AXON

Excellence in Business

Cost of Providing Roaming Wholesale Services – CNECT/2022/OP/0065

Descriptive manual

Axon Partners Group

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Contents

1. Introduction

The European Commission (hereinafter "EC") commissioned Axon Partners Group Consulting S.L.U. (hereinafter "Axon Consulting" or "Axon") for the study "*Cost of Providing Roaming Wholesale Services – CNECT/2022/OP/0065*" ('the Project').

As described during Workshop 1 held on 21 June 2023, the EC deemed relevant to develop a new cost study to understand the costs of providing mobile services in EU/EEA countries. This initiative was necessitated by the new roaming regulation ('the Regulation')[1], which requires comprehensive review reports in the years 2025 and 2029. With such objective in mind, the EC/Axon team has updated the Bottom-Up Long Run Incremental Cost (hereinafter 'BULRIC') model previously elaborated by the EC/Axon during the project SMART 2017/0091[2], which calculates the costs of providing mobile services in the EU/EEA countries. The updated model aligns with the current market conditions and adheres to the regulatory framework established by the Regulation, ensuring that the EC's approach is both current and compliant for the forthcoming review periods.

This document constitutes the 'descriptive manual' of the cost model. Its main objectives are to:

▶ Describe the approach and structure followed in the development of the costing model.

▶ Describe the calculation processes and analyses performed in the model.

▶ Provide comprehensive descriptions of the calculation blocks of the model.

In particular, the model has been developed according to a Bottom-Up structure as graphically represented in the exhibit below:

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[1] Regulation (EU) 2022/612 of the European Parliament and of the Council of 6 April 2022 on roaming on public mobile communications networks within the Union.

[2] The complete list of public materials developed as part of such project is available in the following link: https://digital-strategy.ec.europa.eu/en/library/finalisation-mobile-cost-model-roaming-and-delegated-act-single-eu-wide-mobile-voice-call
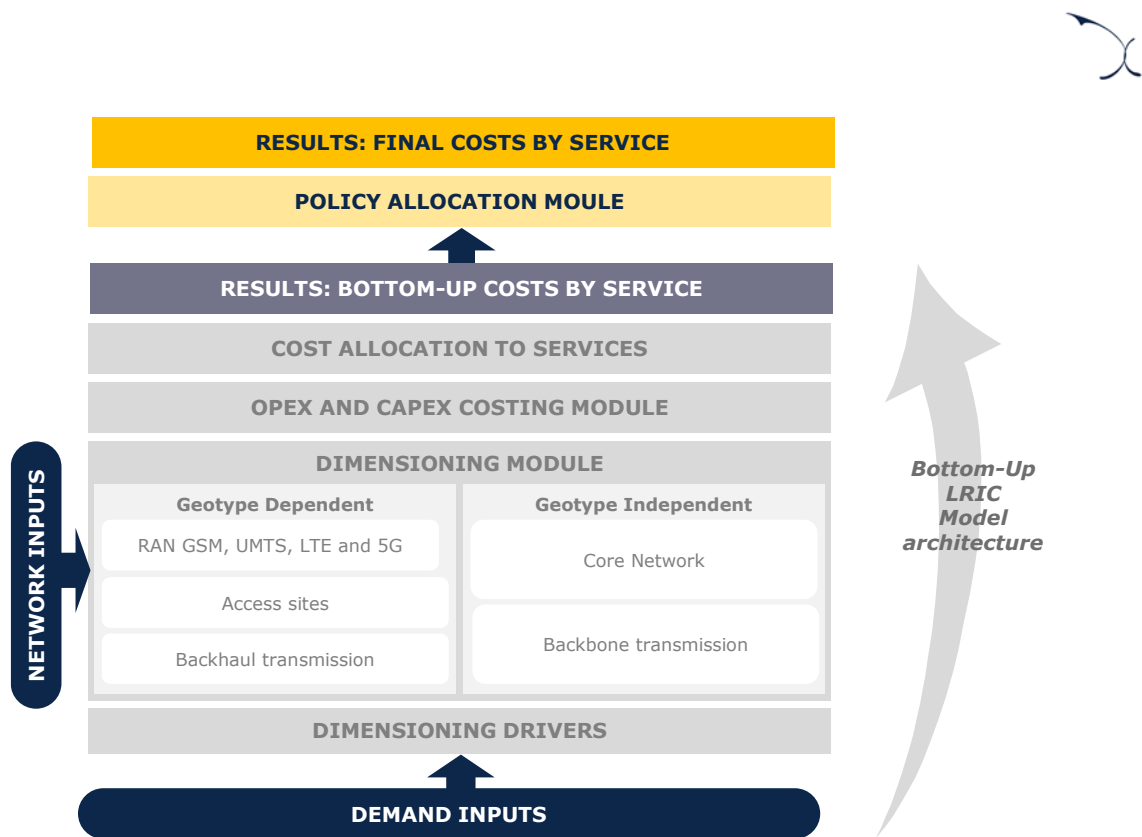
Exhibit 1.1: Structure of the model [Source: Axon Consulting]

As the exhibit above shows, the model is designed based on 5 key functioning blocks which are presented below:

▶ **Dimensioning Drivers (section 2):** Converts traffic into dimensioning drivers which help to perform the network dimensioning calculations.

▶ **Dimensioning Module (section 3):** Calculates the number of resources needed to supply the main services provided by the reference operator. It comprises different modules such as RAN GSM, RAN UMTS, RAN LTE, RAN 5G, Sites, Backhaul, Backbone and Core Network. The traffic for all modelled services is used by the Dimensioning Module. Additionally, geographical data is introduced in the dimensioning module to take into consideration the relevant geographical aspects of the EU/EEA countries.

▶ The model recognises that the different sections of the reference operator's network can be geotype-dependent or independent. For example, the dimensioning process corresponding to GSM RAN, UMTS RAN, LTE RAN, 5G RAN Sites and Backhaul is performed separately for each geotype.

▶ **OPEX and CAPEX costing module (section 4):** Calculates the costs of resources, both in terms of CapEx and OpEx. In addition, it includes the implementation of the economic depreciation mechanism to annualise capital investments over the years.

▶ **Cost allocation to services (section 5):** Calculates the costs of services by allocating resources' costs, including incremental, fixed and common costs to them.

▶ **Regulatory policy allocation module (section 6)**: Performs the reallocation of the costs at service level calculated in the previous block based on a set of regulatory policy rules.

The following sections further develop each block of the model.

2. Dimensioning Drivers

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

The recognition of dimensioning "Drivers" is intended to simplify and increase the transparency of the network dimensioning process. Drivers enable the model to transform the demand of different services (which are measured in MB, minutes or SMS) into technical units which are relevant for the dimensioning process.

As such, the drivers defined in the cost model are listed below:

DRIVER	Unit
2G Voice traffic in the access network (Erlangs in the busy hour)	Erlangs
2G Download data traffic in the access network (Erlangs in the busy hour)	Erlangs
3G Voice traffic in the access network (Erlangs in the busy hour)	Erlangs
3G Download data traffic in the access network (Mbps in the busy hour)	Mbps
4G Voice traffic in the access network (Erlangs in the busy hour)	Erlangs
4G Download data traffic in the access network (Mbps in the busy hour)	Mbps
5G Voice traffic in the access network (Erlangs in the busy hour)	Erlangs
5G Download data traffic in the access network (Mbps in the busy hour)	Mbps
2G traffic in the backhaul (Mbps in the busy hour)	Mbps
3G traffic in the backhaul (Mbps in the busy hour)	Mbps
4G traffic in the backhaul (Mbps in the busy hour)	Mbps
5G traffic in the backhaul (Mbps in the busy hour)	Mbps
Traffic in the backbone (Mbps in the busy hour)	Mbps
Traffic in the SGWs (Mbps in the busy hour)	Mbps
Traffic in the PGWs (Mbps in the busy hour)	Mbps
Traffic in the GGSNs (Mbps in the busy hour)	Mbps
Traffic in the SMSCs (SMS in the busy hour)	SMS
2G traffic in the BSC (Erlangs in the busy hour)	Erlangs
3G traffic in the RNC (Mbps in the busy hour)	Mbps
2G/3G Busy Hour Call Attempts in the MSC-Ss	BHCA

DRIVER	Unit
Busy hour Call Attempts in the CSCF	BHCA
2G/3G Total Subscribers	Subs
4G Total Subscribers	Subs
2G/3G Simultaneous Active Subscribers in the busy hour	SAU
4G Simultaneous Active Subscribers in the busy hour	SAU
Traffic in the SBCs (Mbps in the busy hour)	Mbps
CS Voice traffic in the core platforms (Erlangs)	Erlangs
Traffic in the BCs (Billed events)	Billed Events
4G voice traffic in the core network	Mbps
5G traffic in the core network	Mbps
5G Total Subscribers	Subs

Exhibit 2.1: List of drivers used in the model (Sheet '0B PAR DRIVERS') [Source: Axon Consulting]

The following steps are required to calculate the dimensioning drivers:

▶ Mapping services to drivers

▶ Converting traffic units into the driver units

▶ Calculation of dimensioning drivers

2.1. Mapping services to drivers

To calculated drivers' values, it is necessary to indicate what services are related to them. 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 are considered in the drivers related to the radio access network and to the core network.

This operation is performed at internal service level (i.e. services with technological disaggregation). These services are only defined internally in the model as a disaggregation of the so-called 'external services' (i.e. technology-neutral services).

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

SERVICE (Variable Name)	DRIVER (Variable Name)
LTE.Data.Domestic.Domestic Data.Retail.Data Traffic	4G Download data traffic in the access network (Mbps in the busy hour)
LTE.Data.Roaming (EU/EEA).Roaming inbound.Wholesale.Data Traffic	4G Download data traffic in the access network (Mbps in the busy hour)
LTE.Data.Roaming (Non-EU/EEA).Roaming inbound.Wholesale.Data Traffic	4G Download data traffic in the access network (Mbps in the busy hour)
LTE.Subscribers.Domestic.SIM Cards.Retail.Subscribers	4G Simultaneous Active Subscribers in the busy hour
LTE.Subscribers.Domestic.SIM Cards.Retail.Subscribers	4G Total Subscribers
LTE.Data.Domestic.Domestic Data.Retail.Data Traffic	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Data.Roaming (EU/EEA).Roaming inbound.Wholesale.Data Traffic	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Data.Roaming (Non-EU/EEA).Roaming inbound.Wholesale.Data Traffic	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.Domestic.On Net.Retail.On-net	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.Domestic.Outgoing.Retail.Off-net national	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.International.Outgoing.Retail.Off-net international	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.Domestic.Incoming.Wholesale.Incoming from national	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.International.Incoming.Wholesale.Incoming from international	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.Roaming (EU/EEA).Roaming inbound.Wholesale.Outgoing	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.Roaming (EU/EEA).Roaming inbound.Wholesale.Incoming	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.Roaming (Non-EU/EEA).Roaming inbound.Wholesale.Outgoing	4G traffic in the backhaul (Mbps in the busy hour)
LTE.Voice.Roaming (Non-EU/EEA).Roaming inbound.Wholesale.Incoming	4G traffic in the backhaul (Mbps in the busy hour)

**Exhibit 2.2: Excerpt from the mapping between services and Drivers. (Sheet '3A MAP SERV2DRIV')
[Source: Axon Consulting]**

2.2. Converting traffic units into the driver units

Once services have been mapped to drivers, volumes need to be converted to obtain drivers in the relevant units of measure. For this purpose, a ratio has been worked out representing the number of driver units generated by each service unit. In general, the calculation of this ratio consists of five factors, in accordance with the following structure:
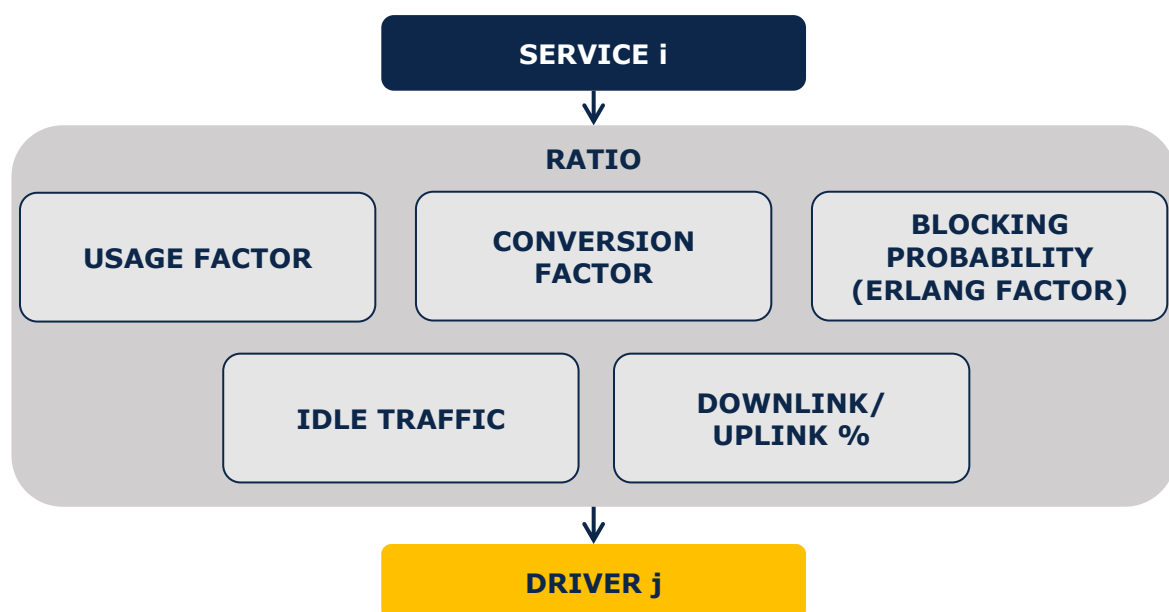
Exhibit 2.3: Units conversion process from services to drivers [Source: Axon Consulting]

This ratio thus includes the following items:

▶ Usage factor (UF)

▶ Conversion Factor (CF)

▶ Blocking Probability - Erlang Factor (EF)

▶ Idle Traffic (IT)

▶ Downlink/Uplink percentage (DLUL)

Unit conversation ratios are then obtained as per the following formula:

$$RATIO = UF \times CF \times EF \times (1 + IT) \times DLUL$$

▶ **Usage factor** represents the number of times a service makes use of a specific driver. For example, when calculating drivers related with the access network, it is necessary to recognise that they will be used twice by on-net services. On the contrary, off-net and termination services will only use them once.

