Bottom-up LRIC model specification

A REPORT PREPARED FOR ILR

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1 Introduction

This document forms part of the call for inputs by the Institut Luxembourgeois de Régulation (ILR) on the development of a bottom-up long run incremental cost model (BU-LRIC) to assist in assessing the SMP operator's compliance with its cost orientation obligation. This document sets out the specification of the BU-LRIC model of an efficient fixed network operator in Luxembourg. In particular, this document sets out:

- An overview of the bottom-up modelling approach (see Section 2);
- An overview of the model structure (see Section 3);
- A description of the calculation of demand forecasts (see Section 4);
- A description of how cable and duct network requirements are determined (see Section 5);
- A description of how active network equipment requirements are determined (see Section 6);
- A description of how the costs of the access and core networks are determined(see Section 7); and
- A description of the approach to quality assurance in developing the model (see Section 8).

In the rest of this section, we set out:

- An overview of the definition of the LRIC standard; and
- A summary of the services modelled.

1.1 Definition of LRIC

In the discussion below, we highlight various aspects of LRIC and how these aspects are taken account of in the model.

1.1.1 Long run

The long run refers to the time period over which all costs are variable, including sunk fixed assets which are not variable in the short run. This means that the model incorporates all assets, including sunk assets such as trench, as well as operating costs. Since capital assets last for a number of years, the model allows for the investment costs of these assets to be recovered in an efficient manner over time (see Section 2.2 on the time period modelled, and Section 7.1.2 on how costs are recovered over time).

1.1.2 Forward looking

LRIC is generally applied on a forward looking basis which means that it reflects the costs that an efficient operator would incur if it were to roll out its network today to serve future demand. However, care must be taken to ensure that the existing operator has the opportunity to recover efficiently incurred costs.

1.1.3 Incremental cost

Incremental cost can be defined as the additional cost that would be incurred if an operator were to provide a particular increment of output in addition to other products and services it provides. It can also be considered as the cost that would be avoided if the operator were no longer to provide an increment of output. In principle, incremental cost can refer to either:

- A very small change in the output of a particular service – this measure is sometimes also referred to as marginal cost;
- The addition of an entire service – this measure is sometimes also referred to as service-based incremental cost;
- A network component; or
- The addition of two or more services.

In the regulation of fixed telecoms networks, the traditional practice has been to measure the incremental cost of large increments defined as groups of network components. Specifically, the focus has been on two main parts of the network, namely the access network and the core network. The access network consists of all components which are driven by the number of subscribers, whereas the core network consists of all components driven by the volume of traffic. The costs of services delivered by these two parts of the network are then determined on the basis of network usage[1]. A further discussion of the access and core networks and the dividing line between them is provided in Section 2.5.

The model calculates the costs of the access and core network as a single increment. In addition, it also contains the functionality to calculate the cost of the narrowly defined increment of "terminating calls".[2] The EC has recommended that termination rates should be set according to the cost of this increment.[3]

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1 A long run average incremental cost approach.

2 These are wholesale terminating calls and do not include self-provided termination (i.e. do not include on-net calls).

3 EC Recommendation of 7 May 2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU (2009/396/EC).

Call termination rates are likely to be considerably lower where set using the narrower termination increment rather than the core increment. For example, the amount of trench required would be essentially the same whether or not termination services were provided. This would imply that the incremental cost of trench and duct is zero, or close to zero where the increment is defined narrowly as termination. However, if the increment is more widely defined as the core network, the incremental cost of trench would be much higher and a share of these costs would be attributed to termination services based on their usage of these assets.

1.1.4 Common costs

Some costs of a particular asset or class of operating cost are fixed and common between increments (in other words, there are costs that would be incurred even if the increment were no longer provided). An example of common fixed costs, are corporate costs incurred independently of the volume of services delivered.

Fixed and common costs do not form part of an incremental cost measure. However, there may be a mark-up to allow for the recovery of these costs from cost-oriented prices[4] where all incremental costs are increased by a fixed percentage.

The treatment of common costs highlights a further difference between the traditional approach to incremental costing and the approach recommended by the EC for termination services. In the former case, as noted, a share of common fixed costs would be attributed to termination services and to all other services. However, under the latter definition there is no mark-up to take account of common fixed costs.

1.1.5 Different approaches to estimating LRIC

There are two main ways of estimating LRIC: a top down approach and a bottom-up approach. This model is based on a bottom-up approach.

A top down approach starts with an operator's cost and asset data and uses cost volume relationships to identify the extent to which the costs of the business would change if a particular service or groups of services were no longer provided. In contrast, a bottom-up approach starts with the demand and then calculates the network needed to serve that demand. The model then estimates the costs that efficient operator would incur in serving that demand.

There are several advantages of a bottom-up approach:

4 Otherwise the regulated operator would not be able to fully recover all efficiently incurred costs if all prices excluded fixed and common costs,

- It provides an independent estimate of the efficient level of network costs;
- It is transparent since the data and methodologies used to produce the cost estimates can be seen in the model; and
- It allows the costs of hypothetical networks to be modelled with levels of demand and/or technologies which differ from actual operators.

We provide a more detailed overview of the bottom-up approach and its underlying principles in Section 2 below.

1.2 Services modelled and model outputs

As the purpose of the model is to assist in the monitoring of the SMP operators' compliance with ex ante regulations (as described above), the model estimates the network costs of all the services which are currently subject to those regulations.

The model estimates the total and unit wholesale costs for the following product groups:

- Voice interconnection services;
- Wholesale line rental services (resale of access network and subscriber sensitive element of access node);
- Wholesale infrastructure access services (local loop and sub-loop unbundling);
- Wholesale broadband access services (resale of wholesale line and user defined bitstream); and
- Dedicated capacity (modelled as Ethernet access and transmission as the modern equivalent of leased lines and partial private circuits).

In some cases, such as bitstream, the model costs services under alternative technologies. A full list of services is provided in an annexe to this document.

The SMP operators also provide a number of services that are not directly regulated but which use the same network components. These services are included in order to dimension the network correctly, taking account of economies of scale and scope.

2 Bottom-up modelling process

In this section we present an overview of the bottom-up modelling process. We also describe some of the principles and assumptions which underlie the approach:

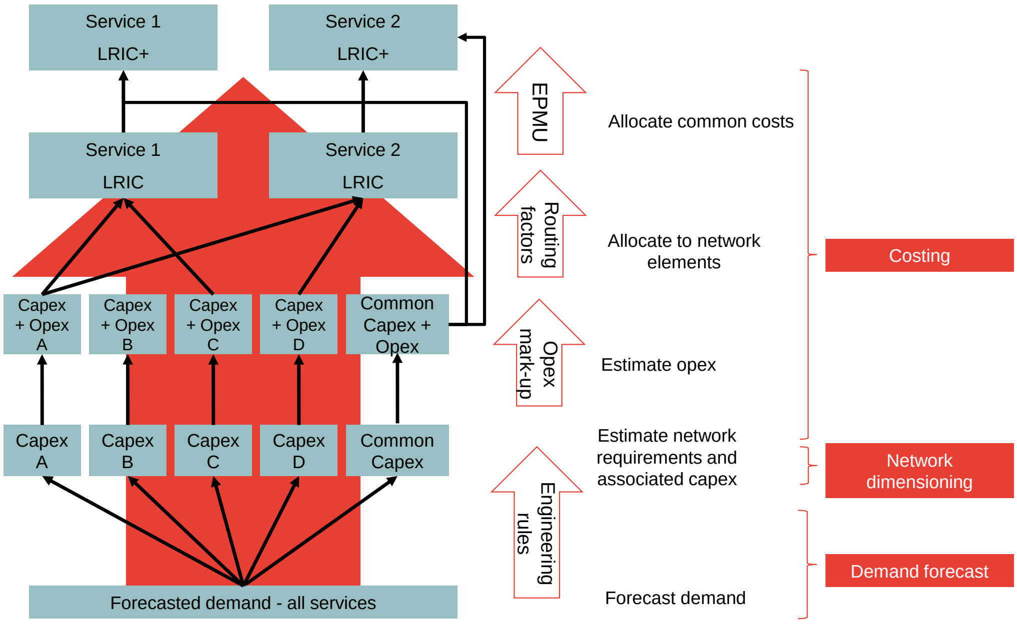
- The time period modelled;
- The use of a scorched node approach;
- The choice of technology for the core and access networks; and
- The division between the core and access networks.

The remaining sections of this document describe the practical implementation of the model itself in terms of the model structure (Section 3), and the calculations in each module (Sections 4-7) and quality assurance of the model (Section 8).

2.1 Overview of the modelling process

The figure below provides an overview of the bottom up modelling process. It can be seen that there are three main stages of the modelling process namely: demand forecasting, network dimensioning and costing. These are described in further detail below.

Figure 1. Overview of the bottom-up modelling process



Source : Frontier Economics

2.1.1 Demand forecast – penetration and traffic

The starting input for bottom-up models is current and forecast levels of demand for services provided across the relevant increments.[5] For services provided over the access network, network size is driven by the availability of services (i.e. network coverage) and number of subscribers. For services provided over the core network, network size depends on the level of traffic generated by subscribers on the access network (both incoming and outgoing).

In the access network, the demand forecast is used to determine the requirements for access infrastructure (e.g. duct and cable).

In the core network, the traffic forecasts is used to determine the forecast peak aggregate traffic intensity, taking into account any quality of service differentials, for each node of the network.

These forecasts feed into the network dimensioning module.

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5 The increment may be defined in terms of services (e.g. "all call services" or "all voice and data services") or in terms of network elements (e.g. "the whole access network" or "the entire core network"). Where the increment is defined in terms of the latter, the relevant list of services is all services that use those network elements.

2.1.2 Network– topology and dimensioning

The next stage of the model determines the quantity of active network equipment and network infrastructure (duct and cable) required to serve the network demand. The quantity of equipment and infrastructure required depends on the network topology and on network dimensioning rules.

Network topology includes the position and location of nodes in the network (e.g. MDFs in the traditional copper network, OLTs in GPON networks and Ethernet switches and IP routers) as well as links between the nodes.

Network dimensioning rules are engineering rules that determine the network equipment required (in terms of configuration and number of pieces of equipment) to serve a given level of demand, given a defined level of resilience and quality of service requirements.

2.1.3 Costing – network and service

Once the volume of equipment and network infrastructure has been determined, the next stage of the modelling process is to determine the relevant cost of that equipment. For each asset category it is necessary to multiply the volume of equipment of each type required by the unit gross replacement cost (GRC) of those types of equipment. GRC should include the cost of installing the assets. As far as possible, the GRCs are estimated for both direct network equipment and infrastructure and for indirect network equipment.

