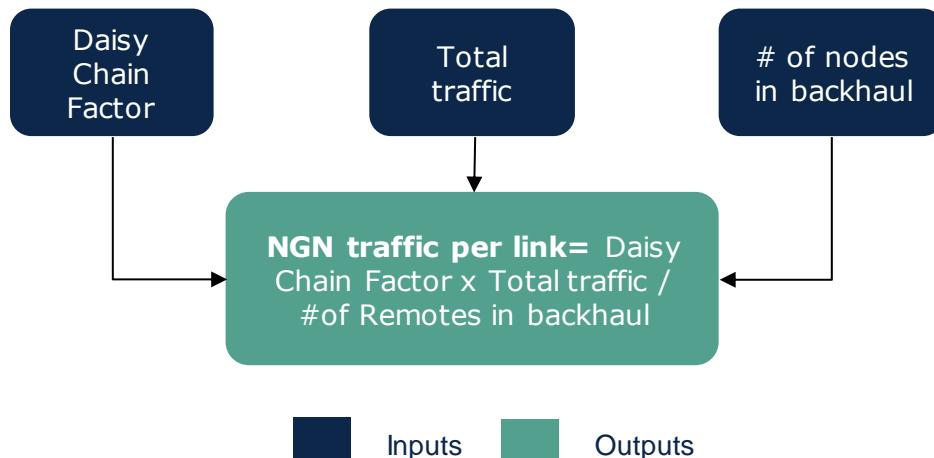


Exhibit 6.32: Algorithm for calculating the NGN traffic per backhaul MW link [Source: Axon Consulting]

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

- ▶ For calculating the voice traffic.
- ▶ For calculating the data traffic.

Once the total NGN traffic per link is obtained (voice plus data traffic), the number of microwave hops is calculated according to the following algorithm for each geotype (see section 5.3):

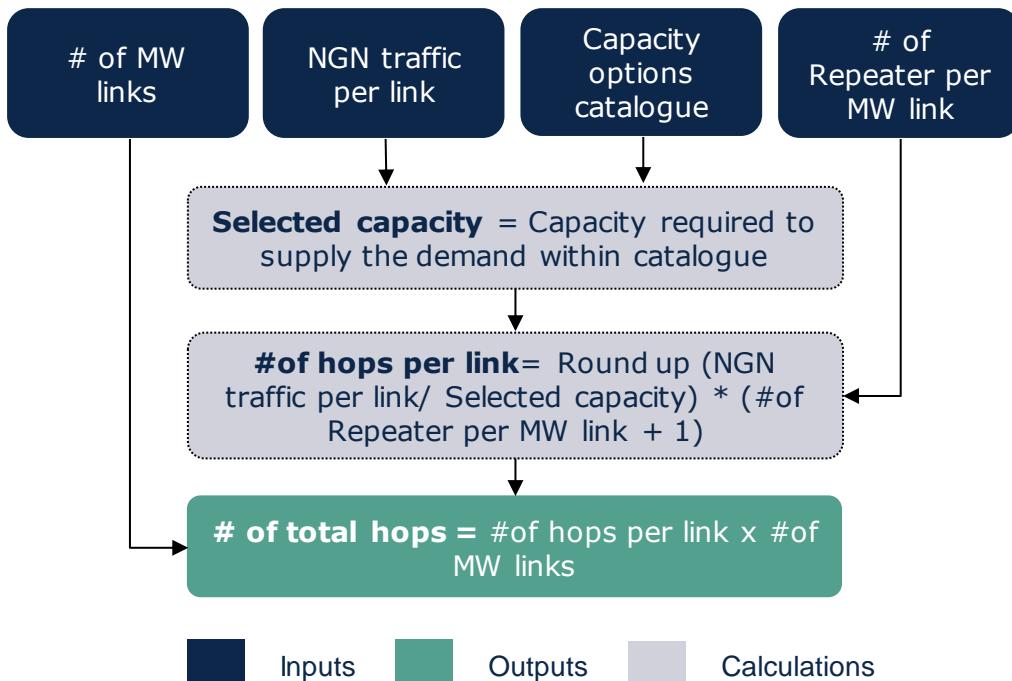


Exhibit 6.33: Algorithm for calculating the number of backhaul MW hops in cabinets [Source: Axon Consulting]