▶ **Conversion Factor** represents the relationship between services' units (e.g. minutes) to drivers' units (e.g. Erlangs).

For example, the conversion from voice minutes in the busy hour to Erlangs should be based on the following factor:

$$CF = \frac{1}{60}$$

▶ The **Blocking probability** is used for voice services to recognise the implications in network dimensioning of ensuring a given quality of service. It is necessary to apply Erlang tables to properly dimension the network under a given blocking probability[3].

▶ **Idle traffic** represents the difference between the traffic conveyed from the users' viewpoint and the required resource consumption the network needs to face. For instance, it recognises the traffic consumption generated by unanswered calls which, even though not invoiced, generate additional load to the network.

The calculation of the idle-traffic factor is based on the following elements:

• *Time required to set up the connection which is not considered as time of service*. It represents the waiting time until the recipient picks up the phone to accept the call. During this time an actual resource allocation is performed and, therefore,

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

needs to be taken into consideration in the dimensioning of the network. Its calculation is performed as follows:

$$Connection\ Time\ (\%) = \frac{ART}{ACD}$$

Where:

- ART is the average ringing time.

- ACD is the average call duration.

- *Time required for missed calls*: This factor takes into consideration the time elapsed in trying to reach a recipient that does not answer the call. It is calculated as follows:

$$Uneffective\ time\ (\%) = \frac{\frac{PNRC}{1 - PNRC - PB} \cdot ART + \frac{PB}{1 - PNRC - PB} \cdot AT}{ACD}$$

Where:

- PNRC represents the percentage of non answered calls.

- PB is the percentage of calls where the recipient is busy.

- ART is the average ringing time.

- AT is the average duration of the message indicating the impossibility to contact the callee.

Finally, the total idle traffic is calculated as the sum of the time required to set up the connection and the time required for missed calls.

▶ The **downlink/uplink ratio** applies to data transmission services and represents the percentage of services' data traffic that is handled in the downlink over the total data traffic circulating through the network (downlink + uplink).

2.3. Calculation of dimensioning drivers

Once each relationship between services and drivers has been fully defined (in terms of mapping and conversion factors) the contribution from each service to the drivers can be added up as follows:

$$Driver_j = \sum_i Demand_i \cdot Ratio_{i,j}$$

When calculating the values of the final drivers to be used in the dimensioning module, two additional considerations are made:

▶ **Geotype dependency**: As previously indicated, the dimensioning process takes place separately for the different parts of the network. Some network sections, such as the access and the backhaul, are geotype-dependent and, therefore, need to be dimensioned independently for each geotype.

Therefore, the drivers related to these network sections need to be defined at geotype level. To perform this disaggregation, traffic is split by geotype based on the population covered in each of them.

▶ **Busy hour applicability**: The dimensioning of most of the network elements considered in the cost model is performed in the busy hour. Consequently, the yearly traffic needs to be multiplied by the percentage of traffic that is handled in the busy hour of an average day in the busy month of the year. This percentage may be defined separately for each geotype, based on the assessment of traffic patterns in each country, provided that the data was reported by the NRA (see methodological approach document for further indications on how this percentage has been calculated).

Not all drivers are measured in the busy hour. For instance, the HLR/HSS are dimensioned based on the total number of subscribers in the network rather than the number of subscribers making use of the network in the busy hour.

3. Dimensioning Module

The Dimensioning Module aims at dimensioning the network resources required to serve the reference operator's traffic. This module is structured in the following blocks:

▶ Radio Access Dimensioning

▶ Radio Sites Dimensioning

▶ Backhaul Network Dimensioning

▶ Core Network Dimensioning

Each of these blocks is described in the sections below.

3.1. Radio Access Dimensioning

The dimensioning algorithm for the radio access network follows a common approach to design the 2G, 3G, 4G and 5G networks. Therefore, a single methodology is described below that is applicable to all of them. The objective of this block is to determine the number of access elements that would be required for each radio access technology.

The dimensioning process is performed in the following steps:

▶ Step 0. Adjusted Traffic Calculation

▶ Step 1. Coverage Sites Calculation

▶ Step 2. Capacity Sites Calculation

▶ Step 3. Total Sites

▶ Step 4. Required access elements

The algorithms implemented for these steps run separately for each geotype and increment.

These algorithms are implemented in worksheets '6A CALC DIM GSM' (2G), '6B CALC DIM UMTS' (3G), '6C CALC DIM LTE' (4G) and '6D CALC DIM 5G' of the model.

Step 0. Adjusted Traffic Calculation

The first step adopted in the radio access dimensioning process consists in calculating the adjusted traffic that needs to be considered when determining the number of network elements needed. This adjusted traffic not only takes into account the drivers' demand,

but also a maximum load factor of the equipment, which is used for security purposes, to avoid network failures in case of a sudden peak in demand.

The dimensioning drivers considered to dimension each access technology are listed below:

▶ 2G (GSM)

- 2G Voice traffic in the access network (Erlangs in the busy hour)

- 2G Download data traffic in the access network (Erlangs in the busy hour)

▶ 3G (UMTS)

- 3G Voice traffic in the access network (Erlangs in the busy hour)

- 3G Download data traffic in the access network (Mbps in the busy hour)

▶ 4G (LTE)

- 4G Voice traffic in the access network (Erlangs in the busy hour)

- 4G Download data traffic in the access network (Mbps in the busy hour)

▶ 5G

- 5G Voice traffic in the access network (Erlangs in the busy hour)

- 5G Download data traffic in the access network (Mbps in the busy hour)

Step 1. Coverage Sites Calculation

The calculation of the number of sites required for coverage under each access technology is performed based on:

▶ The area of the geotype

▶ The average radius of a cell for the different spectrum bands

▶ The percentage of population covered

▶ The orography of the terrain (for rural geotypes only)

▶ The geographical distribution of population (for rural geotypes only)

More specifically, the following substeps are carried out to calculate the minimum number of sites required for coverage:

▶ Substep 1.1: Geotype area to be covered
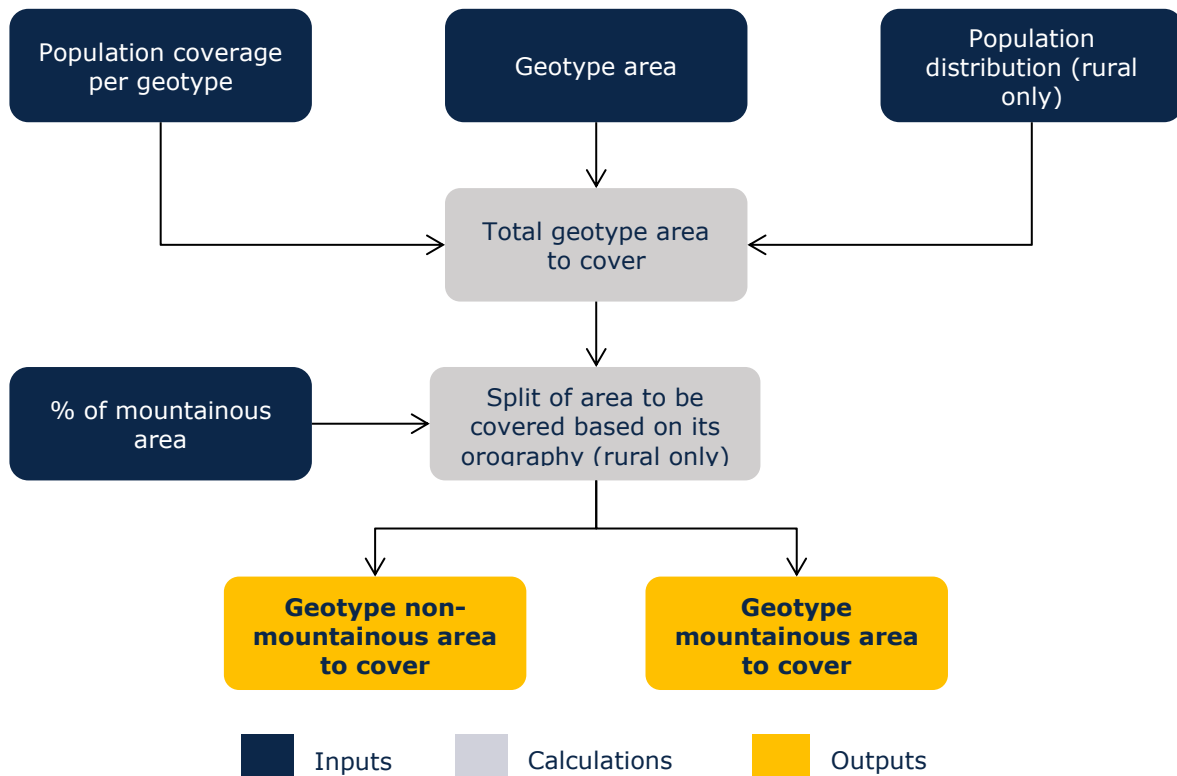
▶ Substep 1.2: Area covered per site

▶ Substep 1.3: Sites required for coverage

Substep 1.1: Geotype area to be covered

In order to calculate the number of sites required for coverage, the first step consists in calculating the area that has to be to be covered in the geotype.

This calculation is performed based on the algorithm presented below:

**Exhibit 3.1: Calculation of geotype area to be covered. [Source: Axon Consulting]**

The two key calculations performed in this algorithm are described below:

▶ **Total geotype area to cover**: This calculation is performed in two steps as follows:

• The "population coverage per geotype" (percentage of population that is covered by the access network in each geotype) is converted to area coverage per geotype based on the population distribution patterns in rural geotypes.

The "population distribution" input represents the percentage of population that is covered within a given percentage of the territory. This input allows us to recognise that population is not homogeneously distributed across the territory, but uses to follow an exponential pattern, as illustratively represented below:
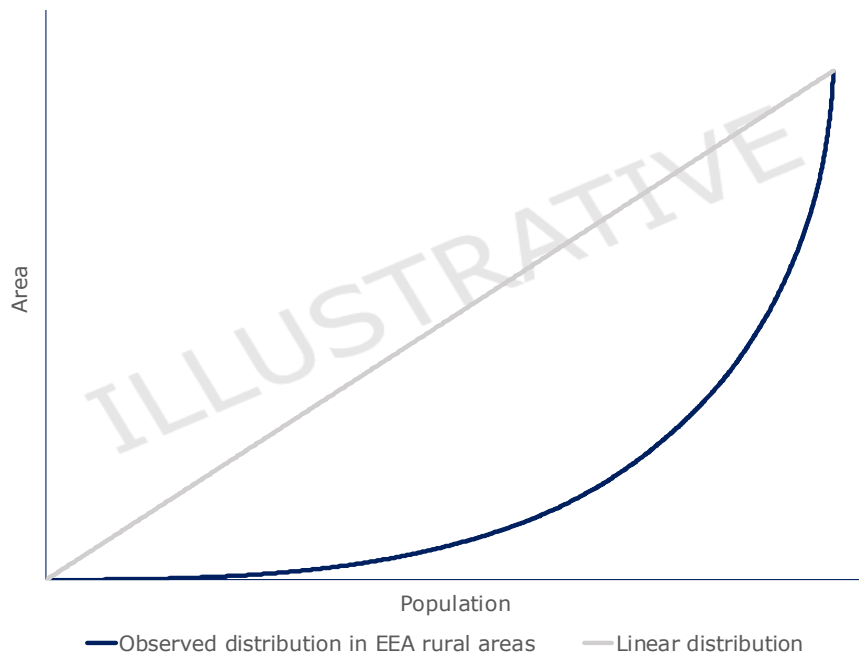
Exhibit 3.2: Illustrative example of population distribution in rural areas [Source: Axon Consulting]

This step is performed for rural geotypes only, given the limited relevance it would have for suburban and urban geotypes. In urban and suburban geotypes, the percentage of population covered is assumed to be equal to the percentage of area covered.