Since assets are used for a number of years it is necessary to calculate an annualised cost for each asset type to recover the expenditure on these assets. The approach is adopted in the model is a tilted annuity formula which shows the combined depreciation and capital charge associated with an asset based on the current GRC.

Operational expenditure refers to the on-going costs of maintenance and associated activities, power, air conditioning and accommodation. Bottom-up models typically calculate the operational expenditure associated with network and non-network assets as a mark-up over GRC. This can be based on the mark-ups on data from operators in Luxembourg and as well as international benchmarks. In addition, for some categories of operational expenditure, it may be possible to dimension the quantity required (e.g. power consumption and air-conditioning) in order to estimate the associated cost.

In the case of some assets such as vehicles, general purpose land and buildings and office equipment it may not be possible to dimension requirements specifically and hence some form of mark-up is needed to take account of these assets. This is applied as a percentage mark-up over annual costs (operational expenditure, depreciation and capital employed).

Once capital and operating costs have been estimated, these are attributed to individual services (either directly for specific assets or in a way which reflects the use each service makes of the network for shared components). The attribution process takes account of traffic volumes, routing factors and potentially other factors to adjust for quality of service issues.

Relevant fixed and common costs (costs that are not incremental but which the regulator determines should be recovered from the regulated services) are allocated to services based on equal proportionate mark-ups (EPMU). The exception to this is the calculation of the pure LRIC of call termination which, by definition, receives no allocation of fixed and common costs.

2.2 Time period modelled

As described in the introduction, the LRIC approach is forward looking. For this reason, the model takes account of future demand growth and network changes. Specifically the model covers a five year forecast period, starting from 1 January 2013, with results available for each year. The model forecast starts from a base year, allowing the model to be calibrated with actual costs and traffic. The time period modelled in other jurisdictions varies from one year (for example in Austria and Germany) to up to 50 years depending on a number of factors. In particular, we note that where long time periods are modelled, this is typically where complex economic depreciation methodologies[6] are used to annualise capital costs. This is because such economic depreciation approaches rely on forecast demand over the lifetime of the network. Such an approach has been used in some regulatory cost models Belgium, Spain and France. Modelling over a five year period allows the model to take account of an efficient structure of the network given medium term demand. For example, where significant growth in demand is forecast over the next few years, it is typically less costly to build a network to meet demand at the end of that period, rather than building a network that can only serve the current level of demand and then increasing capacity each year.

A further advantage of modelling over such a period is that the model covers at least the duration of the current market review and resulting ex ante regulatory obligations. This allows for a reasonable degree of regulatory certainty over the period.

Modelling a longer time period than five years is unlikely to offer significant benefits. This is because the outputs of the model depend to a significant degree

6 Such depreciation approaches determine the annual costs of the hypothetical network in the medium term based on assumptions about the cost of the network over its full lifetime and th relative usage of the network over that period.

on the accuracy of forecasts for demand, technology, equipment prices and many other parameters. Given the rapidly changing nature of the telecoms market (with demand for services such as broadband and data intensive services increasingly rapidly, and volumes for some voice services declining), longer term forecasts are likely to be highly subjective.

Stakeholder question 1

Do stakeholders agree with the time period modelled? If not, please provide evidence and justification to support an alternative time period.

Other comments

Could stakeholders please provide any additional comments they might have on this section.

2.3 Scorched node approach

The model takes account of the location and number of existing network nodes. This is known as a "scorched node" approach and is consistent with international best practice. Under this approach, bottom up access network models are typically based on the existing number of nodes, although the technologies and equipment employed at these nodes often differs from the currently installed technologies and equipment.

The alternative ("scorched earth" or "greenfield approach") considers a fully optimised network, independent of the current location of equipment. Under this approach, the number and location of nodes would be optimised based on the number and location of subscribers, the demands these subscribers place on the network and any known limitations on the siting of nodes. While the scorched earth has some intuitive appeal, it gives rise to a range of practical difficulties. Further, it takes no account of the time it would take to move from the current network structure to the idealised structure, which itself may change significantly over time. For these reasons, the current model, in common with bottom-up models used by regulators in other jurisdictions, is based on the scorched node approach.

A scorched earth approach may lead to an over-estimation of potential efficiency savings. This is because even an efficient operator does not have the option to relocate nodes instantaneously and without cost in order to continually optimise the network to reflect current demand and technology. Further, a scorched earth approach is also computationally more complex since there are more degrees of freedom.

While the model adopts a scorched node approach, sensitivities are run on the impact of varying the number of nodes from that in the current network. The access network is currently evolving in light of changing technologies which will provide a network operator with an opportunity to change the location of access nodes as the current "anchor asset" – the main distribution frame – is being replaced. In determining the number and location of nodes, the model allows sensitivities to be run on the number and location of nodes, although without running a full scorched node approach. This sensitivity analysis will provide information on the potential impact on costs of variations in the number of nodes.

Stakeholder question 2

Do stakeholders agree with the scorched node approach? If not, please describe an alternative approach and the underlying rationale for suggesting such an approach.

Other comments

Could stakeholders please provide any additional comments they might have on this section.

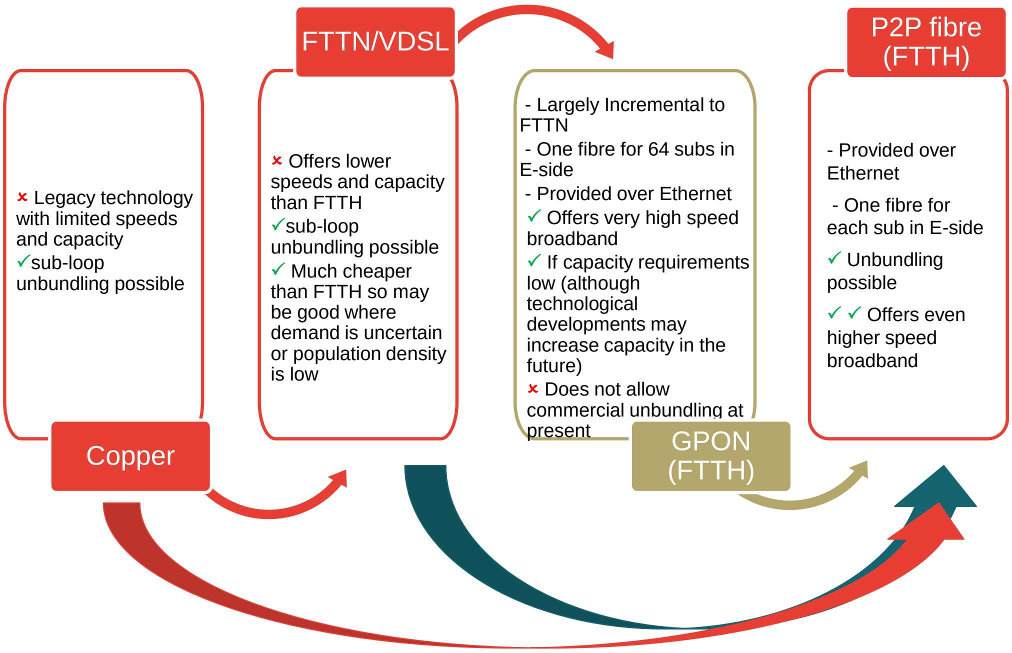
2.4 Choice of technology

As described in Section 1.1, LRIC is a forward looking concept and reflects the costs that an efficient operator would incur if it rolled out its network today. Therefore, the model includes fibre technologies in the access network and an IP based core. However, as described below, it is also necessary to consider the cost of the copper access network, the legacy technology, in the access network as copper based access products are likely to predominate during the forecast period.

2.4.1 Choice of technology in the access network

The figure below summarises how available technology in the access network has evolved over time and the relative advantages and limitations of these technologies.

Figure 2. Evolution of technology in the access network



Source: Frontier Economics

A traditional copper network can provide ADSL based broadband services also including wholesale "bitstream" services. However, the speeds available to each subscriber are limited by the length and quality of the copper loop.

Installing fibre from the cabinet to the exchange (sometimes referred to as the E-side) allows a move to FTTC. This is sometimes also known as FTTN (fibre to the node). FTTC with VDSL allows higher broadband speeds than ADSL. The cost of upgrading an existing copper network to FTTC is significantly lower than installing an FTTH in place of the existing copper network.

FTTH can deliver higher peak speeds than FTTC. Two forms of FTTH architecture are commonly used in access networks:

- Point to point (P2P) where a dedicated fibre (or fibres) is used to connect premises to an active access node; and
- Gigabit passive optical network (GPON) where each fibre from the active access node is shared between a number of premises, with passive optical splitters at intermediate points, splitting the signal between the premises.

While P2P fibre offers higher theoretical bandwidth than GPON, as there is no shared use of fibre, roll outs of FTTH networks internationally have been a mix of technologies, indicating that maximum theoretical bandwidth is not the only factor to consider.

In theory, there could be re-use of certain network components during a transition from traditional copper access networks to higher speed networks. This is possible if:

- There is unutilised duct capacity available, since all technologies can use the same network of ducts;
- The copper "sub-loop" from the customer to a distribution point is re-used in FTTC;
- Fibre cable in the feeder network could serve both FTTH and FTTC; and
- Fibres connecting premises for GPON could be reused for P2P fibre.

While the move from a copper access network to FTTC can be seen as an evolutionary path to an all fibre access network, this is something of a simplification in some respects. For example, a move from an all copper network to FTTC involves the installation of MSANs in the cabinets. However, these MSANs are not required in either a FTTH network and hence could become stranded assets if the investments in these assets were not fully recovered. Also, the economics of different technologies may differ between areas. For example, in metropolitan areas the per subscriber roll out costs of FTTH may be relatively low because of high subscriber density while the costs of installing FTTH may be relatively high in rural areas. As a result it may be more difficult make a return on roll out in rural areas. If, in addition the demand for ultrafast broadband is higher in metropolitan areas due to the high concentration of large business user, this can increase the difference in the returns in different areas.

The fact that the economics of different technologies may vary by location means that it may be rationale for an efficient network operator to run a number of technologies in parallel, even in the medium to long term. Hence, the costing model allows for the parallel running of technologies.