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 5.5.1):

- ▶ 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:

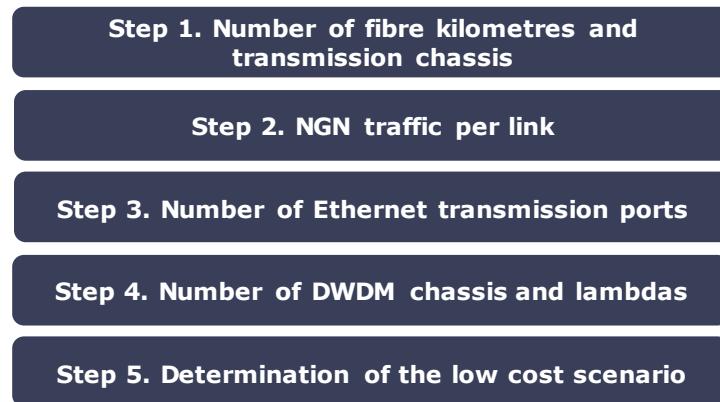


Exhibit 6.34: Schematic Steps for dimensioning the backbone transmission network by fibre
 [Source: Axon Consulting]

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 transmission technology (legacy transmission chassis and Ethernet transmission chassis). These elements are calculated as follows for each link type:

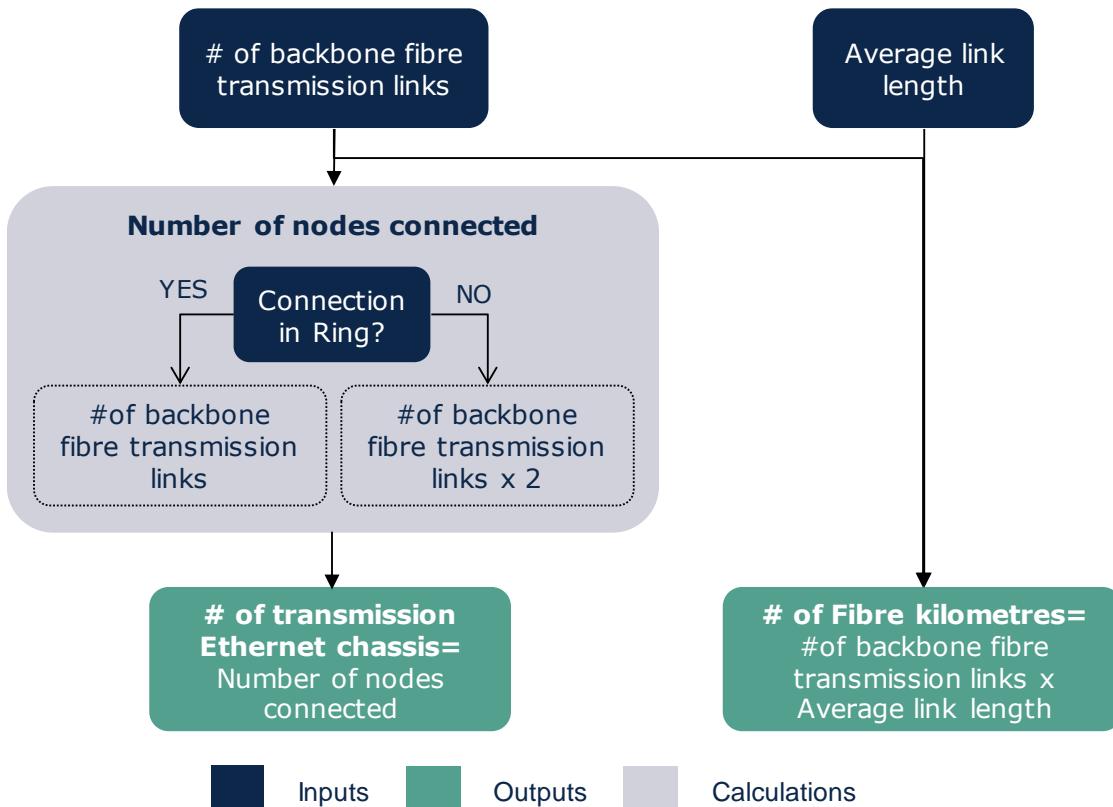


Exhibit 6.35: Algorithm for calculating the fibre kilometres and transmission chassis in backbone network [Source: Axon Consulting]