- The geotype area (total surface of the geotype, in km^2) is then multiplied by the percentage of area covered to obtain the total area of the geotype that needs to be covered.

▶ **Split of area to be covered based on its orography (rural only)**: For rural geotypes, based on the total area to be covered in the geotype, the model splits this area based on its orography. Particularly, taking the percentage of the area of the geotype that is mountainous, it splits the area to be covered between "non-mountainous area to be covered" and "mountainous area to be covered". The algorithms of the model will always give preference to covering non-mountainous areas rather than mountainous areas, as they are more cost-efficient.

This split is not introduced in suburban and urban areas, as orography is not identified as a relevant factor of the access network dimensioning in these areas.

Substep 1.2: Area covered per site

In parallel to assessing the geotype area to be covered, the model needs also to calculate the area covered by each site. This is performed based on the algorithm presented below:
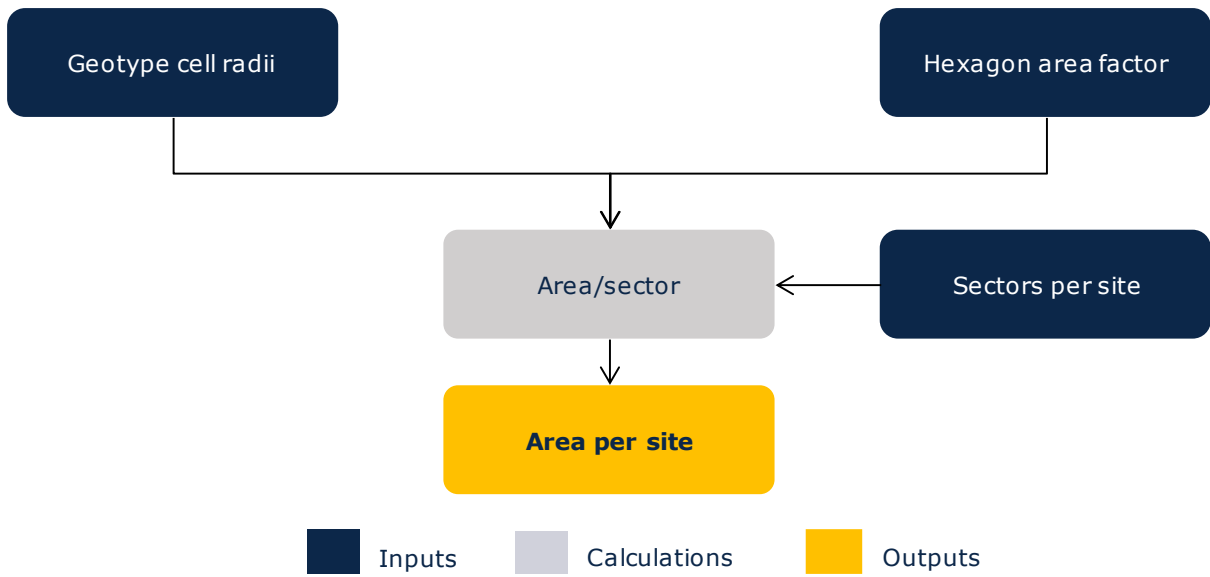
Exhibit 3.3: Calculation of area covered per site [Source: Axon Consulting]

The first step in this algorithm consists in calculating the area covered per sector. The site configuration along with the areas covered considered in this calculation is presented in the exhibit below:
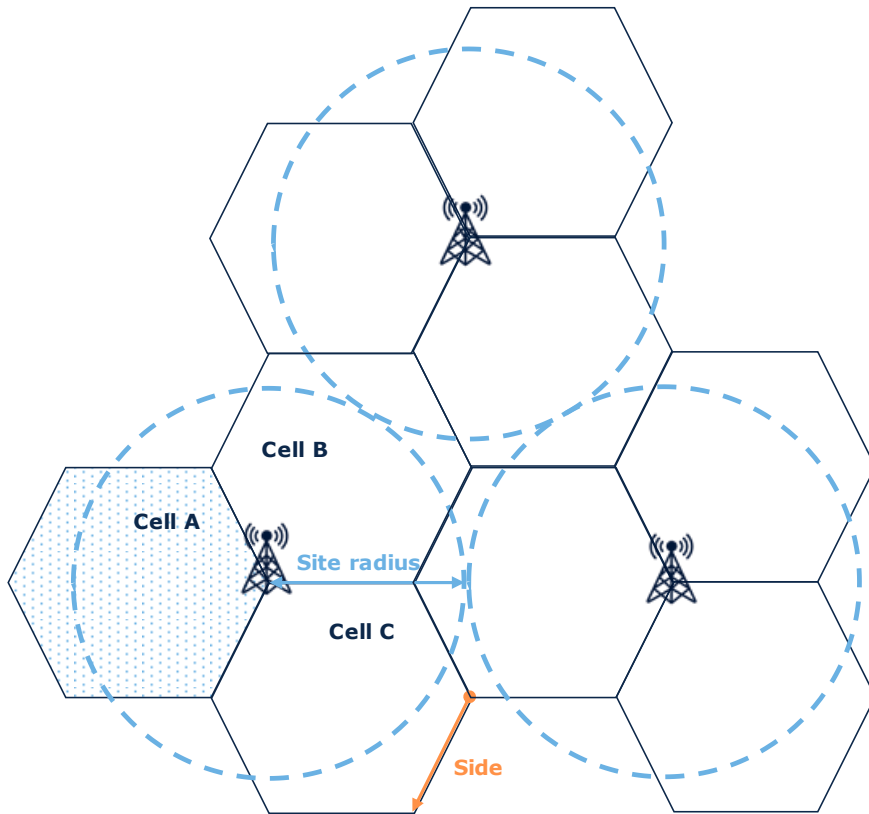
Exhibit 3.4: Illustrative diagram of hexagonal area covered by a site [Source: Axon Consulting]

The main input considered to calculate the area covered by a radio cell (which is considered to have the shape of a hexagon) is the cell radii. The definition of this input may not be, in cases, universal. Particularly, some NRAs may opt to follow a relatively different approach. However, if the input is defined in accordance with the formulae considered in the dimensioning algorithms, the outputs of the different approaches should be equivalent.

In this case, the cell radius is measured as the average distance between sites, as shown in the exhibit above.

Based on this, the area of a hexagon may be obtained from the side length based on the following expression:

$$Area = \frac{3\sqrt{3} \times side^2}{2}$$

At the same time, the site radius is always 3/2 of the length of one side of the hexagon:

$$Site\ radius = \frac{3}{2}\ x\ side$$

From the previous two equations, the following relationship between the area and the cell radius may be defined:

$$Area = \frac{3\sqrt{3} \times (\frac{2x\ Site\ radius}{3})^2}{2} = \frac{3\sqrt{3}}{2} \times \left(\frac{2}{3} \times Site\ radius\right)^2$$

Where the $\frac{3\sqrt{3}}{2}$ term is considered to be the 'hexagon area factor', or the relationship between the area of a hexagon and its apothem.

The cell radius included in this formula will depend on:

▶ The spectrum band considered (it will be higher for lower spectrum bands and vice versa).

▶ The orography of the terrain (it will be higher for non-mountainous areas and vice versa) – applicable to rural geotypes only -.

Finally, the area per site is calculated by multiplying the area per sector by the average number of sectors per site.

Substep 1.3: Sites required for coverage

Based on the outcomes produced in substeps 1.1 and 1.2, the model is able to calculate the minimum number of sites required for coverage through the following algorithm:
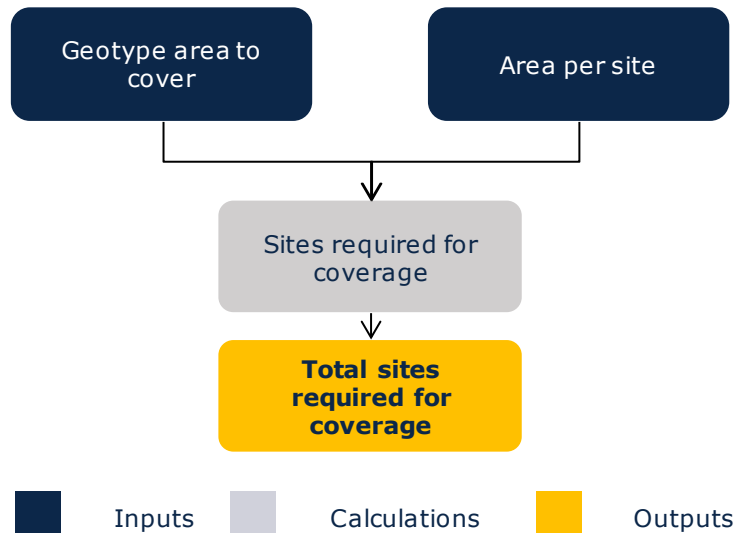
Exhibit 3.5: Calculation of sites required for coverage [Source: Axon Consulting]

As the exhibit above shows, the model divides the total area to be covered by the area covered by a site (depending on the spectrum band used and the orography of the geotype in rural areas) to calculate the minimum number of sites required for coverage.

When different spectrum bands are used by a MNO in a geotype, the lowest spectrum band is always taken into consideration when assessing site coverage requirements.

Step 2. Capacity Sites Calculation

This step calculates the minimum number of sites required according to capacity constraints. This is, it calculates the minimum number of sites that need to be deployed in order to serve the network's overall traffic.

Based on the drivers defined for the dimensioning of each access network, the capacity sites are calculated as per the algorithm below:
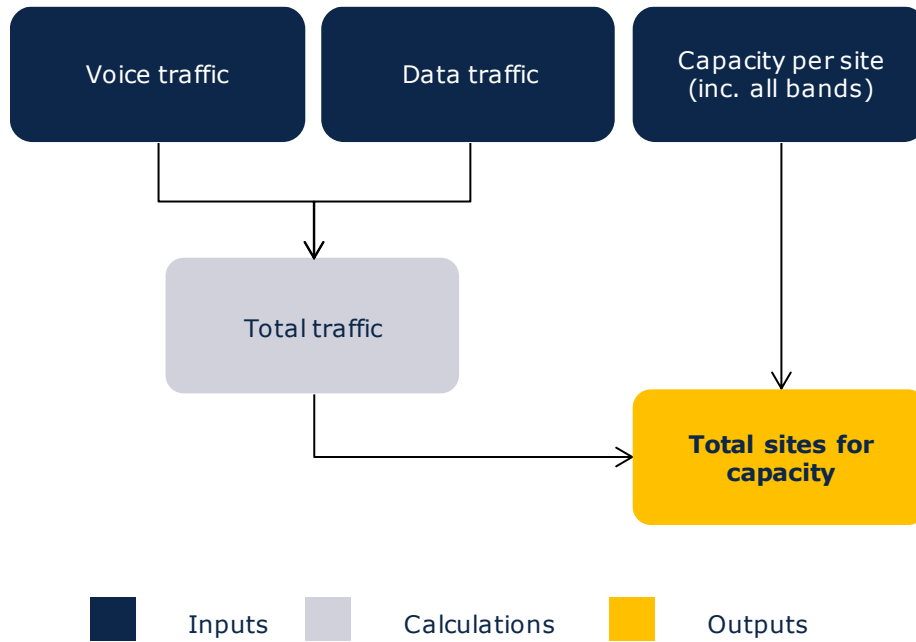
Exhibit 3.6: Calculation of sites for capacity [Source: Axon Consulting]

This is, the model takes into consideration the total traffic per access technology from the drivers defined and divides it by the capacity of a site (including all the potential bearers it may hold in a given access technology) to calculate the minimum number of capacity sites required.

Step 3. Total Sites Calculation

Based on the outcomes of steps 1 and 2 above, this step calculates the total number of sites that need to be deployed in the network.