In the long term, many fixed telecoms operators internationally are rolling out fibre-based networks, although the extent of fibre roll-out differs significantly between countries. In Luxembourg, fibre has been rolled out extensively to the cabinet with high coverage. FTTH roll out has been slower, based on GPON initially but with P2P now being rolled out. However, we understand that existing GPON networks will continue to operate in the medium term. Further, EPT still operates and maintains the copper network to provide legacy services and this is likely to remain in place in the short to medium term since the one off costs of forcibly migrating customers to new networks are high. Therefore, the ILR considers it appropriate to design the model to allow the estimation of the costs of the dual running of networks. Given this, we propose to model the following technologies in the access network:

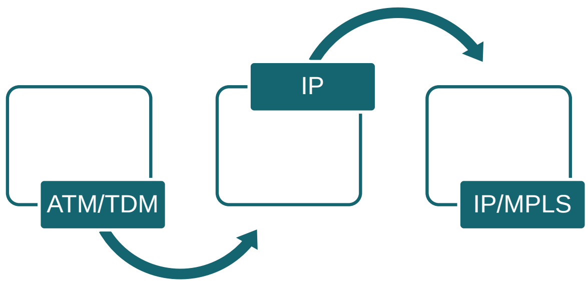
- Full modern equivalent asset (MEA) – fibre with P2P architecture;
- Fibre with PON (GPON);
- Fibre to the cabinet with VDSL (FTTC); and
- Combinations of the above.

As the model is of an efficient operator, when modelling combinations of different technologies, the model allows the modelling of different scenarios of migration of new subscribers to new technologies over time.

2.4.2 Choice of technology for the core network

The figure below summarises the evolution of technology in the core network.

Figure 3. Evolution of technology in the core network



Source: Frontier Economics

Currently, most fixed incumbent operators continue to convey voice traffic over TDM networks, relying on packet switched networks to deliver broadband data services (initially ATM based but now generally IP based). In the past, IP-based packet data networks were not considered to provide sufficient quality of service to replace TDM networks. However, IP/MPLS networks now provide sufficient quality of service to deliver voice, broadband data and other services, such as leased capacity.

If an operator were to roll out its network today, it would not use a TDM-based PSTN for voice with an IP overlay network for data. Indeed, TDM switches are no longer produced. Instead, a forward looking operator would use an all-IP NGN technology.

We understand that EPT continues to use legacy TDM technology to carry a large proportion of voice traffic while SDH equipment is used both to transmit voice traffic and also leased lines and other data services.

While this parallel running of networks is not efficient within a narrow definition of LRIC, overall costs may be minimised by the use of legacy technology in the short term due to switching costs (that is, the cost of migrating subscribers across to a new technology). However, setting wholesale prices based on obsolete TDM equipment would not result in efficient competitive outcomes. In order to ensure that competitors' build or buy decisions with respect to entry and/or expansion will result in cost minimisation, wholesale prices would need to be based on the cost of current technology. Therefore, in order to ensure correct pricing signals, the model is based on an all-IP core network.

There are also practical advantages of this approach. In particular, the resources required to model a TDM core network on a bottom-up basis would not be justified by the short expected life of the network. In addition, the capital costs of a TDM network would be merely notional as the equipment is no longer available for purchase so any replacement costs estimates would have no robust basis. Further, the ILR's proposed approach is suggested in the EC recommendation relating to termination rates.[7]

Stakeholder question 3

Do stakeholders agree with the technologies modelled in the core and access networks? Where stakeholders propose that alternative technologies should be modelled, please describe the rationale for doing so.

Other comments

Could stakeholders please provide any additional comments they might have on this section.

2.5 Distinction between access and core networks

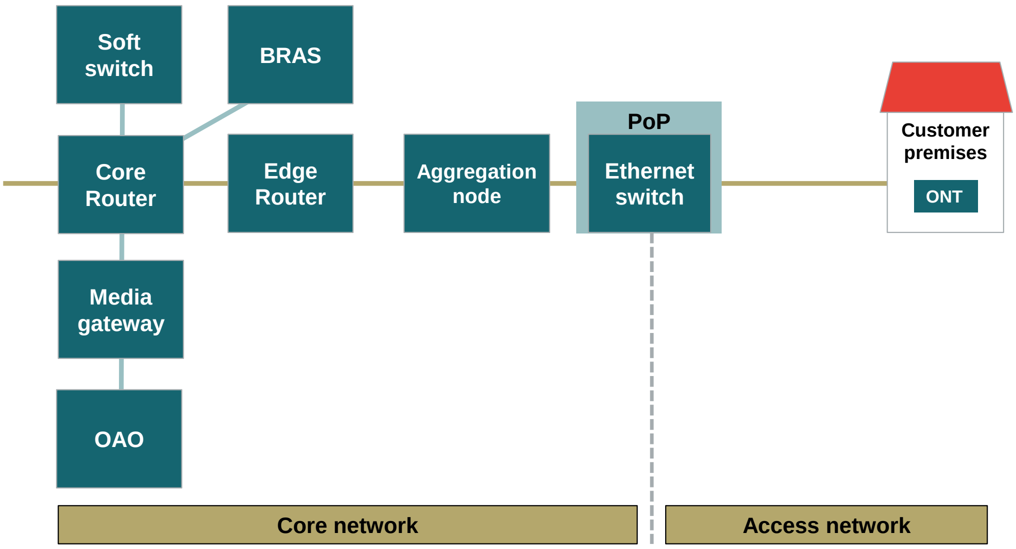
The distinction between access and core networks is an important one in developing a bottom-up model and costing the services in such a model. In the current model, we make a further distinction between the regulatory costing and the modelling of access and core services.

Specifically, from a regulatory costing perspective, the access network includes all costs between the subscriber and the first active network element (which could be an MSAN, OLT or Ethernet switch). In addition, the access network includes the line card within the first active elements and any overhead costs associated with the line card. The core network includes the traffic driven parts of the first active network element, as well as all other active network elements and the trench, duct, fibre and transmission links between these elements.

7 EC Recommendation of 7 May 2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU (2009/396/EC).

The figure below provides an overview of access and core network technologies in an FTTH P2P network. As can be seen, the access network consists of the ONT, the passive network elements from the subscriber to the Ethernet switch and also includes the line card within the Ethernet switch. The core network consists of the remainder of the Ethernet switch, the aggregation nodes, routers, media gateways and soft switches and also the BRAS. In addition, it includes the infrastructure links between nodes.[8]

Figure 4. Overview of core and access networks



Source: Frontier Economics

Based on the regulatory definition, the dividing line between the access and core networks may vary according to the technologies used. This is described in further detail in Annexe 3.

However, from a modelling perspective the model is split into:

- Infrastructure (trench, duct, copper and fibre costs);
- The costs of the network elements themselves; and
- Associated overheads such as power and air conditioning equipment.

This means that the infrastructure part of the model includes the trench, duct, copper and fibre in the access network and also includes the trench, duct and

8 Where trench and duct routes are used both by the access and core networks the trench and duct is a common fixed cost. A further advantage of the modelling approach used here is that makes it easy to identify common fixed trench and duct.

fibre in the core network. A further implication of this approach is that the first active network element includes both line driven elements (notably the line card) and traffic elements.

While there is a large degree of correlation between the passive elements and the "access" network, and between the active elements and the "core" network, this correlation is not perfect as shown in the table below.

Table 1. Relationship between core/access and passive/active

	Core	Access
Passive	Duct used for transmission between active nodes Cable used for transmission between active nodes	Feeder network duct Distribution network duct Access copper cables Access fibre cables Splitters Flexibility point chambers
Active	Switches Routers Application servers Transmission equipment	Access node line cards

Source: Frontier Economics

The advantage of this approach is that it allows assets of similar types to be modelled together. Hence, passive network elements are modelled in one part of the model and active network elements in another part of the model. At the same time, it is straightforward to produce costing outputs which are consistent with the traditional split of access and core costs.

A further advantage of this approach is that it allows for easier consideration of a range of technologies as it is sufficiently flexible to take account of how the dividing line between the core and access network changes with the access network technology.

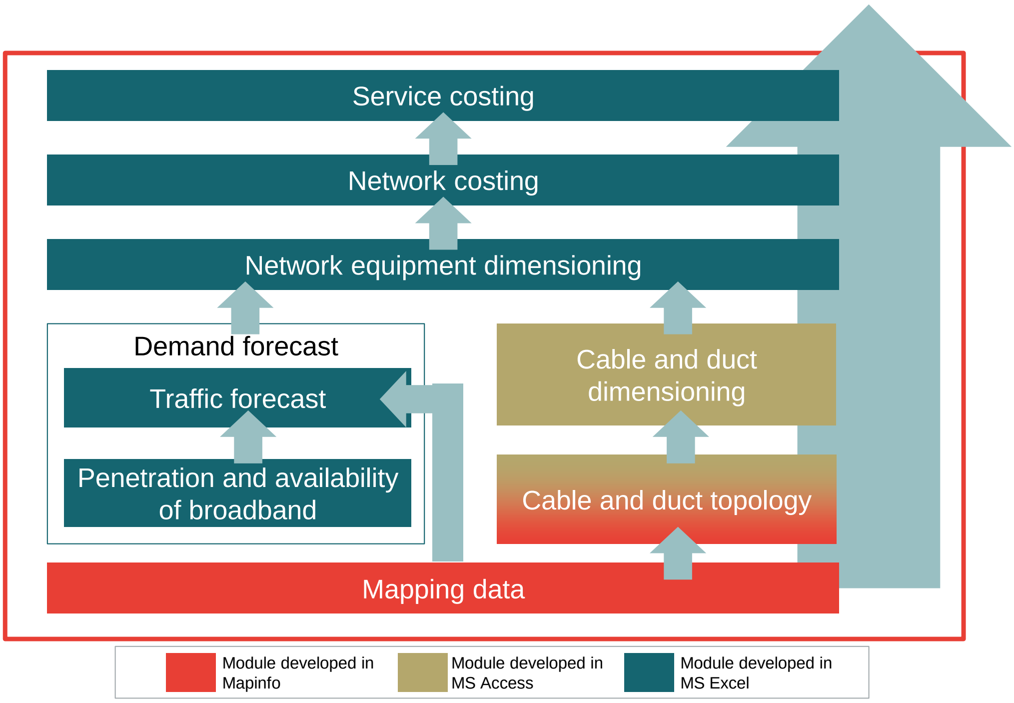
3 Model structure

As described in Section 2, the bottom-up modelling process consists of three main stages:

- Development of demand forecast;
- Calculation of network requirements; and
- Costing.