Step 2. NGN traffic per link

The NGN traffic per link is calculated according to the algorithm outlined below for each one of the link types:

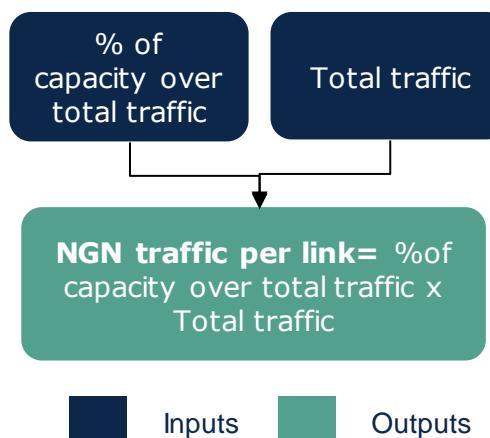


Exhibit 6.36: Algorithm for calculating the NGN traffic per backbone fibre link [Source: Axon Consulting]

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

Step 3. Number of Ethernet transmission ports

The number of Ethernet ports is calculated as follows:

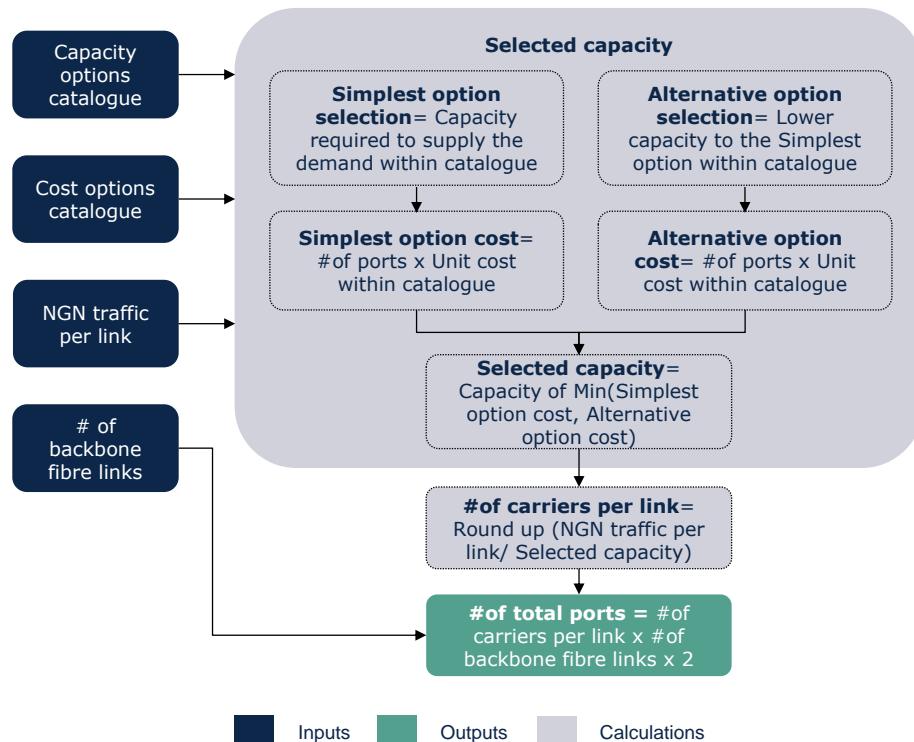


Exhibit 6.37: Algorithm for calculating the number of backbone NGN ports [Source: Axon Consulting]

The number of Ethernet ports is calculated according to the following algorithm for each geotype (see section 5.3):