To do so, the model identifies the most limiting constraint (coverage or capacity) when determining the total sites to be deployed in the network, as graphically represented in the exhibit below:
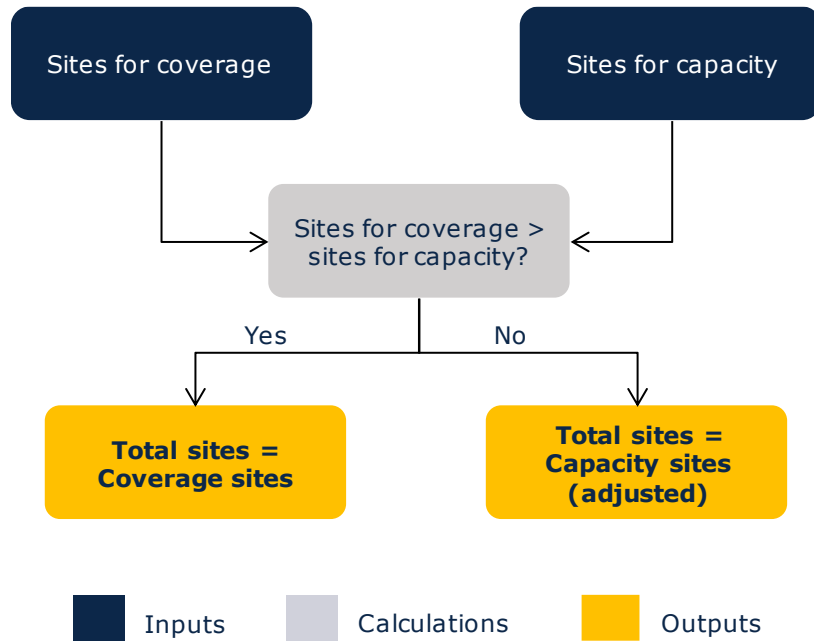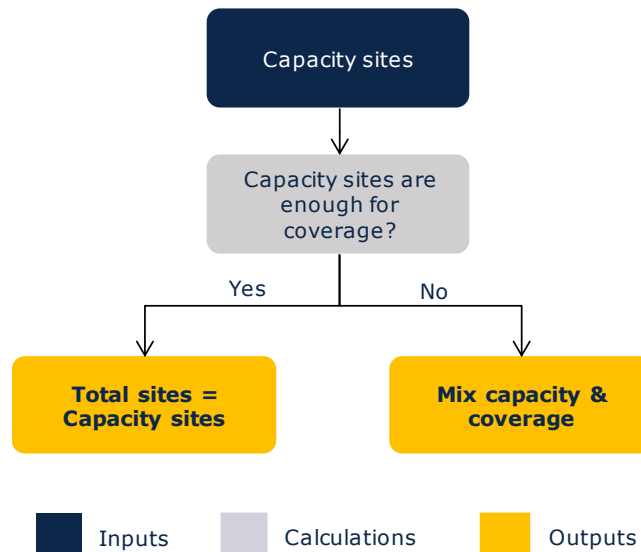
Exhibit 3.7: Identification of the most limiting constraint in the determination of the number of sites to be deployed [Source: Axon Consulting]

As the exhibit above shows, in case the number of coverage sites is higher than the number of capacity sites, then this constitutes the total number of sites to be deployed in the network.

On the other hand, if capacity is found to be the most limiting constraint, a final adjustment will be required to calculate the total number of sites based on the capacity sites calculated in step 2. Such adjustment is required because, given that the number of capacity sites was calculated assuming the usage of higher spectrum bands, these may not be sufficient to comply with the coverage constraints defined in Step 1, as the area covered by these sites is below the area covered by the coverage sites considered in that section.

In this case, the following algorithm needs to be adopted:

Exhibit 3.8: Determination of the total number of sites when capacity is the most limiting constraint [Source Axon Consulting]

If the coverage provided by the capacity sites is already sufficient to comply with the coverage requirements, then the total number of sites to be deployed is made equal to the number of capacity sites.

On the other hand, if the coverage reached by the capacity sites is not enough to fulfil the coverage requirements the following steps need to be performed in order to calculate the optimum mix of coverage and capacity sites:

1. Calculate the area covered by capacity sites.

2. Calculate the uncovered area as the difference between the total area of the geotype to be covered and the area covered by capacity sites.

3. Calculate the number of coverage sites required to provide service to the uncovered area, based on the approach described in Step 1 "Coverage Sites Calculation".

4. The additional number of sites considered imply that there is now an excess of capacity (given that more sites are added on top of the strict number of sites required to serve the traffic generated in the network).

   Consequently, a recurring process is started to calculate the number of capacity sites that may be removed (given the excess of capacity obtained) and the additional number of coverage sites required (given the coverage loss registered after the removal of some of the capacity sites). This process is iterated and is aimed at minimising the total number of sites that complies with both the capacity and coverage constraints of the access network.

Step 4. Required access elements

Once the minimum total number of sites for each technology has been determined, this step includes the calculation of some relevant indicators that summarise the outcomes of this dimensioning process for each access technology:

▶ 2G (GSM)

- 2G Sites with the 900 MHz band (only) – coverage sites -

- 2G Sites with the 1800 MHz band (only) – capacity sites -

- 2G Sites with the 900 and 1800 MHz bands.

- TRXs

▶ 3G (UMTS)

- 3G Sites

- 3G Bands (total number of bands deployed in 3G access sites - 1 band per site in 900/2100 MHz-only sites and 2 bands per site when both bands are used -).

▶ 4G (LTE)

- 4G Sites

- 4G Bands (total number of bands deployed in 4G access sites)

▶ 5G

- 5G Sites

- 5G Bands (total number of bands deployed in 5G access sites)

In addition to the dimensioning of the above (macro) sites, in the case of 5G networks, the model also estimates the number of small-cell sites required in the network to handle the traffic which will be carried by such small-cell configurations. For this purpose, the following algorithm is adopted:
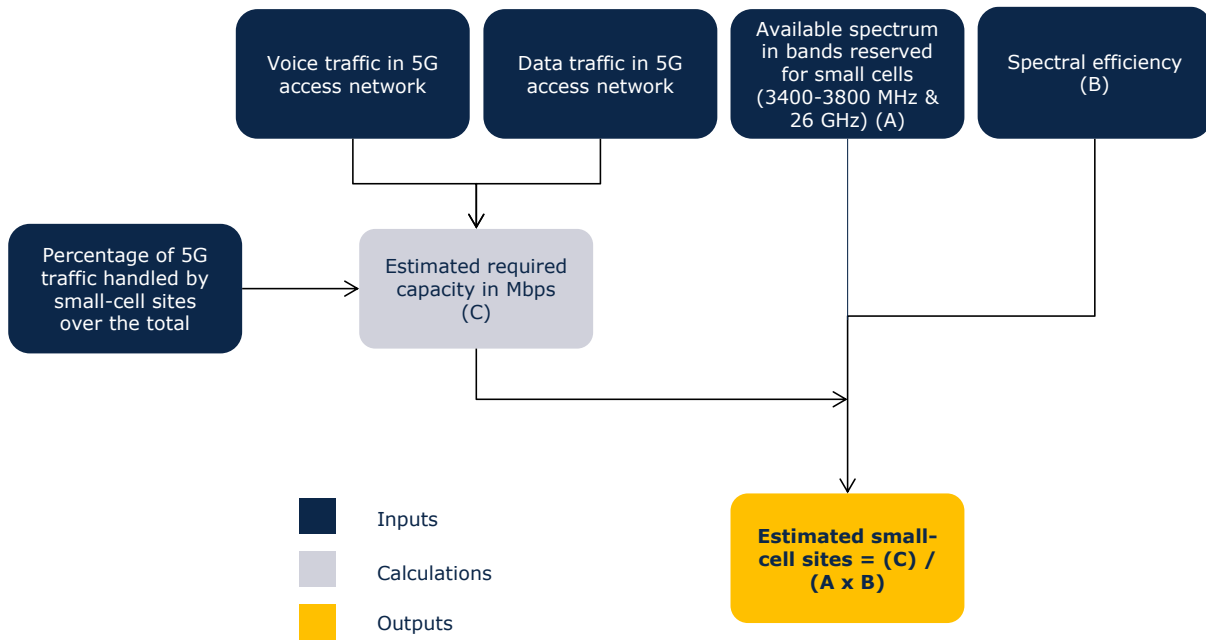
Exhibit 3.9: Determination of the total number of small-cell sites [Source Axon Consulting]

As it can be extracted from the above exhibit, the model assumes that the deployment of small-cell sites is driven by the capacity handled by them. It is also important to note that the mmWave band (26 GHz) is reserved within the model for small cells, while the spectrum band 3400-3800 MHz may also be employed by them when available. The final number of required small-cells is obtained as the division of the capacity to be served and the capacity per small-cell.

3.2. Radio Sites Dimensioning

The Radio sites dimensioning block is responsible for the calculation of the required number of sites as well as the Single-RAN equipment for each technology.

When dimensioning the access network for each access technology, indicators about the number of sites required were already produced. However, it is common practice among operators to provide more than a single access technology through a single site to minimise their costs.

Therefore, to calculate the final number of sites required in the network the following steps are performed:

▶ Step 1. Co-location Calculation

▶ Step 2. Distribution of tower and rooftop sites

▶ Step 3. Single RAN Equipment Calculation

Step 1. Co-location Calculation

Once the number of radio sites per each technology is known (from the radio access dimensioning modules), the co-location between different technologies is assessed as per the following potential combinations:

▶ GSM+UMTS+LTE+5G

▶ GSM+UMTS+LTE

▶ GSM+UMTS+5G

▶ GSM+LTE+5G

▶ UMTS+LTE+5G

▶ GSM+UMTS

▶ GSM+LTE

▶ GSM+5G

▶ UMTS+LTE

▶ UMTS+5G

▶ LTE+5G

▶ GSM Only

▶ UMTS Only

▶ LTE Only

▶ 5G Only

The following algorithm has been adopted to assess the co-location of sites:
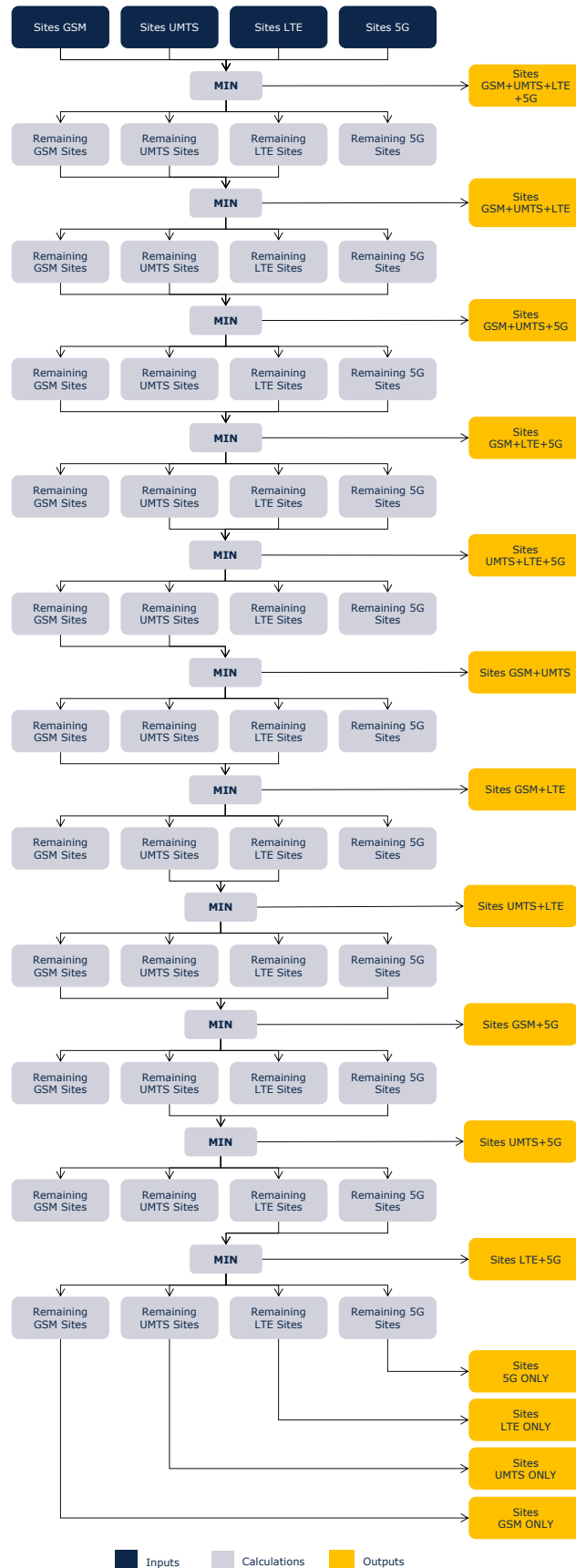
Exhibit 3.10: Algorithm used for the calculation of the technologies co-location [source: Axon Consulting]

The outcome of this step is the optimal calculation of the total number of sites required in the network, with the access technologies that will be used in each of them.