The model is therefore structured in three modules, each of which corresponds to one of the stages. The model is developed using Microsoft Office and using MapInfo software to analyse the geographic information system (GIS) data. The colour coding in the figure below indicates the software that is used for each calculation step. For efficiency reasons the parts of the model conducted in Excel have been consolidated in a single file. Due to the volume of geographic data used, the MS-Access model consists of a number of linked databases. Section 3.4 describes how the central model control panel ensures consistency between the different files.

Figure 5. Modules, calculation steps and software used in model



Source: Frontier Economics

3.1 Demand forecasting module

There is a single demand forecasting module for both subscription services (delivered over the access network) and traffic services (delivered over the core network). This enables the forecasts to be internally consistent.

This module is developed in Excel. The underlying methodology for this is described in Section 4 of this report.

Using Excel has a number of advantages, for example:

- It is widely accessible which allows easier updating of the model; and
- It does not require expensive software that is only proprietary to a narrow user group.

3.2 Network requirements modules

The network requirements modules start by setting out the structure of the network in terms of routes and nodes (topology) and then dimension the network equipment given this topology.

The module to calculate the duct network topology is developed in GIS (MapInfo). This allows for the consideration of detailed road and address mapping data and means that trench and duct can be laid out a way which is consistent with the actual road network of Luxembourg.

The network dimensioning process is based on the outputs of the demand forecasting module as well as routing factor information, information on equipment modularities and other factors.

The module to calculate the passive network dimensioning is developed in Microsoft Access. The advantage of Access over Excel is that it is better suited to handling large datasets.

The modules to calculate the core network dimensioning is developed in Microsoft Excel. The topology of the core network is largely based on inputs, i.e. a scorched node assumption.

3.3 Costing module

There is a single costing module based on the output of the demand module, in terms of demand and the network requirements module in terms of an inventory of equipment. This module:

- Calculates the GRC of direct and indirect assets;
- Calculates annualised costs for the above;
- Calculates total annualised costs (annualised capital costs plus operational expenditure);
- Calculates network element and service costs; and
- Applies mark-ups as appropriate;

This module is described in further detail in Section 4.

3.4 Model control

The model is controlled using:

- Centrally controlled key assumptions; and
- Specific assumptions for each module.

These are used as inputs to each module to ensure consistency between the assumptions used in each module. This also enables the model user to more easily identify the impact of changing key assumptions.

4 Demand forecast

This section sets out how the model forecasts the demand for subscription and traffic services that the network needs to serve. As set out in Section 2.1.1, demand estimation starts with current and projected availability of services and associated penetration. This is described in further detail in Section 4.1 below. This is then used to estimate usage and traffic forecasts (see Section 4.2 below). Therefore, there are two parts to this module:

- Customer accesses; and
- Traffic forecast.

4.1 Customer accesses

This part of the module calculates the number of active lines (broadband, voice and corporate connections) by network point of presence (except for lines provided over legacy copper, which are calculated by remote aggregation node).

The first part of the demand calculations is an estimation of the country level of demand split between broadband, voice and corporate connections for different customer segments (residential and business). This is determined on an aggregate basis without considering the access network technology used to provide services. This estimation can take account of a number of different factors including:

- Historic levels of growth in the market;
- Industry forecasts of demand for higher speed products;
- Demographic factors (e.g. population growth or trends in household size); and
- Macroeconomic conditions.

The second step is to estimate what share of this market demand is served over the modelled network on an aggregate level (i.e. including both retail and wholesale level services, in other words, directly by the modelled operator or by an alternative operator using the modelled network operator's infrastructure).

The third step is to estimate what share of the modelled operator's demand is served over different types of access network technology. This is based on assumptions of the rollout of each technology on a national basis. The implicit assumption is that rollout happens on a pseudo-random basis. We understand that this is consistent with EPT's roll out strategy to date which has focused on ad hoc rollout of new technologies (e.g. in roads where the roads are being dug up by other utilities companies) rather than targeting particular areas (e.g. those that are high density or high income areas).

The final step is to estimate demand (accesses and traffic) at the level of each point of presence. The model uses address and electricity billing data to determine the number and location of all residential and business premises in order to identify all potential subscribers. Premises are then grouped at the level of POPs. This is used to estimate the "spread" of subscribers across different POPs. This approach implicitly assumes that take up is the same in each area.

4.1.1 Wholesale versus retail subscribers

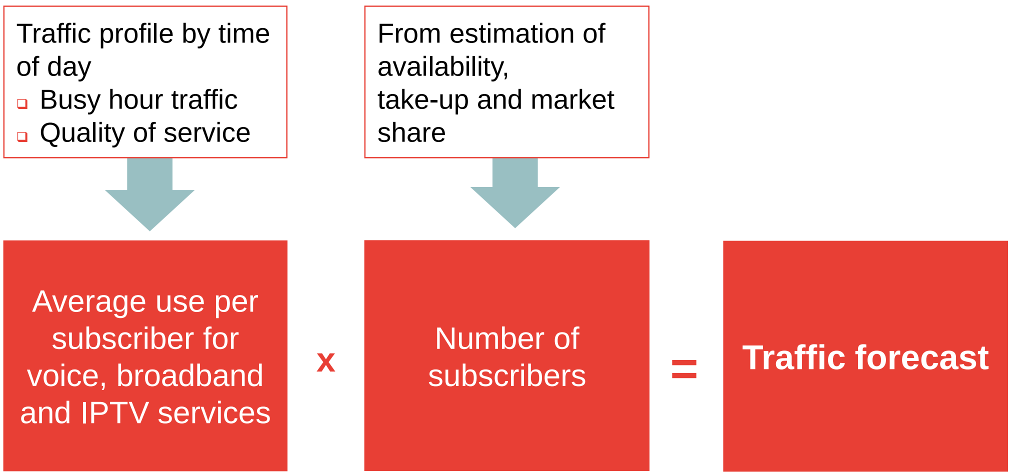
Since wholesale and retail subscribers place different demands on the network, it is necessary to determine the split of the subscriber base (calculated as described above) between wholesale and retail subscribers.

4.2 Traffic forecast

The dimensioning of core network elements is driven by busy hour traffic requirements. Therefore, the model takes account of how different types of customers use the services modelled and how these in turn place different demands on the network.

The figure below provides a summary of the way in which the model calculates the traffic that the modelled network will need to serve. These calculations are described in further detail in the rest of this sub-section.

Figure 6. Overview of traffic forecast calculations



Source: Frontier Economics

The model takes the forecasted number of subscribers (calculated as described in Section 4.1 above) and multiplies this by estimates of the traffic per subscriber (voice and data) in order to determine the total traffic per street segment, node and nationally. Assumptions relating to the average usage per subscriber may vary by technology (for example, we might expect that FTTH subscribers would have a higher usage than ADSL subscribers since they would be more likely to use fibre based technologies to access higher speeds). Wholesale customers are expected to be similar to retail customers on the network. The model also contains the flexibility to consider how average usage per subscriber may change over time. For example, voice traffic per subscriber may fall over time as people use alternative forms of communication more.

Broadband capacity is offered on a 'best effort' basis. That is, subscribers are not guaranteed the speed that they subscribe to. The maximum speed is only available during periods where the network is not congested.

Voice traffic is based on the forecasted number of voice subscribers and the traffic per subscriber for different types of call. The total traffic based on these forecasts is subject to busy hour assumptions – i.e. the maximum amount of concurrent traffic during the day. While voice traffic in an NGN is converted to data traffic it is still necessary to make a distinction between broadband and voice traffic. This is because, as described above, broadband is offered only on a 'best effort' basis while voice is a real time service. The distinction is therefore necessary to ensure that the relevant quality of service (QoS) factors are applied to the appropriate data volumes.

The network is dimensioned according to the average bandwidth available/used per subscriber in the busy hour, taking into account the quality of service requirements of the different services.

4.3 Output of the demand module

The output of the demand module is on demand on a POP basis and a national level for:

- Accesses by different product type (voice, broadband and corporate data lines); and
- Traffic by different product type and quality of service (best effort, real time, and so on).

This is used in the network module and for service costing.

Stakeholder question 4

Please comment on the proposed approach to forecasting demand.

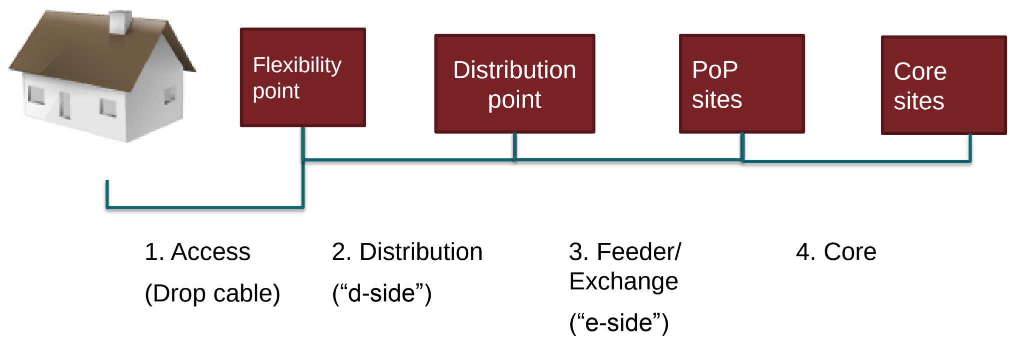
Other comments

Could stakeholders please provide any additional comments they might have on this section.

5 Cable and duct network requirements

This module covers the cable and duct network for both the core network (between network nodes) and the access network (from network nodes to end users). This is illustrated in the figure below. The module dimensions the amount of infrastructure required based on potential demand (i.e. number of business and residential customer premises rather than the forecast number of subscribers) and assumptions relating to technical specifications of infrastructure.

Figure 7. Modelled passive network structure



Source: Frontier Economics

The largest part of the cable and duct network falls within the access network. However, this module also covers cable and duct in the core network. Duct may be shared between the core and the access network.