Step 4. Number of DWDM chassis and lambdas

DWDM technology is considered when several transmission links must be aggregated in the same cable. The maximum number of carriers per link is defined as a parameter. In the case that the number of carriers required is greater than the maximum, some 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:

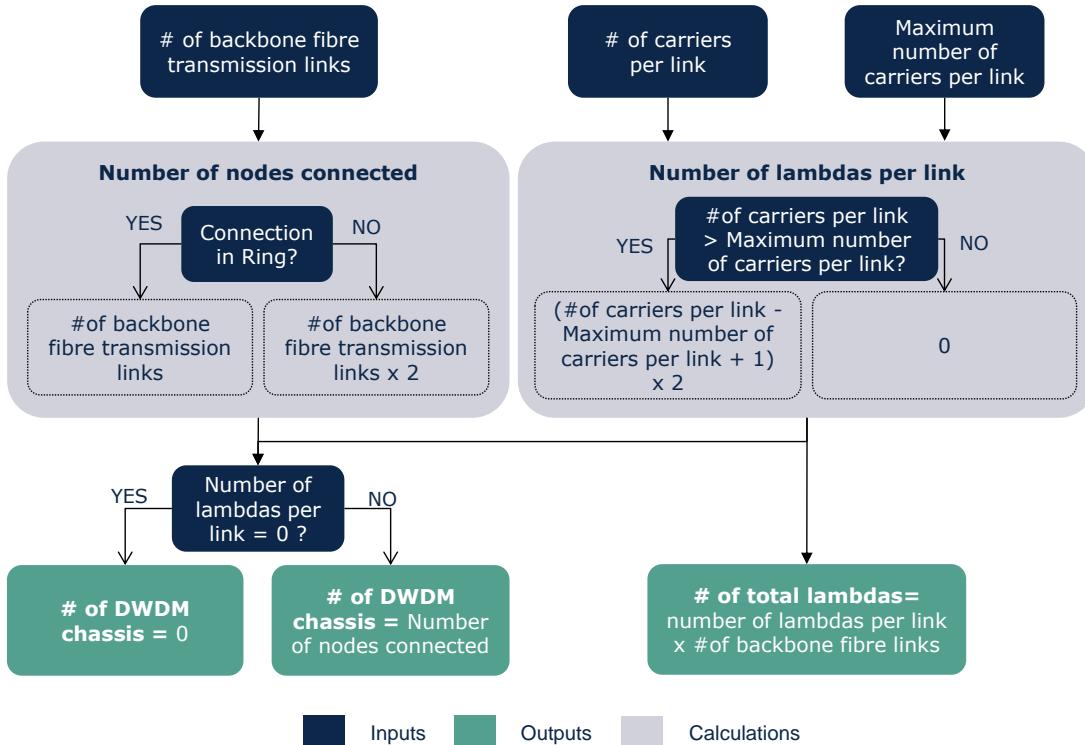


Exhibit 6.38: Algorithm for calculating the number of DWDM chassis and lambdas [Source: Axon Consulting]

Step 5. Determination of the low cost scenario

Despite the fact that the calculation of NGN ports is based on the principle of minimum cost, it is necessary to evaluate different scenarios including the DWDM equipment with the ports. Therefore, a number of scenarios are calculated in order 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 5.5.2):

- ▶ 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 6.39: 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 repeater locations. The number of towers is calculated according to the following algorithm for each link type:

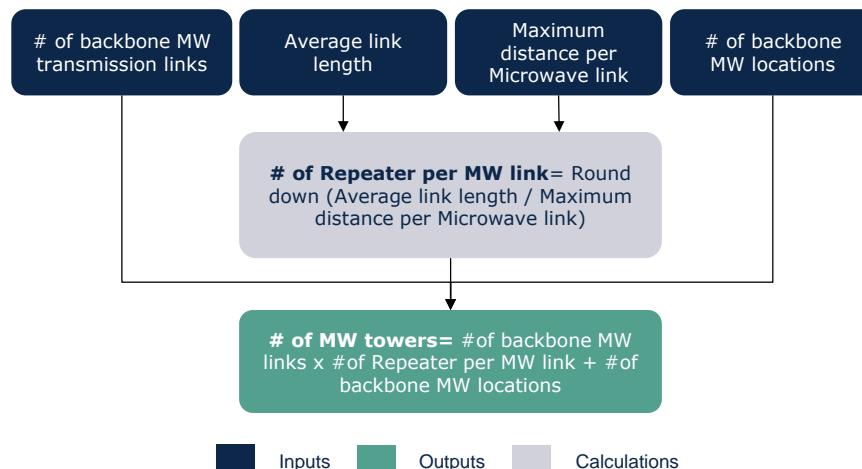


Exhibit 6.40: Algorithm for calculating the number of towers in the backbone [Source: Axon Consulting]

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 at 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:

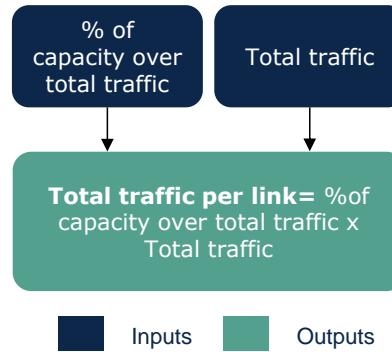


Exhibit 6.41: Algorithm for calculating the total traffic per backbone MW link [Source: Axon Consulting]

The algorithm in the exhibit above must be applied twice: once to calculate the voice traffic and once to calculate 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 of the link types:

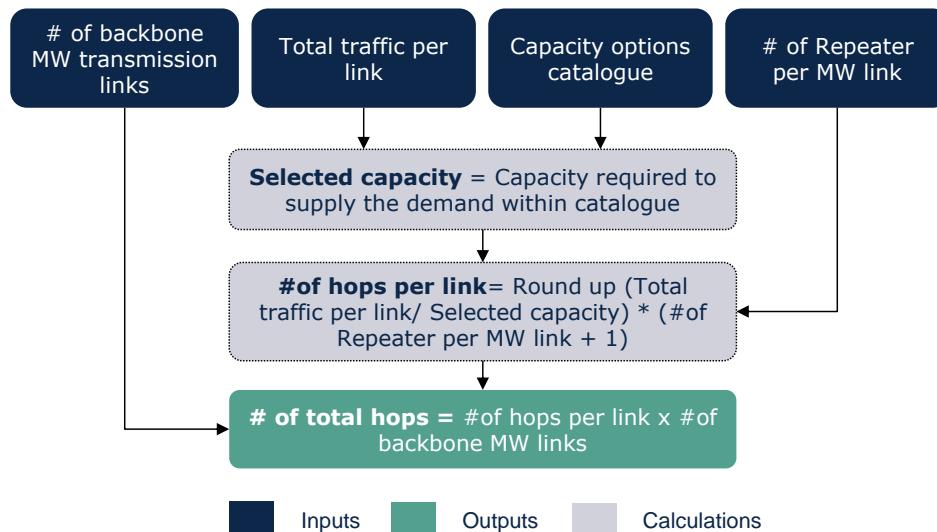


Exhibit 6.42: Algorithm for calculating the number of backbone MW hops [Source: Axon Consulting]

6.6. Direct Costs Dimensioning

In addition 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 for each step.

6.6.1. Interconnection costs

The interconnection costs are defined as a fixed tariff per minute. Dimensioning these resources is simple.

These resources are measured in minutes, and therefore are equal to the retail traffic for each one of the following concepts:

- ▶ Fixed termination.
- ▶ Mobile termination.
- ▶ International termination.

6.6.2. Specific costs

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

Terminating from international fee

This resource is measured in minutes, and is therefore equal to the traffic for the following concept:

- ▶ Wholesale termination traffic from international direct to fixed.

DQ and Emergency services

This resource is measured in minutes, and therefore is equal to the traffic for the following concepts:

- ▶ National DQ Service.
- ▶ International DQ Service.
- ▶ Emergency Service.

Wholesale billing system

The wholesale billing system is an outsourced system responsible for collecting and correlating chargeable call details records for billing purposes.

The wholesale billing software is measured in minutes, and is therefore equal to the traffic for the following concept:

- ▶ Total wholesale traffic.