Step 2. Distribution of tower and rooftop sites

Once sites are optimised considering existing co-location levels, the total number of sites of each type (rooftop and tower) are obtained according to the algorithm presented below:
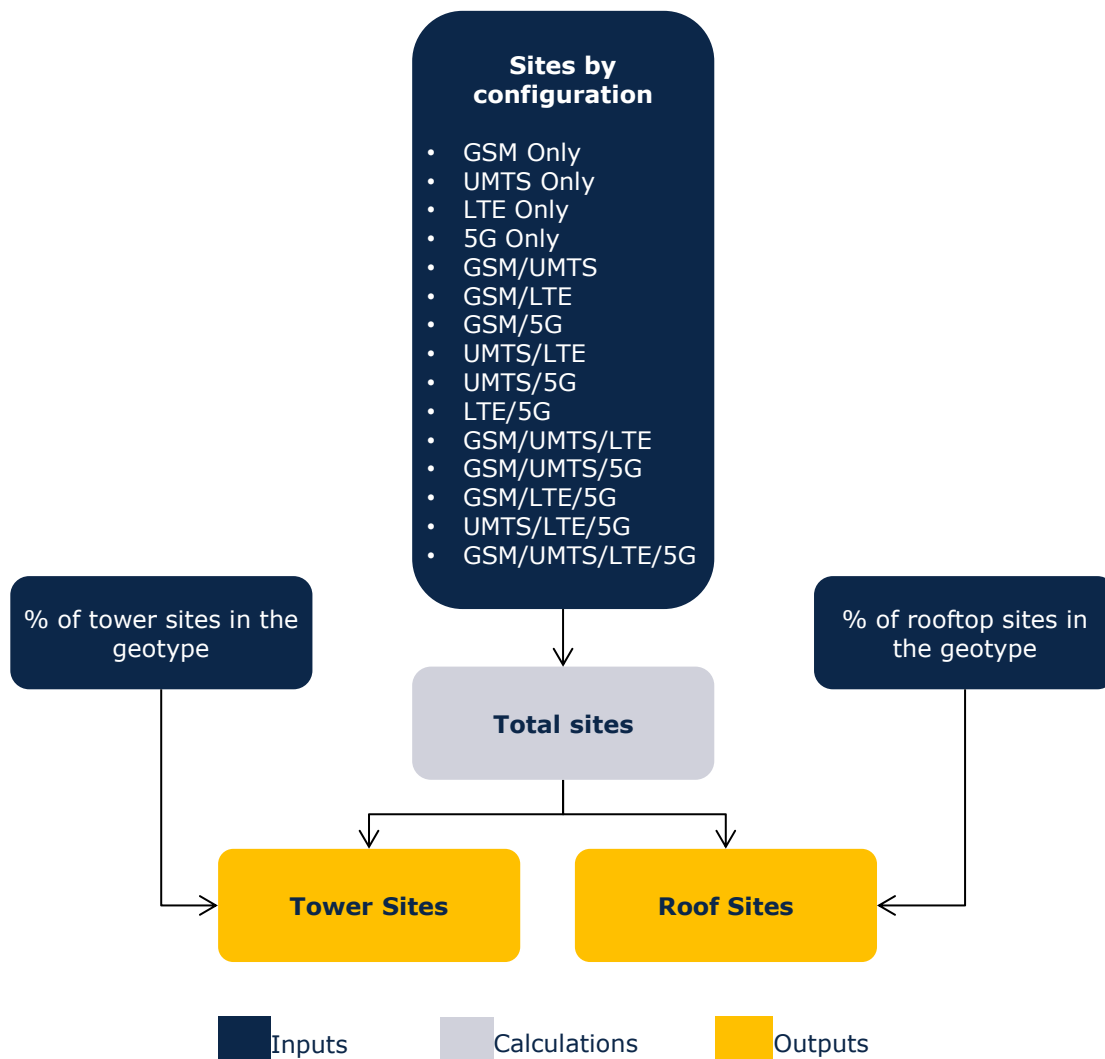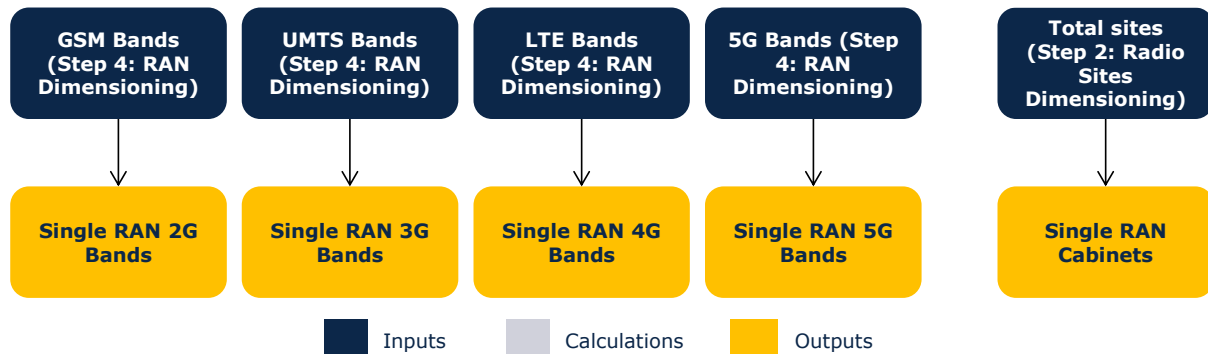

Exhibit 3.11: Algorithm for the calculation of Tower and Rooftop sites [source: Axon Consulting]

The total number of sites is obtained by adding up the number of sites per technological configuration calculated in Step 1 above. This value is later multiplied by the percentage of tower and rooftop sites to calculate the total number of tower and rooftop sites respectively.

Step 3. Single RAN Equipment Calculation

Finally, the number of SingleRAN equipment (including bands and cabinets) is calculated as per the algorithm illustrated below:

Exhibit 3.12: Algorithm for the calculation of the Single RAN equipment. [Source: Axon Consulting]

As the exhibit above shows, the number of network elements is calculated as follows:

▶ *Single Ran 2G Bands*: Equal to the number of bands for the GSM technology already calculated in Step 4 of the RAN Dimensioning block.

▶ *Single Ran 3G Bands*: Equal to the number of bands for the UMTS technology already calculated in Step 4 of the RAN Dimensioning block.

▶ *Single Ran 4G Bands*: Equal to the number of bands for the LTE technology already calculated in Step 4 of the RAN Dimensioning block.

▶ *Single Ran 5G Bands*: Equal to the number of bands for the 5G technology already calculated in Step 4 of the RAN Dimensioning block.

▶ *Single RAN Cabinets*: Equal to the number of sites already calculated in Step 2 of the Radio Sites Dimensioning block.

3.3. Backhaul Network Dimensioning

The backhaul network dimensioning module is responsible for calculating the number of links, their capacity and distance between the radio sites and the network controllers. The Backhaul dimensioning algorithm is implemented in worksheet '6F CALC DIM BACKHAUL' of the model.
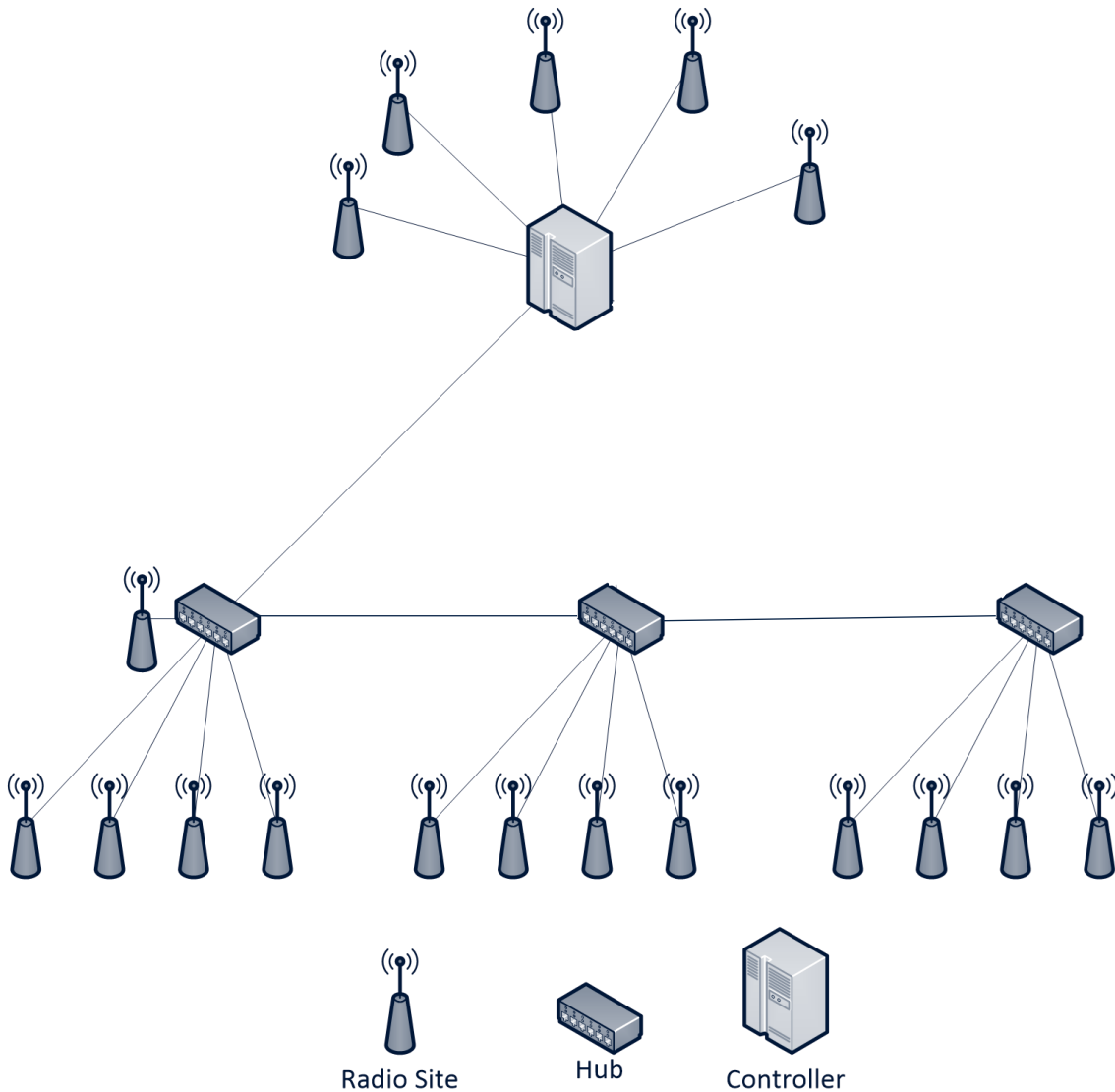
The backhaul network topology considered is based on a two-tier structure:

▶ **Radio Site – Hub**: Connections between a radio site and a traffic aggregator (Hub).

▶ **Hub – Hub/Controller**: Connections between traffic aggregators (hub) and controllers. Hubs are connected to other hubs closer to the controller until the controller is reached.

The exhibit below provides a graphical illustration of the backhaul network topology considered:

Exhibit 3.13: Backhaul topology considered in the model [source: Axon Consulting]

As shown in the chart, the elements somehow related with the backhaul transmission network are:

1. Transmission links between radio sites and a Hub (or Controller), which may use a mix of different technologies (microwave, leased lines or fibre)

2. Hubs or Aggregators: The traffic from radio sites is added in this element. The aggregator is placed in the location of an existing radio site (i.e. it is not a separated that needs to be separately dimensioned).

3. Transmission links between Hubs and the Controller. These links may also employ different technologies (microwave, leased lines or fibre). The mix of technologies used in the transmission links between Hub and the Controller is not equal to the one used in the radio links between sites and hubs.

4. Controllers: These include controllers of different technologies. The locations are shared by all access technologies and, similarly to the aggregators, controllers are located in a shared location with a radio site and an aggregator in the same location of a core site.

Note that this block is focused only in the dimensioning of the links between the different equipment (i.e. items 1 and 3 above).

The backhaul network dimensioning is split in the six steps listed below, which are described in detail in the coming paragraphs:

▶ Step 1. Hubs Calculation

▶ Step 2. Traffic per Site and Hub Calculation

▶ Step 3. Distance Calculation

▶ Step 4. Backhaul network calculation (total links and distances) from sites to hubs

▶ Step 5. Backhaul network calculation (total links and distances) from hubs to controllers

As for the previous dimensioning blocks, the backhaul network is dimensioned independently for each geotype and increment.