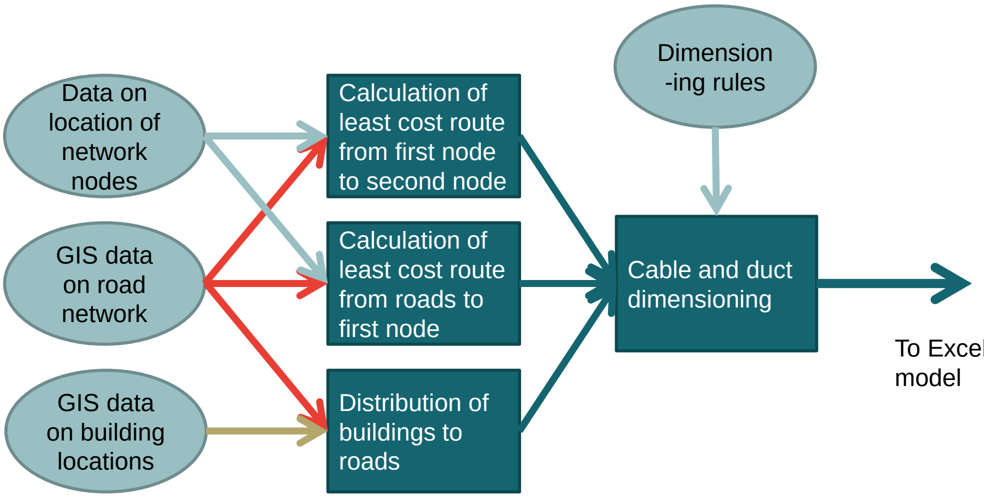
Cable and duct network requirements are driven by coverage requirements rather than the demand forecast in the demand module described in Section 4 above[9]. That is, this module considers the number and location of business and residential premises in Luxembourg and builds a network to allow these premises to be connected to the network. Premises are defined to be individual units within a building consisting either of potential residential subscribers (household premise) or business subscribers (business premise). This module also considers data on the road network in order to determine route distances. Therefore, in order to dimension the cable and duct requirements for the access network, the following information is required:

9 The dimension of the cable and duct network is generally independent of the amount of traffic generated by customers. While cable in the "core" network, is driven to some degree by the total volume of traffic in the core network, this is a small proportion of total costs.

- Locations of potential subscriber premises;
- Location of nodes where network equipment is sited;
- Road network data; and
- Technical characteristics to dimension the network.

This is illustrated in the figure below.

Figure 8. Input data and calculations



Source: Frontier Economics

5.1 Requirements for geographic data

This module uses a range of geographic data that is specific to Luxembourg. In particular:

- Complete address data on buildings in Luxembourg that should be connected to the network including information on which buildings are currently occupied and the number of potential customer premises (business and residential) in those buildings;
- Location of current EPT network sites in coordinate format (current sites and potential additional sites); and
- Road network data with routing information (links between roads/ intersections) for Luxembourg.

Given the relatively small size of Luxembourg, the model is based on complete data for the whole of the territory, rather than using a sample approach, which is typically used in larger jurisdictions.

5.2 Overview of approach to modelling cable and duct network requirements

In order to estimate the amount of duct and cable network required to meet potential levels of demand, this module of the model performs a number of different calculations. These are summarised in the bullet points below and then described in further detail in the rest of this section.

- The module uses information about the location and number of potential customer premises in Luxembourg.
- The number of nodes in the access network is set based upon a scorched node assumption (see Section 5.3).
- An algorithm is run which connects street segments, and hence the premises in these street segments, to the closest distribution points (DPs) using a least cost route. As a second stage a similar algorithm determined which DPs are served by which PoPs (i.e. which subscribers are served by each node, see Section 5.4).
- The model then calculates how the core network is routed (see Section 5.5). This is done in two stages. First, by building an efficient spanning tree that connects all of the nodes in the network (i.e. connecting all PoP sites using the shortest route to the nearest aggregation node site). And second, a spanning tree is also used to connect all core sites to a single core site in Luxembourg.
- Once the route of cables has been determined, the model then calculates the length and size of cable required. This takes account of cables in both the access and the core network (see Section 5.6).
- Using the length and size of cables required, the model then calculates the length and number of ducts required to carry these cables (see Section 5.7)
- The outputs of the model are then summarised for use in the rest of the model (see Section 5.8).

5.3 Scorched node approach

The model is based on a "scorched node" approach.

In this context the term "nodes" refers to the sites where network elements are installed. In theory, the position and number of nodes could be optimised using algorithms which take into account factors including:

- The geographic dispersion of end user premises;
- The availability of sites for network nodes;
- The trade-off between the length of the duct network and the number of nodes; and
- Physical constraints on the length of access lines and the size of access nodes.

However in practice it is difficult to appropriately model such an optimised "scorched earth" network topology. In general a 'scorched node' approach is used, where the location of existing nodes is used as the basis for the model. Part of the reasoning for this approach is that it would be costly to relocate network nodes due to the high level of sunk costs.

In order to simplify the calculation, the base case of the model is based on the existing PoP sites in EPT's FTTH network, as well as the FTTC nodes in the case of FTTC. Aggregation nodes are assumed to be located at sites where EPT has local exchanges in the legacy TDM network.

In theory, under FTTH technologies such as GPON and P2P, the efficient number of nodes required is driven by a range of factors, such as:

- Attenuation – fibre nodes can serve customers over much longer distances implying that in theory fewer nodes are required than in an all copper access network;
- Cost minimisation; and
- Network resilience (availability and security)[10].

5.3.1 Analysis of number of nodes

As described in Section 2.3, the model uses a scorched node approach when modelling the network. However, to take account of the evolving nature of an efficient operator's network and the rollout of new technologies, the model will

10 According to EPT, the issue of supply interruption in Luxembourg is sufficient to justify an increase in the number of nodes required for FTTH compared to copper.

consider how results vary with the is number of nodes. This analysis of the number of nodes will aim to model the overall cost of the network while recognising the need for network security (in other words, the need to provide sufficient resilience and redundancy in the network to ensure an acceptable level of quality of service).

Changing the number and location of nodes in this way (i.e. as an input assumption) allows the model to consider what the implications are for other parts of the network and therefore the costs.

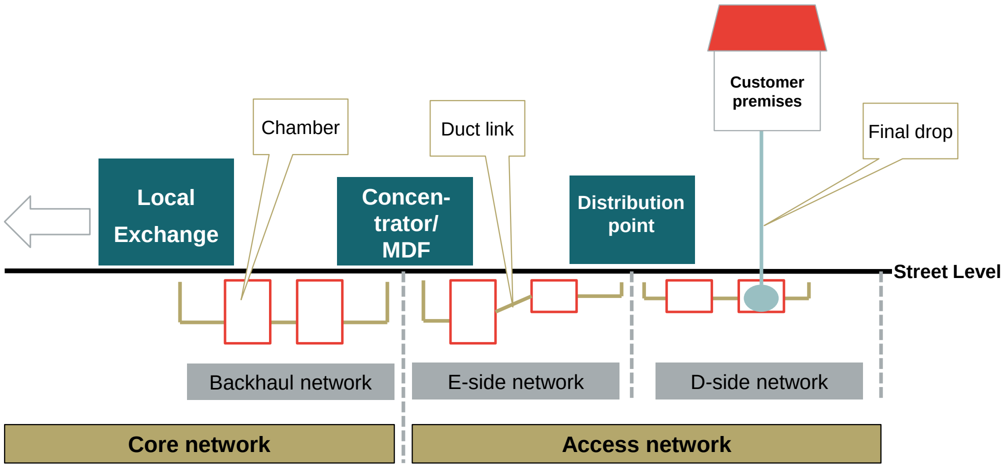
5.4 Determining which subscribers are served by which nodes

5.4.1 Access network topology

The figure below illustrates how the network can be split into the D-side and the E-side (also known as distribution and feeder/exchange, respectively). The E-side is the part of the network between the first active element, in the diagram this is the concentrator, and the distribution point. The D-side is the part of the network from the distribution point to the subscriber premises (including the final drop). In quantitative terms, by far the largest part of trench and duct falls into the D side of the network[11].

11 Which is a major reason why it is much cheaper to move from an all copper network to FTTC than it is to move to FTTH

Figure 9. The traditional access network can be split into D-side and E-side



Source: Frontier Economics

The model connects customer premises to nodes through a multi-stage approach.

The model determines which subscribers are served by which nodes by:

- Defining street segments – i.e. sections of roads/streets – based on the road and mapping data;
- Using address data and road network data to determine which road segments have buildings (and therefore potential customer premises) adjacent to them;
- Determining which street segments are served by each DP by minimising the distances between street segments and DPs;
- Determining which DPs are service by each PoP site by minimising the distance between street DPs and PoPs.

The least cost routes used to determine the mapping of premises to roads is also used as the routings for cables, and hence the extent of the duct network.

5.4.2 Defining street segments

The model uses road and mapping data to determine which street segments have buildings on them. The model excludes road segments with no buildings on them since they do not need to be connected to the access network. The model does not consider future buildings in empty streets since it is not possible to forecast where these will be. Further, the number of new buildings over the modelled period is likely to be sufficiently small as to have limited impact on the overall model results.

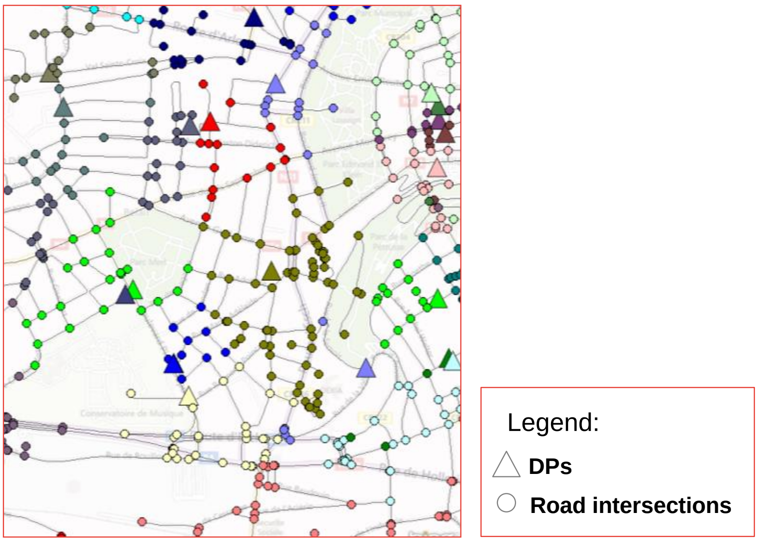
5.4.3 Assigning buildings to distribution points

The model attempts to minimise cable length and provide for an efficient distribution duct network connecting all the buildings to distribution points.

A mapping algorithm assigns all street junctions in Luxembourg to the distribution point (or site of a node in the FTTC network) which is nearest to that street junction. The distance measured is the shortest distance along the road network (rather than as the crow flies). This defines Voronoi polygons around each of the DPs.