The number of wholesale billing hardware units is calculated based on the total wholesale traffic:

$$\text{Wholesale billing hardware} = \begin{cases} 1 & \text{if wholesale traffic} \neq 0 \\ 0 & \text{if wholesale traffic} = 0 \end{cases}$$

7. Cost Calculation Module

The purpose of this module is to calculate the expenditures GBV and OpEx associated with the required network resources from the Dimensioning Module. This section presents the steps to obtain these expenses, as illustrated in the following figure.



Exhibit 7.1: Resources Costing [Source: Axon Consulting]

The following sections explain each step in detail.

7.1. Step 1. Determination of Resource Unit Costs and Cost Trends

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

- ▶ **Historic unitary cost:** separated into CapEx and OpEx (for those resources where applicable). Unitary costs can be introduced in the local currency 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 the unit cost has not been introduced (i.e. usually in future years). The formula used for the application of cost trends is the following.

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

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, OpEx and G&A

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

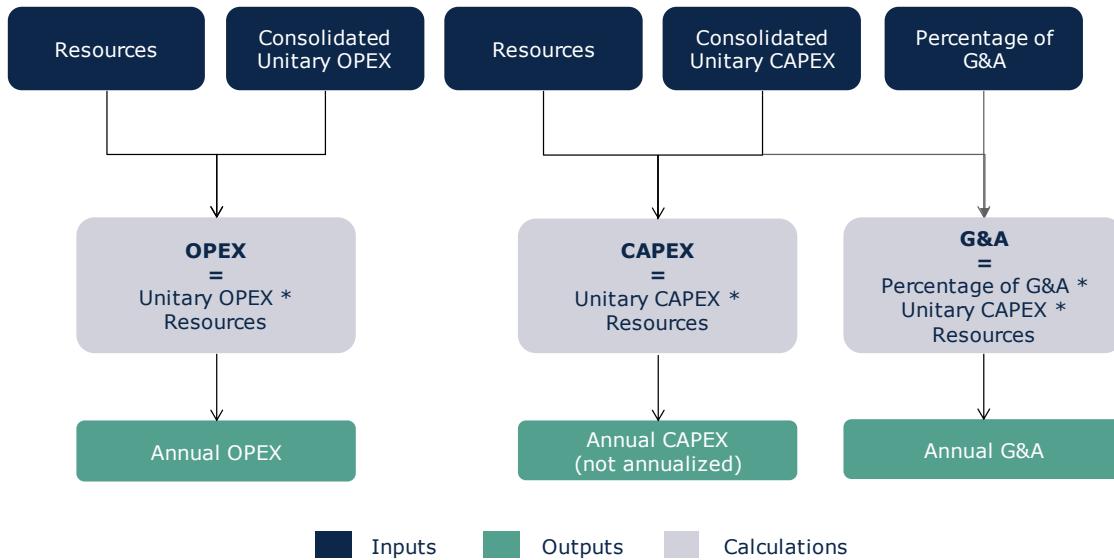


Exhibit 7.2: Algorithm for the calculation of GBV, G&A and OpEx [Source: Axon Consulting]

Aligned with the methodology, G&A percentage is based on the Gross Book Value (GBV) of network assets, compared to the total GBV. As explained in the following formula:

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

8. Depreciation Module

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

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

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

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

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

Where:

- ▶ *WACC = the weighted average cost of capital;*
- ▶ *Δp = 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 inflation is eliminated from the WACC to avoid including it twice.

Although the tilted annuities do not separate depreciation from the cost of capital components (as may be done in straight-line depreciation methodology), the model separates 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

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

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

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

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

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

9.1. Increment Definition

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

In the BULRIC fixed model, only one increment that includes all traffic is considered.