Step 1. Hubs Calculation

The number of hubs (or aggregators) is calculated in this step following the algorithm presented below:
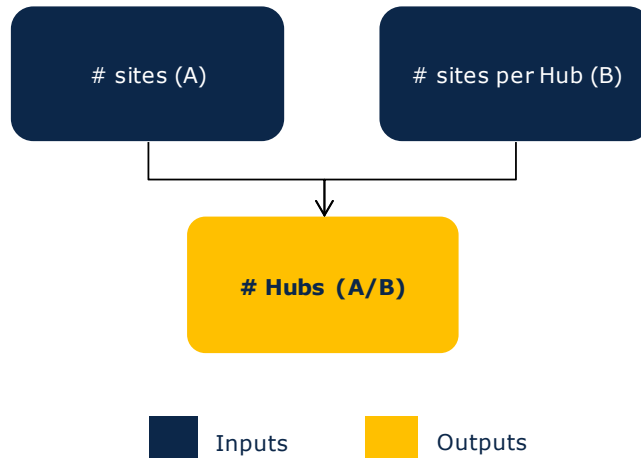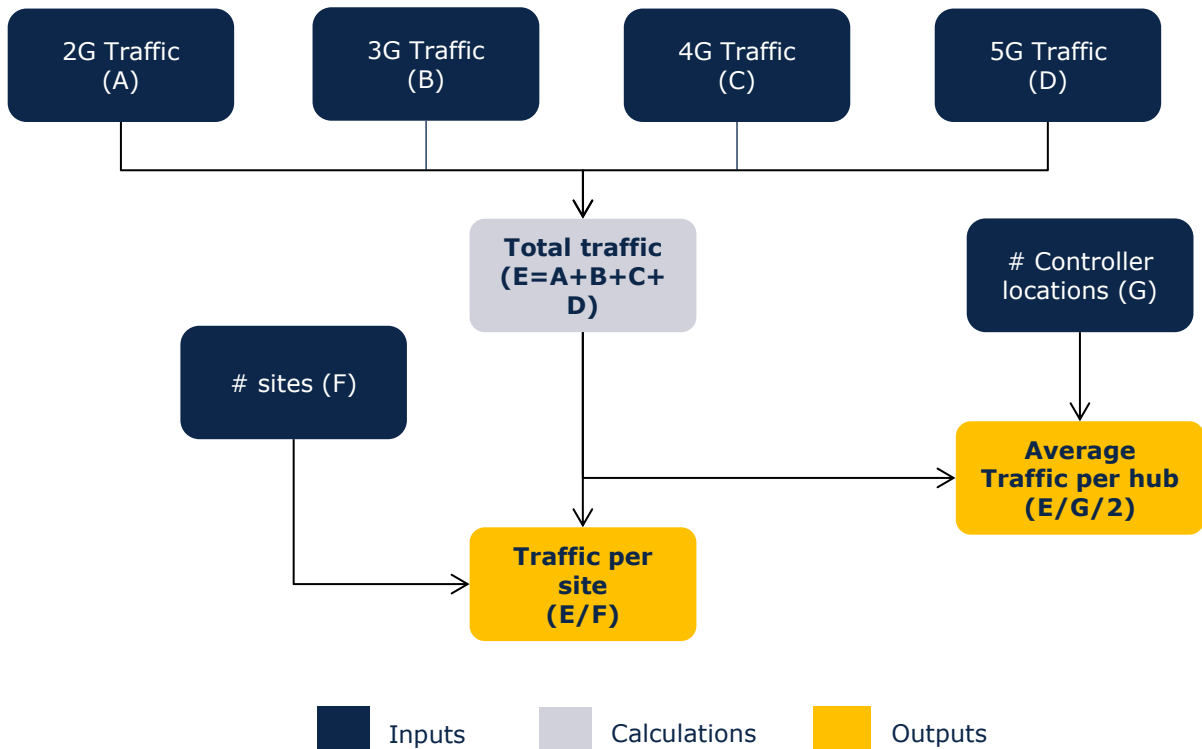
Exhibit 3.14: Hubs calculation [Source: Axon Consulting]

As the exhibit above shows, the number of hubs (or aggregators) is calculated as the number of sites in a geotype (obtained in section 3.2 above) divided by the number of sites per Hub (defined as seven).

Step 2. Traffic per Site and Hub Calculation

The traffic per site and hub (originated by 2G, 3G, 4G and 5G radio access networks) is calculated in this step following the algorithm presented below:

**Exhibit 3.15: Traffic per Hub calculation [Source: Axon Consulting]**

As the exhibit above shows, the traffic per hub is calculated based on three steps:

▶ The total traffic circulating through the backhaul network (per geotype) is calculated as the sum of the traffic generated in 2G, 3G, 4G and 5G radio access networks.

▶ The traffic per site is calculated as the total traffic circulating through the backhaul network (per geotype) divided by the number of sites in the geotype.

▶ Finally, the traffic per hub is obtained as an average of the traffic aggregated by the hub closest to the core (which handles the total traffic in the backhaul divided by the number of controller locations) and the one furthest from the controller.

Step 3. Distance Calculation

The distances between radio sites and hubs as well as between hubs and controllers are calculated in this step. The algorithm used to perform the estimation of distances is shown in the figure below:
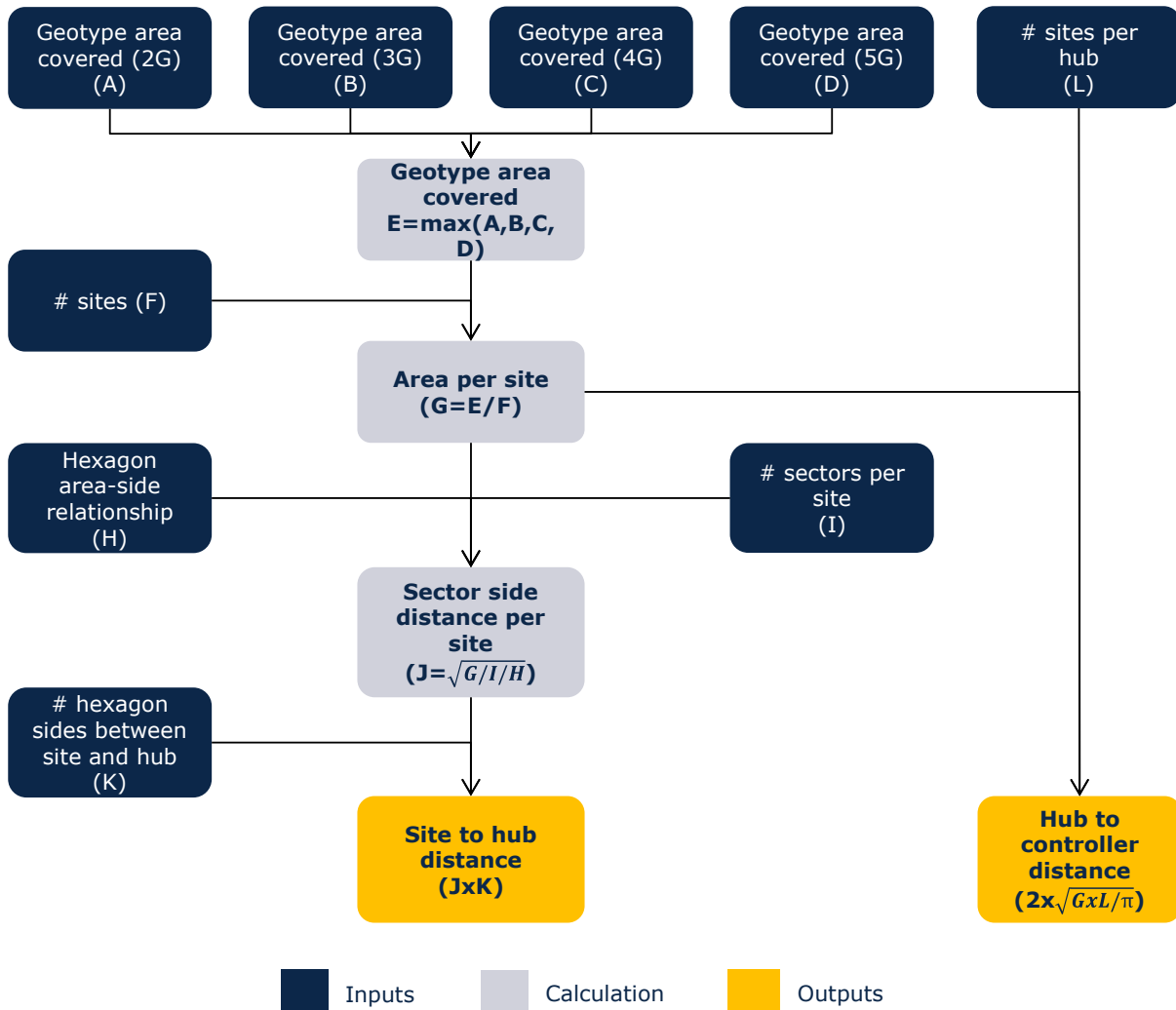
Exhibit 3.16: Distance calculation from site to hubs and from hubs to controllers Distances. [Source: Axon Consulting]

Based on the geotype area covered (obtained as the maximum area covered under any radio access technology) and the number of sites, the model calculates the distance from sites to hubs and from hubs to controllers as follows:

▶ *Site to hub distance*: Assuming that the area per site sector is equal to the area of a cell (defined as a hexagon), the site to hub distance is calculated as follows:

$$Site - hub\ distance = n \times \sqrt{\frac{Average\ area\ per\ site}{\frac{6\sqrt{3}}{4} \times Number\ of\ sectors\ per\ site}}$$

Where,

- n is the distance separating the site and hub measured in number of sides of the hexagon.

- $\frac{6\sqrt{3}}{4}$ represents the relationship between the area and the side of a hexagon.

▶ *Hub to controller distance*: The distance between two hubs (or between a hub and a controller) is calculated based on the average area per site through the following equation:

$$Hub - Controller\ distance = 2 \times \sqrt{\frac{Average\ area\ per\ site\ \times Number\ of\ sites\ per\ hub}{\pi}}$$

Step 4. Backhaul network calculation (total links and distances) from sites to hubs

The optimal backhaul network configuration between sites and hubs is calculated in this step through the following algorithm:
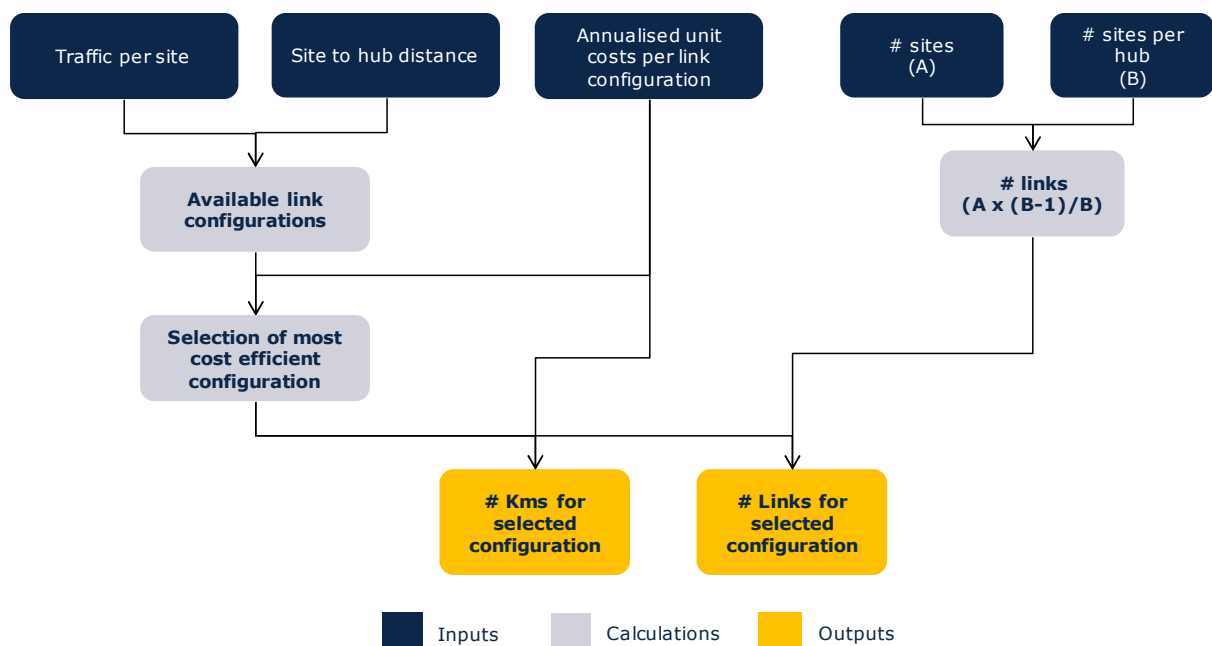
Exhibit 3.17: Backhaul network calculation (total links and distances) between sites and hubs [Source: Axon Consulting]

The first step in the implementation of the backhaul network calculation block consists in identifying the available link configurations (e.g. optical fibre at 10 Gbps, leased lines of 1000 Mbps, microwave links at 500 Mbps). This is done by assessing both the distance to be covered (to identify potential limitations in microwave links) and the capacity requirements (e.g. it is not feasible to serve a traffic of 50 Gbps with 100 Mbps microwave links).

Based on the available link configurations, the model selects the most cost-efficient solution by selecting the configuration that generates less costs. When making this selection, the model calculates the annualised costs resulting from each of the available configurations. As a result of this step, the technology of the link as well as the capacity and number of ports is calculated. This step is particularly relevant to ensure the optimisation of the backhaul network given that, even though transmission link configurations are set per steps (e.g. 100 Mbps, 500 Mbps, 1Gbps), if the traffic circulating through a link is equal to 150 Mbps, it may be more efficient to deploy two 100 Mbps ports rather than a single 500 Mbps port.

In this case, the model considers a time horizon of 5 years to assess the capacity required in the backhaul to avoid constant changes of the optimum technology for deployment throughout the time period modelled.

Once the link configuration is known, the total number of kms (when applicable) as well as the total number of links is calculated.