Each street segment can then be assigned to a DP by looking at which Voronoi polygon each end of the road segment is in – where the two ends of the road segment are in the Voronoi polygons around different DPs, the street segment can be allocated based on which end of the road segment is nearer the respective DP. An illustrative example is provided in the figure below.

Figure 10. A mapping algorithm assigns buildings to DPs

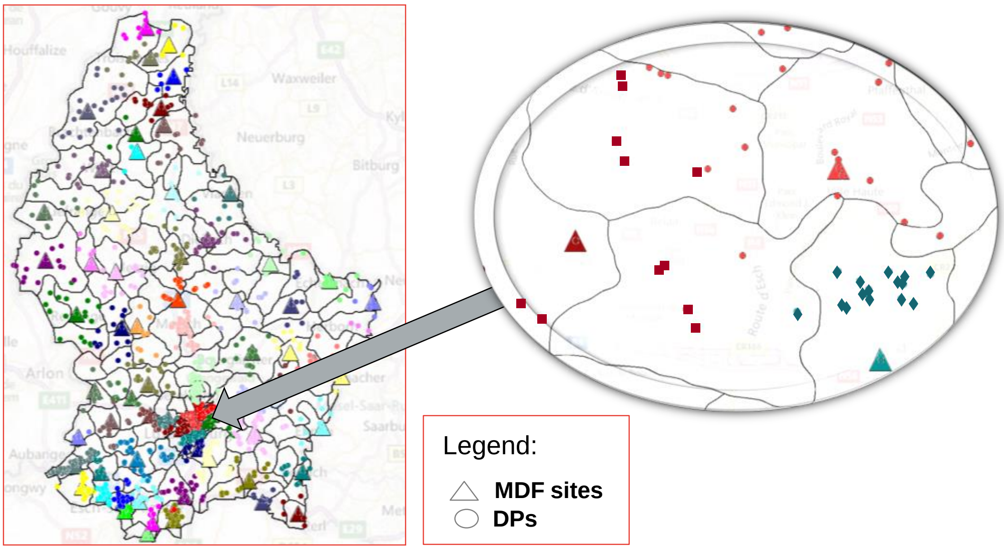


Source: Frontier Economics

5.4.4 Assigning DPs to PoP sites

A similar approach to the one assigning building to distribution points is used to allocate DPs (and hence the customers served by the DPs) to PoP sites. In particular, Voronoi polygons are created around the PoP sites in Luxembourg. DPs are then assigned to PoPs based where they are sited in the respective Voronoi polygon around the PoP.

Figure 11. Voronoi polygons are used to allocate DP to PoP sites.



Source: Frontier Economics

5.4.5 Access network routing

The model determines routes along which cables run from end user premises to PoP sites, via DPs. These routes are made up of three levels:

- Routes along the road segments where there are buildings;
- Routes form road segments to DPs; and
- Routes from the DP to the PoP site.

These routes are used to determine both the cable requirements and the need for duct along routes (on street segments where no cables are routed there is no need for duct).

Cables on street segments

In order to determine the routing of duct and cables, the model identifies which side of the street each building is on. As a result street segments where buildings are sited can be divided into two groups:

- Those with building only on one side of the street; and
- Those with buildings on both sides of the street.

In the first case we assume that cables are only routed down the side of the street where the buildings are sited, along the whole street segment.

In the second case we assume that cables are routed along the whole street segment on the side of the street where the majority of buildings are sited (the 'primary' side). Buildings on the other side of the street (the 'secondary' side) are assumed to be connected via a duct across the street, and then a length of duct sufficient to serve all of the buildings on the secondary side.

The location of DP and PoP sites is based on data provided by EPT in response to the data request described under 5.3.1 and detail of current and proposed FTTH sites in EPT's network.

Street segments to distribution points

Cables are assumed to be routed from street segments to the nearest DP (measured from the ends of the street segment). The algorithm used to determine Voronoi polygons, also derives the shortest route between any road junction and the nearest DP using the road network and this route is used for the routing of cables.

Distribution points to PoP sites

Cables are routed from DPs to the nearest PoP site using the shortest route over the road network. This route is derived as part of the calculations of Voronoi polygons around the PoP sites.

5.5 Core network route network

The aim of the core route network design is to build an efficient spanning tree that connects all of the nodes in the network. The model assumes that sufficient resilience can be built into the network through redundancy in equipment, without route diversity being necessary (route diversity would imply a network of loops rather than a spanning tree) given the highly centralised nature of Luxembourg.

The spanning tree is built in two stages:

1. All PoP sites are connected via the shortest road route to the nearest aggregation node site; and
2. All aggregation node sites are connected to a core network site in Luxembourg.

This results in a short physical route network connecting all core sites in Luxembourg. Links between any two nodes can be delivered over this network.

For the first stage, the PoP sites are assigned to sites where local exchanges are currently sited in the legacy TDM network which are assumed to house aggregation nodes, by defining Voronoi polygons around each local exchange site using the same underlying algorithm as used in the access network. The routes between the PoP site and aggregation node site is then determined as the shortest route between the PoP site and the aggregation node site over the road network.

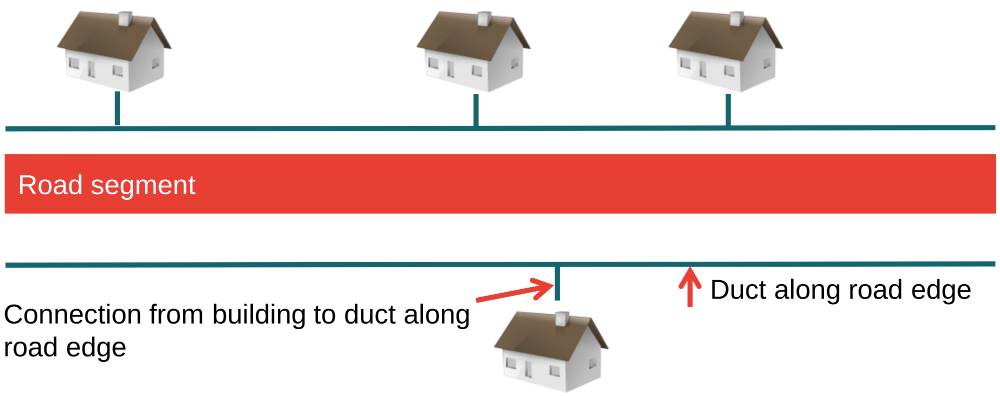
For the second stage, the shortest route along the road network between each aggregation node and one core network location in Luxembourg City is defined.

5.6 Cable dimensioning

5.6.1 Street segments with buildings

There is assumed to be a cable running along the street segment to each building connected to the network. This is illustrated in the figure below.

Figure 12. Street segments with buildings



Source: Frontier Economics

The number of copper pairs and fibres per connected household or business premise in these cables is an input assumption. The number of pairs/fibres per building takes account of the number of potential subscribers in each building. The model assumes that there are up to four occupants in a single household premise. Where there are more than four residential occupants in a building, the model assumes three people per household premise. This approximation results in an average household size in 2.6 persons which is close to the actual average for Luxembourg.

The size of the cable along each side of the street is a function of the number of potential end users on that side of the street. It is assumed that on at least one side of the street, the cable runs the length of the street. On the other side of the street, the length of cable and hence duct, may be shorter if there are few buildings on that side of the street.

5.6.2 Distribution network

The approach to cable dimensioning is based on a number of inputs:

- The number of pairs/fibres required per potential customer in the distribution network;
- The number of potential customers located in each street segment;
- The routes from the street segment where potential customers are located to the DP, consisting in a list of the street segments between these two points; and
- Details of the potential cable sizes available.

Copper

For each street segment which is on one or more routes from street segments to buildings to a DP, copper distribution is installed based on the requirement of all buildings served by these routes. Those street segments nearer to the DP are likely to serve a larger number of end users and hence cables with more pairs are installed in these routes.

The total requirement for copper pairs in this segment is calculated as the number of customers potentially served along this route (the sum of the customers on street segments who route passes along this street segment) multiplied by the number of pairs installed per customer. The number of pairs includes an allowance of "spare pairs" in case of faults by applying an uplift factor to the number of pairs required.

The cable along the street segment is then dimensioned to be the minimum cable size (in number of pairs) that provides the required number of copper pairs. Cables increase in size nearer the DP, as these road segments serve an increasing number of premises.

Fibre

The dimensioning of fibre cables is somewhat different. Given the relatively high costs of splicing fibre cables, the model assumes that a single cable runs from each road segment where potential customers are located, to the DP along the route specified. This compares to the approach in the copper networks where it is assumed cables are spliced together such that cables with higher numbers of pairs are used closer to the DP. For fibre there are simply a greater number of cables closer to the DP.

The size of fibre cable in the distribution network required to service each road segment with buildings is estimated by multiplying the number of potential users by the number of fibres provided per user. The minimum dimension of fibre cable which can provide at least this number of fibres is then calculated. The length of the fibre cable is then calculated based on the length of the route from the end of the road segment with buildings to the distribution point.

5.6.3 Feeder network

The approach in the feeder network is similar to that in the distribution network being built up from the following information:

- The number of potential customers served per DP;
- The number of fibres/pairs provided in the feeder network per potential customer per technology;
- The routes from DPs to the PoP sites; and
- The available cable sizes.

Copper

The number of copper pairs required in the feeder network between the PoP and the distribution point is calculated by multiplying the number of potential customers served by the DP by the number of pairs provided per potential customer, including an allowance for spare pairs in case of faults by applying a mark-up to the estimated number of pairs.

For each road segment on a route from one or more DPs to the PoP, the minimum copper cable size (in number of pairs) which provides sufficient pairs to serve the potential customers served by the DPs, is selected.

Fibre

Fibre cables are installed along the routes from DP sites to PoP sites taking account of the requirement for fibre from GPON, FTTC and P2P fibre.

The requirements for fibre from the DP sites (where MSANs are sited in FTTC networks or splitters in GPON networks) is relatively small, given that in both cases traffic from a number of subscribers is concentrated into a smaller number of fibres. As a result the number of fibres required is a fraction of the number of customers served with the assumption on the number of customers that can be served per fibre as input assumption.

For P2P fibre, the fibre requirements are based on a multiple of the number of customers served, allowing for some spare capacity.

The size of fibre cable which provides sufficient capacity from the DP to the PoP for all three technologies is calculated, with the cable length being the distance along the road network from the DP to the PoP site.

5.6.4 Core network

High fibre count cables are dimensioned along the routes between core network nodes. This over-dimensioning provides for existing services to be served with the ability to upgrade technologies without first de-commissioning existing technologies. The length of the cable reflects the routes between the nodes.