9.2. Incremental Cost Calculation

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

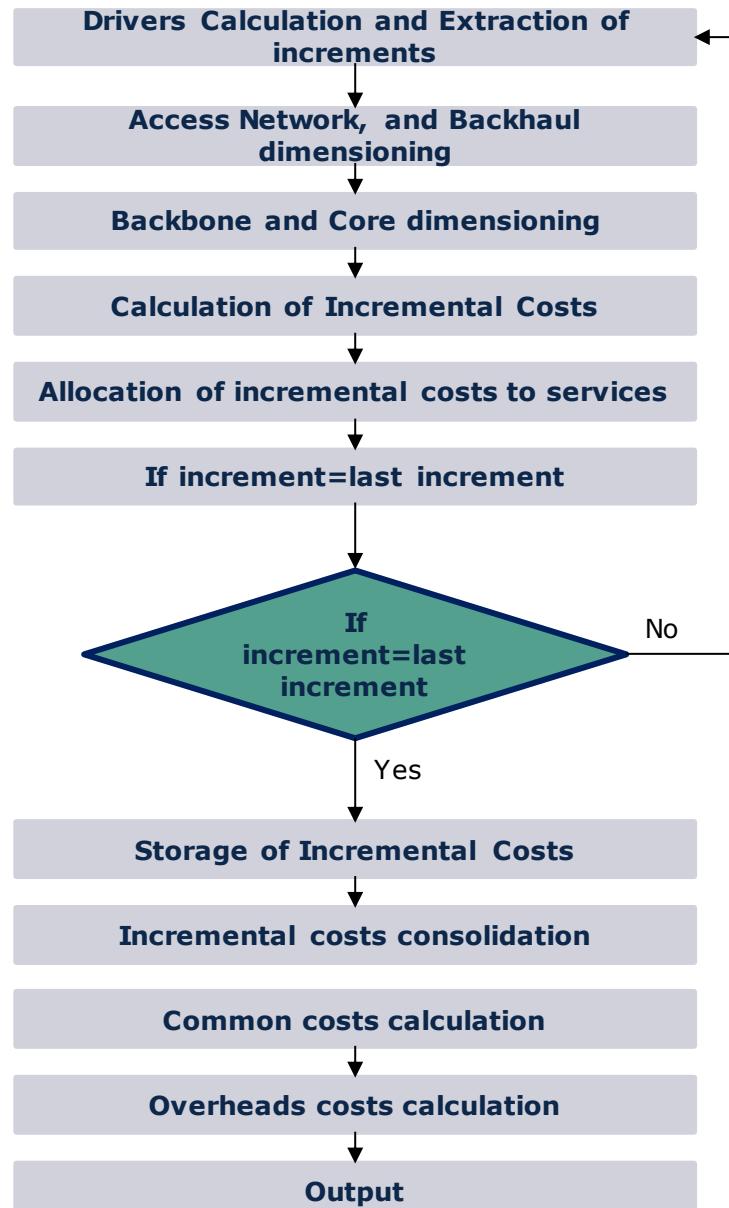


Exhibit 9.1: Simplified Scheme of the Calculation Flow for of All Increments [Source: Axon Consulting]

After subtracting this traffic, the model is run following the steps described in this document.

After finishing the execution of an increment, the annual costs of increments (defined as the difference between the total costs, previously obtained, and costs obtained by removing the increment's traffic) are allocated to services through routing factors and saved in sheet '8B MAC SERV INC COST'. This step represents the 'Storage of Increments Costs' in the preceding chart.

It should be stressed that, for incremental costs, the full model must be run as many times as the number of increments, plus one to obtain the total cost⁶.

9.3. Common Cost Calculation

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

$$\text{Common Costs}^7 = \text{FAC} - \text{PureLRIC}(1) - \text{PureLRIC}(2) - \text{PureLRIC}(3)$$

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

Once the service's common costs are calculated, the LRIC+ methodology is calculated as the following formula:

$$\text{LRIC} + \text{Cost} = \text{Pure LRIC cost} + \text{Common Costs}$$

⁶ This loop is controlled by the Visual Basic macro that manages the execution flow of the model's sheets.

⁷ Common costs represent the cost of the network needed to carry the traffic from any point to any other point in the Member State.

10. Cost overheads

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

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

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

- ▶ Network OpEx working capital:

$$\text{Network OpEx working capital} = WCOverhead * \text{Network OpEx}$$

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