Step 5. Backhaul network calculation (total links and distances) from hubs to controllers

The optimal backhaul network configuration between hubs and controllers is calculated in this step through the following algorithm:
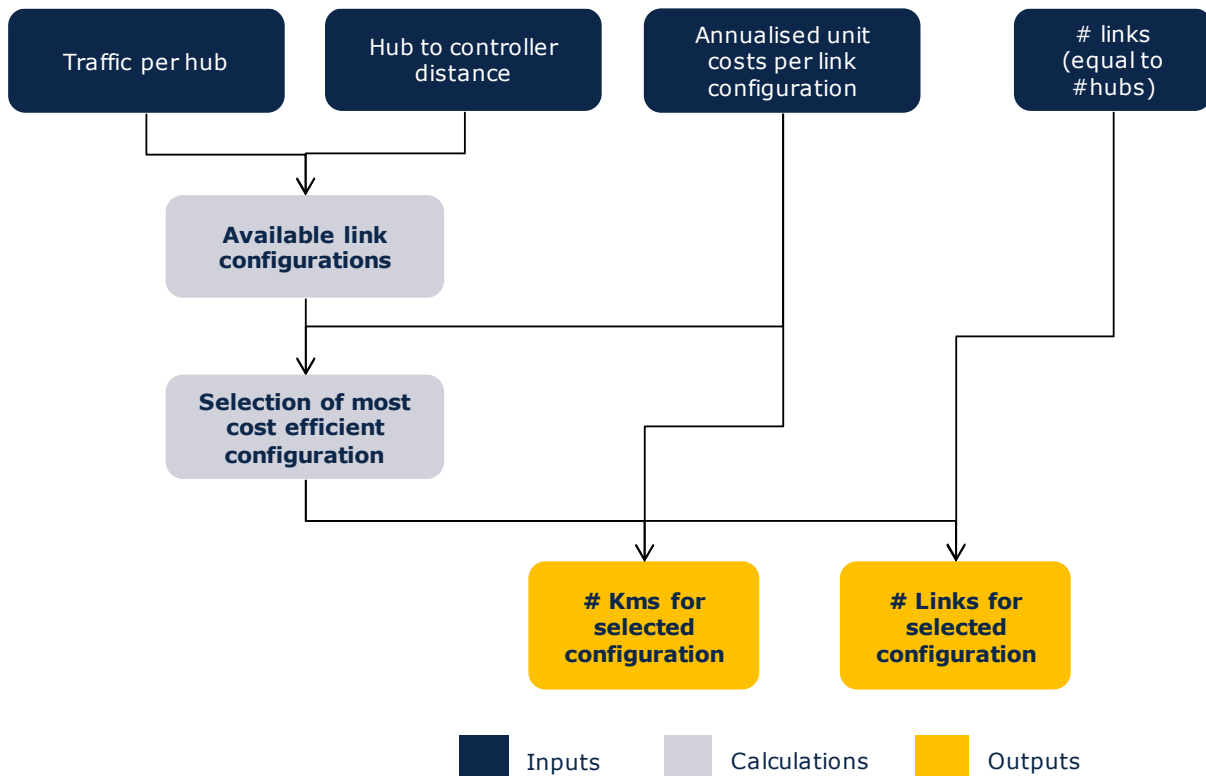
**Exhibit 3.18: Backhaul network calculation (total links and distances) from hubs to controllers
[Source: Axon Consulting]**

The logic behind the calculation blocks presented in the exhibit above is equivalent to the general philosophy described for Step 4.

3.4. Core Network Dimensioning

The Core Network Dimensioning block is responsible for the dimensioning of the backbone network (transmission between core centres) as well as the core platforms. The dimensioning of each of these network sections is described below:

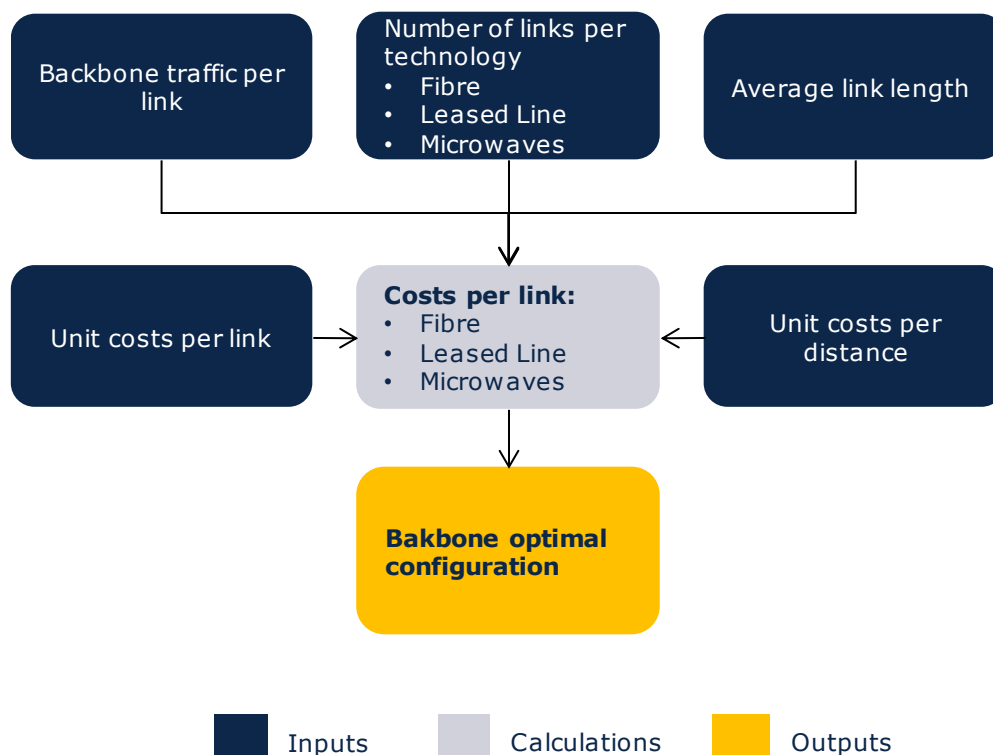▶ Backbone Dimensioning

▶ Core Platforms Dimensioning

3.4.1 Backbone Dimensioning

The backbone network involves the transmission links between the core centres of the modelled operator. The backbone links have been dimensioned taking into consideration the actual location of the MNOs' core centres as well as the typical structure of a backbone network (in terms of redundancy, overall design, etc.).

Based on this information, the model performs the calculation of the backbone network based on the algorithm presented below:

Exhibit 3.19 Dimensioning of the backbone network. [Source: Axon Consulting]

As the exhibit above shows, based on the inputs determined, the backbone links are calculated through an algorithm that, given the length, technology and traffic per link, obtains the link specifications in terms of:

▶ Capacity of the ports

▶ Number of cables required per link

▶ Number of repeaters required (for microwave links only).

Note that the technological split is already set as an input and therefore is not calculated by the model.

3.4.2 Core Platforms Dimensioning

The following illustration shows the core platforms considered in the model:
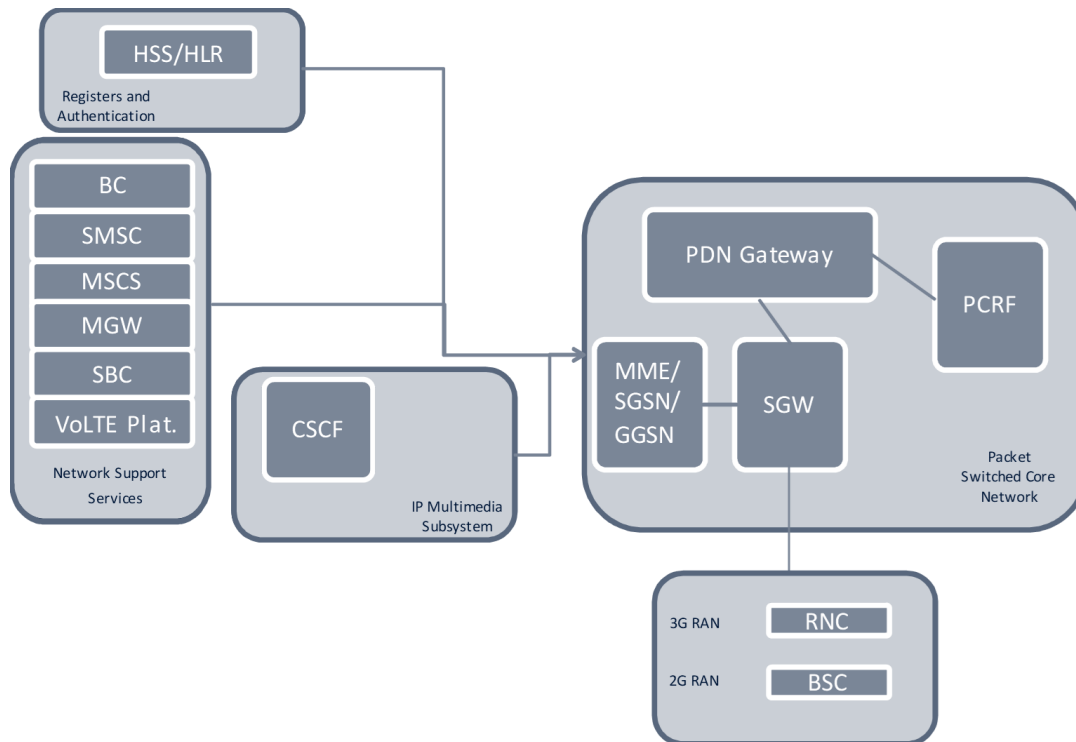
Exhibit 3.20: Schematic model of a mobile network. [Source: Axon Consulting]

A brief description of each of these platforms is provided below:

▶ **BSC (Base Station Controller)**: BSC (Base Station Controller) controls 2G traffic. It handles the allocation of radio channels, frequency administration, power and signal measurements from the user terminal, and handovers from one 2G access element to another (when they are both controlled by the same BSC). A BSC also reduces the number of connections to the Media Gateway (MGW) and allows for higher capacity connections to the MGW.

▶ **RNC (Radio Network Controller)**: The Radio Network Controller (3G) is an important network element in third-generation access networks. It handles mobility management, link management, call processing and handover mechanisms. In carrying out such functions, the RNC has to accomplish a tough set of protocol processing activities at a swift pace that should be reliable and result in the expected performance.

▶ **MSC-S (Mobile Switching Centre Server)**: Responsible for managing the control of circuit call level in the mobile network, i.e. voice and video calls. The MSC manages signalling issues, user mobility and call control. It usually has other features such as built-VLR.

▶ **MGW (Media Gateway)**: The MGW is responsible for managing the circuit traffic calls between core locations, in cooperation with the MSC-S. The MGW is used to route at physical level all data of control layer sent by the MSCs.

▶ **SGSN (Serving GPRS Support Node)**: The SGSN is responsible for establishing packet data connections with end users and delivering data packets between them and the GGSN in both directions.

▶ **GGSN (Gateway GPRS Support Node)**: The GGSN provides data interconnection between the packet core and external packet networks like the Internet. Data traffic from users must go through a GGSN to reach the internet, although radio equipment does not connect directly to the GGSN but to the SGSN.

▶ **HLR (Home Location Register):** The HLR is a central database that contains details of all network subscribers, including data from SIM cards and MSISDN numbers associated with each one. The HLR is the central users' data register and is centralised in the Core Network. HLR communicates with MSC-S and SGSN equipment, but not directly with the radio network.

▶ **BC (Billing Centre):** It is the common name of all the systems and functionalities involved in managing all the billing process in the network. Therefore, it is usually dependent on the number of events recorded (e.g. calls, SMS, data sessions). BC includes the functionalities SCP (Service Control Point) and SDP (Service Data Point) equipment.

▶ **SMSC (Short Message Service Centre):** The SMSC is the equipment responsible for the management, delivery and storage of short messages on mobile network

▶ **MME (Mobility Management Entity)**: The MME is the main control point for subscribers and calls in the NGN network. It is responsible for subscribers' monitoring and paging as well as managing their mobility along access networks. The MME combines the functionalities of the MSC and GGSN in the traditional network.

▶ **SGW (Serving Gateway)**: The SGW is responsible for routing and delivering the packages. It replaces the functionalities of MGW and SGSN in a traditional network. It can be integrated with the MME or the PGW).

▶ **PGW (PDN Gateway)**: The PGW connects the network with external networks. It can be integrated with the SGW.

▶ **PCRF (Policy and Charging Rules Function)**: The PCRF manages network and billing policies of a 4G network.

▶ **HSS (Home Subscriber Server)**: The HSS is the master database of the core network. It combines the functionalities of HLR and AUC in the traditional network and adds the needed functionality for managing the subscribers in IP systems.

▶ **CSCF (Call Session Control Function)**: The CSCF is the set of functionalities responsible for managing multimedia services based on SIP. It incorporates the functionality of session border controller for the interface user-network.

▶ **SBC (Session Border Controller)**: The SBC is an interconnection equipment, responsible for managing signalling, VoIP calls set-up and other multimedia connections based on IP.