5.7 Duct network

5.7.1 Scope of the duct network

The largest element of cost in the access network is trenching costs in order to install duct. The scope of the duct network, i.e. those roads down which trench must be installed, is defined as those street segments which either:

- Have occupied buildings along them; or
- Are used for cables in the distribution, feeder or core networks.

There is clearly a high degree of overlap between these two categories, with in many cases cables being routed down roads along which there are buildings.

Where there are buildings on both sides of a road segment, duct is assumed to be built on both sides (although on the secondary side the length of duct may be shorter than the full length of the road segment). For road segments where there are only buildings on one side, or where there are no buildings (but cable is installed) duct is assumed to be built on one side only.

5.7.2 Number of ducts and allocation of trenching costs

The number of ducts required in the primary side of the road, in addition to a dedicated duct for connecting buildings on the road segment is based on the total cross sectional area of cables that transverse this road segment, including distribution, feeder and core network cables with an allowance to take account of a fill factor. The cost of the trench is allocated based on the number of ducts on this road segment.

Where duct is required on both sides of the road, it is assumed a single duct is dug on the secondary side of the road (the side with fewest buildings) as described under 5.4.5.

5.8 Outputs of the access network module

The main output of the above modelling is an inventory of the total assets required in the access network:

- Length of copper cables by number of pairs in each level in the network (distribution and feeder);

- Length of fibre cables by number of fibres in each level in the network (distribution, feeder and core);
- Number of kilometres of trench required to install duct, allocated between level of the network; and
- Number of kilometres of duct in each level of the network.

This forms an input to the costing module.

The GRC of cable, trench and duct is calculated as the length of each of these multiplied by their respective unit costs. This means that it is necessary to differentiate lengths and costs by type of cable (copper, fibre) and by thickness of cable (number of copper pairs or fibre strands).

The access module also provides information on the number of potential customers served by each network which, in conjunction with assumptions on the penetration of services and the traffic generated by customers, is used to dimension access nodes and other active network components.

Stakeholder question 5

Do stakeholders agree with the approach for modelling the cable and duct network requirements? If not, please describe an alternative approach and the underlying rationale for suggesting such an approach.

Other comments

Could stakeholders please provide any additional comments they might have on this section.

6 Active network equipment requirements

This section discusses the approach which is used to dimension network equipment requirements. The modelled network is based on a hypothetical scorched node network based on NGN technology, rather than an attempt to replicate EPT's current network. The inputs to this module consist of:

- Number of potential subscribers per access node;
- Traffic requirements by node;
- Location of nodes (actual locations of EPT's network equipment are used); and
- Technical parameters associated with network dimensioning, such as equipment modularities and maximum utilisation levels.

This module dimensions the amount of network equipment required based on the demand calculations and assumptions relating to technical specifications of network equipment and the services offered. The output of this module is the quantities of network equipment required to support the services provided by an efficient operator, both now and in the future.

The rest of this section sets out:

- A description of the modelled network topology (Section 6.1);
- A description of the approach used to dimension the amount of network equipment required (Section 6.2); and
- A description of how other parts of the network are dimensioned (Section 6.3); and
- A description of the outputs of this module (Section 6.4).

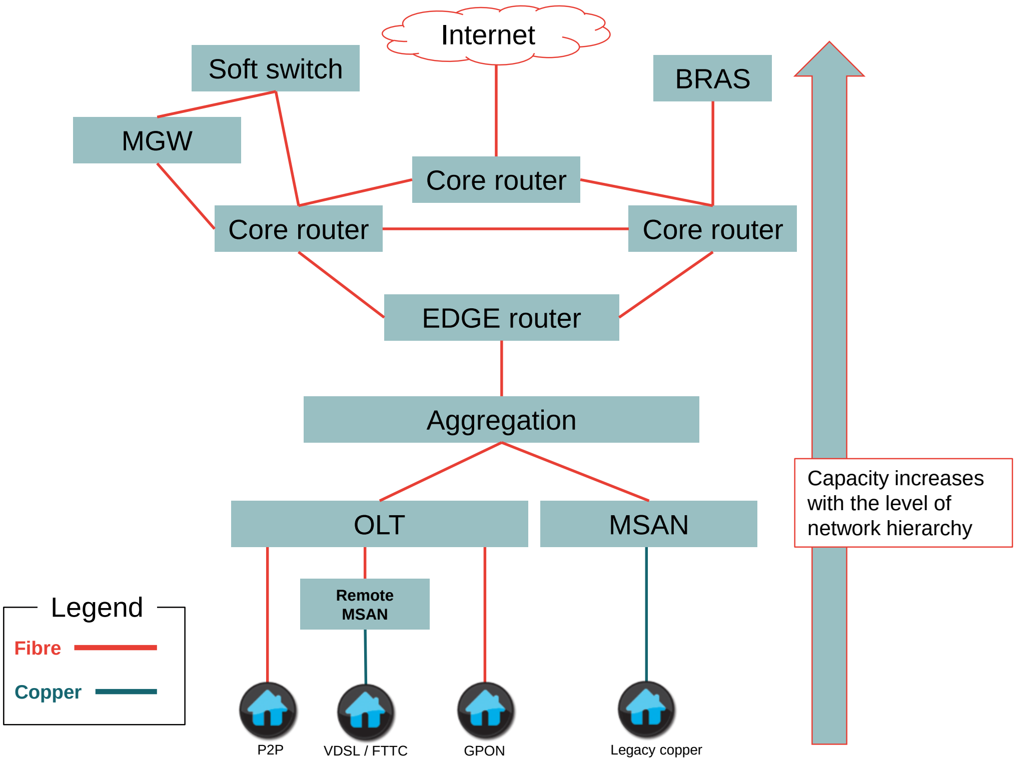
6.1 Network topology modelled

Figure 13 outlines the network equipment nodes in an NGN. The equipment at the first active equipment node depends on the access technology in use at the node. The bullet points below summarise the consideration of active equipment under each type of access technology modelled.

- Under FTTH GPON and FTTH P2P, the active equipment is located at the OLT in the Ethernet access layer.
- Under FTTC, the active equipment consists of MSANs. Since MSANs are installed in the cabinet under FTTC, there are far more nodes than under other technologies.

- Under legacy copper, the active equipment could be a concentrator for voice traffic and a DSLAM for broadband traffic. Alternatively, MSANs could be used to carry both voice and broadband traffic. The model includes MSANs as the active equipment since this is the modern equivalent asset (i.e. what would be used by an efficient operator rolling out its network today).

Figure 13. Network equipment nodes



Source: Frontier Economics

The first active network elements are linked to the Ethernet aggregation switch (except for under FTTC where link is via the remote MSAN). This aggregates the traffic from different MSANs or OLTs onto a smaller number of links and thereby improves the efficiency with which the network is used. To ensure resilience the first network element is linked to two different Ethernet aggregation switches. The resilience assumptions applied in the model are based on international benchmarks and are summarised in Table 2 below.

Active network equipment requirements

Table 2. Resilience assumptions applied in the model.

Network level	Number of links
Cabinet to OLT/MSAN	1
OLT/MSAN to Aggregation	2
Aggregation to IP Edge	2
IP Edge to IP Core	2
IP Core to IP Core	Fully meshed

Source: Frontier Economics

The next level of the network hierarchy is the EDGE router which switches traffic to and from the Ethernet aggregation switch towards its destination. There is also resilience built into this link (i.e. between the Ethernet aggregation node and the EDGE router). The EDGE router is a switch in which traffic is segmented into packets. Packet switching is a more efficient technology than traditional circuit switching because it does not require a dedicated circuit for each call (for voice traffic).

The next level of the network hierarchy consists of core routers. There is also resilience built into this link. These tend to have much higher capacities than EDGE routers. The core network in turn is connected to the internet, and it is fully meshed. This means that every core node is directly connected to every other core node, for added resilience and redundancy.

The network also requires a control layer for voice calls. The main elements of the control layer are soft switches which set up and tear down the calls and media gateway controllers (MGWs) which control media gateway switches (located at interconnection pints) which in turn provide the interconnection functionality between NGN and non-NGN networks.

The control function for broadband networks is provided by BRAS which control broadband sessions. BRAS are located in the biggest core routers. In principle, the functions of the BRAS could be decentralised to, for example, the MSAN or Ethernet Switches. This is the assumption used in the Danish and Swedish core models developed by the national regulatory authorities there. However, there are advantages in using separate BRAS to control broadband sessions and this is the approach network operators have, in our experience, adopted in practice.

A number of other points relating to network topology can be briefly stated.

- As one moves up the network hierarchy the capacity of the equipment used tends to increase while the number of equipment nodes decreases.
- For resilience reasons, equipment at a given level of the network is often linked to two pieces of equipment at the next level of the network. Given the relatively low cost of NGN, there is full resilience at each layer of the network except for the link from the subscriber premises to the cabinet and then on to the first active equipment).
- Equipment at different levels of the network hierarchy may be co-located. For example, there may be both Ethernet aggregation switches and EDGE routers at the same site.

6.2 Network equipment dimensioning

The main driver of network equipment dimensioning is the demand placed on the network by different types of traffic.

6.2.1 Demand

As described below, in order to dimension the different elements of the network, different types of traffic are converted into a capacity requirement in the busy hour.[12]

In addition, the quality of service varies across different traffic services. In particular, some services, such as voice and leased lines, need to be provided in real time whereas others such as residential internet can be provided on a best effort basis.

It is important to take account of the different requirements of real time and non-real time services both in the dimensioning process and in the costing process. The discussion below focuses on the dimensioning process. We take account of the need to provide some services in real time by dimensioning these services at a very low blocking rate. This approach is particularly appropriate for the first active network element because of the relatively large number of such elements (meaning that the imposition of a low blocking rate has significant implications for capacity) and because these elements do not use Multi-Protocol Label Switching (MPLS). Traditionally, MPLS was applied at the router level but

12 The busy hour for different services may vary. For example, the busy hour for voice services is likely to be during daytime whilst the busy hour for broadband may be during the evening. This effect may be adjusted for it is likely to have a large impact on total and unit costs.

many operators have also rolled out MPLS to the aggregation switch level. MPLS enables real time services to be identified and passed through the network in real time while other services can be delayed. Where MPLS is used, the Erlang approach is not strictly necessary. However, it may provide a rough indication of the costs associated with providing real time services.