▶ **VoLTE platform**: The VoLTE platform is the equipment (or set of software upgrades) that allow the provision of VoLTE traffic in the network.

The design of the core platforms is based on their maximum capacity and the traffic they have to bear.

Additionally, a minimum number of core platforms is introduced:

▶ **RNC, BSC**: There is a minimum number of platforms defined per core node (or core location).

▶ **All other platforms**: There is a minimum number of platforms defined at core network level.

The formulation below illustrates the calculation performed in order to calculate the number element of each core platform that should be deployed by the reference operator.

$$\# \ Platforms = MAX \left(\frac{Constraint_1}{Platform \ capacity_1}, …, \frac{Constraint_n}{Platform \ capacity_n}, MinimumPlatf. \right)$$

Finally, regarding the design of the **core network for 5G networks**, the model introduces a dimensioning on a per-user basis (i.e., the number of units for the network resource is assumed equivalent to the number of users). The utilization of this approach, instead of a design of the core network based on differentiated core platforms/solutions has been the preferred method due to the lack of detailed data about 5G core platforms received from countries during the data collection phase. This approach is also aligned with common practices most recently observed in the market regarding the commercialization of 5G core equipment by manufacturers, which generally do not differentiate individual costs per platform/function, and instead, they charge operators a global investment for all 5G core related elements.

More in particular, the constraints considered to dimension each core platform are listed in the table below:

Core platform	Dimensioning constraint
BSC	2G traffic in the BSC (Erlangs in the busy hour).
	Number of TRX per BSC.
RNC	3G traffic in the RNC (Mbps in the busy hour)

Core platform	Dimensioning constraint
MSC-S	CS Voice traffic in the core platforms (Erlangs)
MGW	CS Voice traffic in the core platforms (Erlangs)
SGSN	2G/3G Simultaneous Active Subscribers in the busy hour
GGSN	Traffic in the GGSNs (Mbps in the busy hour)
	2G/3G Simultaneous Active Subscribers in the busy hour
HLR	2G/3G Total Subscribers
BC	Traffic in the BCs (Billed events)
SMSC	Traffic in the SMSCs (SMS in the busy hour)
MME	4G Simultaneous Active Subscribers in the busy hour
SGW	Traffic in the SGWs (Mbps in the busy hour)
PGW	Traffic in the PGWs (Mbps in the busy hour)
PCRF	4G Total Subscribers
HSS	4G Total Subscribers
CSCF	4G Simultaneous Active Subscribers in the busy hour
SBC	Traffic in the SBCs (Mbps in the busy hour)
VoLTE platforms	4G voice traffic in the core network
5G core	5G Total Subscribers

Table 3.1: Dimensioning constraints for core platforms [Source: Axon Consulting]

4. OPEX and CAPEX costing module

The purpose of the OpEx & CapEx costing module is to calculate the annual expenditures (OpEx and CapEx) associated with the required network resources calculated in the dimensioning module. This section is divided in the following sub-sections:

▶ Definition of unitary costs and trends

▶ OpEx

▶ CapEx

4.1. Definition of unitary costs and trends

The calculation of the cost associated to the network relies on the number of network elements (calculated through the procedures described in section 3) and the unitary costs and trends of the resources (defined in worksheet '1F INP UNITARY COSTS' of the model). For further indications on how unit costs and trends are defined in the cost model, please refer to the methodological approach document.

Based on these inputs, the model calculates in worksheet '5A CALC UNITARY COSTS' the Unitary CAPEX and OPEX for each of the years defined in the cost model.

4.2. OpEx

OpEx is calculated as the product between the unitary cost (OpEx) of the assets for each year and the number of elements dimensioned for that particular year.

This calculation is performed at geotype level for each of the increments defined.

4.3. CapEx

While network OpEx is calculated in a straightforward manner, the calculation of the annualised capital expenses requires the implementation of a cost depreciation methodology.

As described in the methodological approach document, an economic depreciation mechanism has been implemented. Please refer to that document for further indications on the formulation employed.

Equivalently to the approach indicated for OpEx, this calculation is also performed at geotype level for each of the increments defined.

5.   Cost allocation to services

This section describes the approach adopted to calculate the costs of the reference operator modelled and allocate these to services under a LRIC+ standard following purely network-based allocation methods.

This section is split according to the 4 cost categories that have been considered in the model:

▶ Incremental costs

▶ Common Cost calculation

▶ General and Administration expenses (G&A)

▶ Wholesale specific costs

5.1. Incremental costs

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

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

Where F is the formula that represents the cost model (which calculates the cost according to demand) and vi represents the demand volume of increment *i.*

To calculate incremental costs, increments are defined as groups of services. Therefore, services have to be assigned to one of the defined increments in worksheet '0A PAR SERVICES'.

In the model, resources' incremental costs are calculated in sheets '7A CALC RES OPEX' and '7B CALC CAPEX'.

Incremental costs associated to each geotype are allocated to services using Routing Factors. This methodology allocates costs to services based on the use made of each equipment.

The Routing Factor is a measure of how many times a resource is used by a specific service in its provision. Once annual costs incurred per resource and geotype are available, these have to be distributed to the final services per geotype, as the following exhibit illustrates:
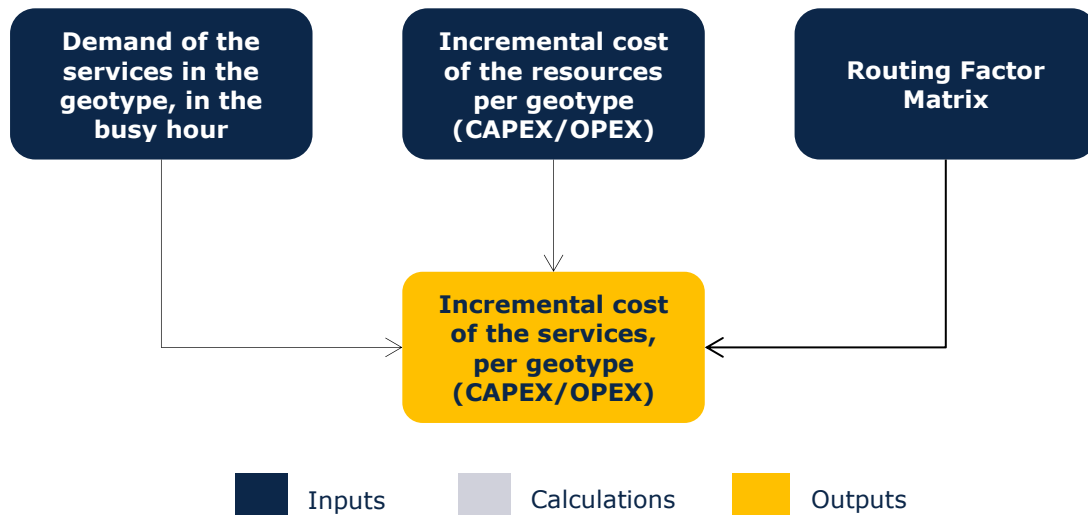
Exhibit 5.1 Incremental cost allocation process through Routing Factors. [Source: Axon Consulting]

This allocation is based on the following formula:

$$ServiceCost(i, year) = \sum_n \frac{Asset(n, year) \cdot Traffic(i, year) \cdot RF(i, n)}{\sum_i Traffic(i, year) \cdot RF(i, n)}$$

Where:

▶ ServiceCost (i, year) is the cost of service i in a given year

▶ Asset (n,year) is the cost of resource n in that year in the considered geotype. This calculation is performed separately for CapEx and OpEx in order to keep this disaggregation at service level.

▶ Traffic (i, year) is the traffic of the service i in a given year in the considered geotype and in the busy hour.

▶ RF (i,n) is the Routing Factor that relates the resource n with the service i

The allocation of resources' incremental cost to services is performed in the sheet `7E CALC SERV COST'.
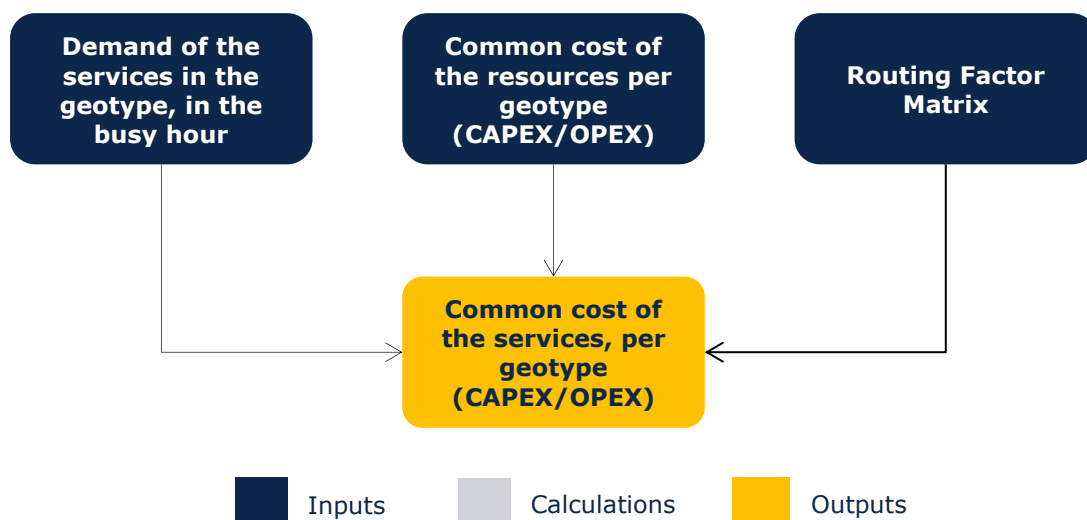
5.2. Common Cost calculation

Once incremental costs have been calculated for each increment as described previously, common costs by resource and geotype are obtained as the difference between the total cost base and the total incremental costs. The following formula shows this calculation:

$$COMMON\ COSTS = TOTAL\ COSTS - \sum_i INCREMENTAL\ COST(increment_i)$$

Common costs are shown in sheet '7C CALC RES COMMON COST'.

The allocation of network common costs is based on the "Effective Capacity" approach which uses routing factors to allocate costs to services.

Exhibit 5.2 Common cost imputation process using Routing Factors. [Source: Axon Consulting]

The formulation followed in this case is identical to the one followed for incremental costs, with the only consideration that in this case, the total demand is used in the allocation process, instead of the demand associated to each of the increments.

5.3. General and Administration expenses (G&A)

General and administrative expenses are non-network related, and are costs originated related to the structure of the company. These costs are typically related to the human resource or finance departments of the MNOs, which are essential for the operation of the business.

In the model, these costs are calculated based on a percentage of the gross book value (GBV) of the network assets, as described in the methodological approach document.

Once the total G&A costs have been calculated, they are allocated to all services based on an Equi-proportional Mark-Up (EPMU) over their total network costs (CapEx + OpEx).

5.4. Wholesale specific costs

Wholesale specific costs relate to the expenses generated by MNOs for the provision of wholesale services (e.g. roaming, termination).

The methodological approach document includes detailed indication on the wholesale cost categories considered and how they have been defined in the model.

The allocation of these costs to services is performed under two different criteria that can be selected by the user in the control panel:

▶ *Allocation based on regression drivers*: Cost allocation is performed based on the drivers (GB or TAPs) defined for each cost category to build up the regressions.

▶ *Allocation based on GB*: Cost allocation for each cost category is performed based on the equivalent number of GB generated by each service.

6. Regulatory policy allocation module

The network allocation module (whose operation has been described in section 5) performs the distribution of costs to services based purely on network rules.

However, the outcomes of this module are not compliant with the regulatory policy decisions adopted so far by the EC in the regulation of wholesale services.

Accordingly, a regulatory policy allocation module has been included in the model that re-allocates the costs at service level in order to ensure compliance with the applicable regulatory landscape. More in particular, the following reallocations have been performed:

Service (Source)	Cost to be reallocated	Services where the cost is reallocated	Justification
Subscription[4]	All costs	All retail services provided to domestic subscribers	Subscriber costs should be recovered from services provided to them.
Voice domestic termination	Network common costs and G&A costs	Domestic voice origination (on-net and off-net).	Adoption of the pure-LRIC standard for voice termination in line with Recommendation (2009/396/EC)[5] on fixed and mobile termination rates and the European Electronic Communications Code (EECC)[6].
Voice roaming termination	Network common costs and G&A costs	Roaming voice origination	
SMS roaming termination	All costs	SMS roaming origination	According to Roaming Regulation (EU) 2022/612[7], Incoming roaming SMS are free of charge

Exhibit 6.1: Reallocations performed in the policy allocation module [Source: Axon Consulting]

These re-allocations have been performed based on an EPMU over the total costs of the services that apply.

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[4] Subscription costs are referred to those costs associated to maintain a client, regardless the traffic it consumes (e.g. costs associated to the registers HLR and HSS).

[5] Source: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:124:0067:0074:EN:PDF

[6] Source: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1547633333762&uri=CELEX%3A32018L1972

[7] Source: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:172:0010:0035:EN:PDF

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