Converting voice demand to capacity requirement

To dimension the different elements of the networks, the calls per minute for each voice service established in the demand model need to be converted to capacity in the busy hour.[13] Using this information, we then dimension network equipment to handle the capacity requirement from voice calls. The following factors are taken into account in order to estimate peak capacity requirements:

- Percentage of traffic in busy hour by type of service;
- Adjustment for weekends (the traffic volume in the busy hour in a working day is likely to be considerably higher than during a day at the weekend); and
- Percentage uplift for variations in the level of traffic over the course of the week and year.

The next step in the process involves the calculation of the capacity requirement for each type of service at the different network elements. The capacity requirement differs according to the type of call. For example, an on-net call uses network elements approximately twice as intensively as an off-net call. This information is reflected in usage factors[14]. Usage factors are based on assumptions of efficient routing based on the modelled network hierarchy and technology.

Dividing the number of call minutes in the busy hour by 60 to convert to busy hour Erlangs (BHE) and multiplying by usage factors produces the maximum capacity requirement in BHE for each element of the network.

In a TDM network, the bandwidth of a voice call is 64 kbps. In an NGN, bandwidth depends on the protocol used and the precise way in which it is used. However, many operators use a bandwidth per voice call of between 95 and 100 kbps and we understand that EPT uses 100 kbps [15]. This is based on the use of G.711 protocol with appropriate allowance for overheads (headers and tags).

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13 As different network elements are dimensioned by different "busy hour" measures, we will calculate Busy Hour Erlang (BHE) and Gbps in the busy hour. We do not propose to use BHCA as a network driver.

14 A usage factor shows the extent to which different services use network elements.

15 This capacity is required in each direction. However, in a modern NGN capacity is bi-directional.

Hence, multiplying BHE by the call bandwidth for each network element gives the kbps requirement. Dividing these totals by 1 million, gives quantities in Gbps.

A further adjustment is made to take account of the real time requirements of voice. Rather than dimension for the average level of traffic a blocking rate of 0.25% is applied to determine the actual capacity needed to ensure a satisfactory quality of service.[16]

Converting broadband demand to capacity requirement

To determine busy hour broadband traffic, the model uses information on the current and forecast number of ADSL, VDSL and FTTN broadband subscribers as well as the average traffic per subscriber during the busy hour. Multiplying the number of subscribers by their usage during the busy hour shows the total peak hour usage.

Usage factors are then applied to dimension different network elements. The model assumes that data traffic is efficiently routed through the network although some traffic may use "non-efficient" routing for load balancing purposes, hence increasing the core peak capacity beyond that initially required to meet direct demand capacity.

Since average busy hour usage is provided in kbps it is straightforward to calculate traffic requirements in Gbps.

Converting other data service demand to capacity requirements

The table below summarises the data required to convert other data service demand into capacity requirements.

16 Strictly speaking this is not appropriate where MPLS is used since tags can be applied to ensure that voice and other real time traffic is given priority.

Table 3. Converting traffic into busy hour network requirements

Service	Data required
IPTV	Number of IPTV channels and the bitrate per channel, disaggregated between standard and high definition channels, This, in combination with routing factors, is sufficient to show the bandwidth required for IPTV.
VOD	Information on the number of VOD subscribers, the percentage of subscribers using the service during the busy hour and the bit rate per video in combination with routing factors.
Leased lines	Number of leased lines at each POP, breakdown of traditional leased lines by capacity and further differentiated between national and international leased lines. This is required separately for Metro-Ethernet leased lines. The model assumes that traditional leased lines do not use NGN equipment although they use the duct and cable transmission network and, in turn, bear a cost of this network. Metro-Ethernet routings on the other hand use EPT's NGN.

Source: Frontier Economics

6.2.2 Aggregating traffic in the network hierarchy

The model aggregates demand within the network hierarchy so that the dimension of each node reflects the customers ultimately served by that node so for example:

- Access nodes are dimensioned according to the number of subscribers served and traffic generated by those customers;
- Aggregation nodes are dimensioned according to the number of links from access nodes and the amount of traffic carried over those links; and
- Traffic on EDGE routers reflect traffic generated on the associated aggregation network.

This aggregation requires the connections between nodes to be explicitly defined, although this is needed in any case for defining the transmission routes.

6.2.3 Other drivers of network equipment requirements

Table 4 highlights the main drivers of the dimensioning of network equipment. It can be seen that, in addition to the volume of traffic which needs to be carried by a particular class of equipment (as described above), the dimensioning process also takes account of a variety of other factors. These include the number of network nodes, resilience requirements and the technical characteristics of the equipment concerned.

Table 4. Input data for network equipment dimensioning calculations

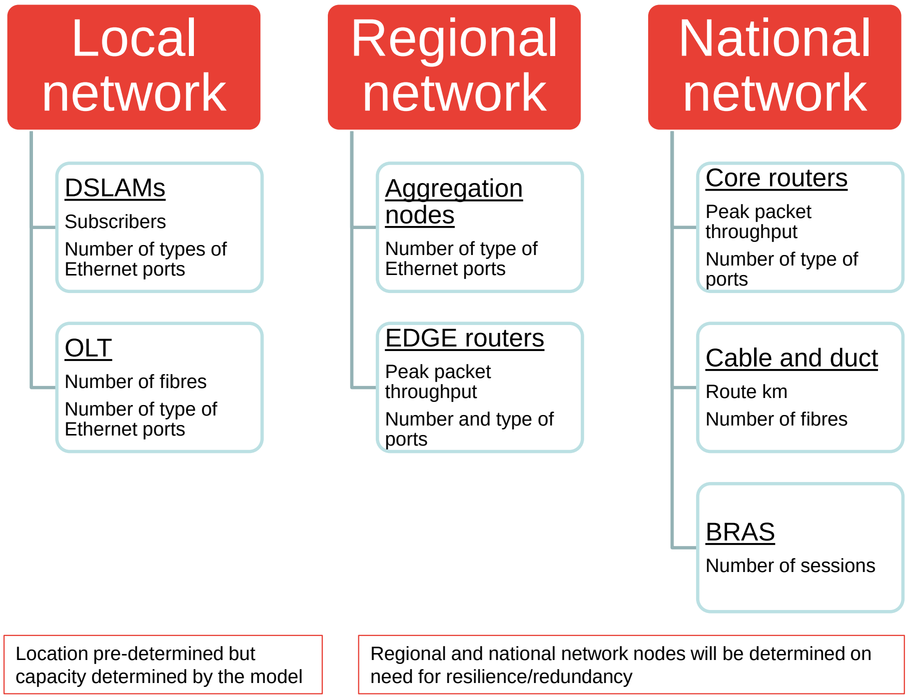
Data	Description
Demand	Either subscriber numbers or traffic to be carried during the busy hour. Where equipment carries voice and broadband traffic, traffic is converted into a common measure.
Network dimensioning options	These include assumptions relating to resilience, redundancy and maximum utilisation of different pieces of network equipment.
Technical characteristics	These include data relating to the maximum capacity and modularity (the maximum number of modules and ports) for different types of equipment.
Location of the network nodes to be modelled and their designated functions	This includes nodes at different levels of aggregation in the network (as described above). This also includes the links between types of equipment.
Number of points of interconnecting operators	Based on current and forecast numbers of interconnection points.

Source: Frontier Economics

The figure below provides some further detail on the drivers of dimensioning for some classes of network equipment.

Active network equipment requirements

Figure 14. Dimensioning of different classes of network equipment



Source: Frontier Economics

Once the number of nodes is determined and resilience requirements specified, there are two key drivers for network equipment. These drivers are: subscriber lines/uplinks from other nodes; and peak hour traffic. Subscriber lines serves as the driver for the access network facing part of the first network element which could be an MSAN, OLT, Ethernet switch or in a legacy copper network DSLAM and concentrator. Links from other nodes in the network are a driver of core network equipment after the access nodes (for example, links from aggregation to EDGE IP routers).

For the core facing part of the access nodes and all other network elements an additional driver is the peak hour traffic. It can be noted that most network elements, such as aggregation switches and routers, carry both voice and data traffic. Hence, it is necessary to convert these different sources of traffic into a common measure. However, soft-switches and media gateways carry only voice traffic while BRAS are only used for the control of broadband sessions.

Soft-switches or servers are required to set-up and tear-down voice calls. Hence, these switches are only used by voice calls and all their costs are allocated to these calls. In order to dimension soft-switches it is necessary to convert voice calls by type into a common unit, typically BHE, and apply routing factors to reflect the respective usage of different types of calls. This equipment is required to provide interconnection between NGN and non-NGN for voice calls. Hence, once again all costs are allocated to voice calls although in this case the equipment is only required for a sub-set of these calls (off-net to non-NGN). Media Gateway Switches and Controllers are dimensioned in an analogous way to soft-switches.

BRAS are used to control broadband sessions and hence all the costs of BRAS is attributed to broadband. The key driver for BRAS is the number of concurrent broadband sessions in the busy hour.

As described previously, it is necessary to dimension the network for all services using the core network even though the focus of the model is on a sub-set of these services. Thus, although the model does not estimate the cost of IPTV, it needs to take account of the demand from IPTV services.

To dimension different equipment items, we establish the peak hour for each network element and the peak traffic which needs to be handled by the core network equipment. This is the traffic carried on the network at the time when the sum of capacity requirements for all services is highest. This requires a conversion of forecast demand to peak hour capacity, as this is the maximum capacity a network element needs to handle. The network is then dimensioned to carry this busy hour traffic, also taking account of maximum utilisation levels and redundancy and resilience assumptions for all equipment types.

6.2.4 Other dimensioning issues

The model differentiates between chassis related costs, equipment costs and software costs. It also uses information on the manufacturer and model type for each piece of equipment. This is used to determine the number of chassis required at each node and the number of cards required within those chassis. For example, a router will contain a number of slots within which ports (capacity cards) can be placed. Information on the number of slots and the capacity of cards is used to determine the number of port cards and slots required on each type of router.

6.3 Dimensioning other parts of the core network

6.3.1 Fibre and duct

The model uses data on all fibre and duct within the cable and duct module which was discussed in Section 5. However, it should be noted that this module and the network elements module are linked. Specifically, the application of routing factors to the different sources of traffic is used to determine capacity requirements both for the network elements themselves and also for transmission fibre.

6.3.2 DWDM network

In an NGN, DWDM equipment is typically used in the transmission network for long and high traffic routes. This equipment allows each fibre to be separated into a number of different colours (frequencies) over which different traffic streams can be transmitted. Hence, DWDM is used to reduce fibre requirements[17]. However, this is unlikely to be an important consideration in Luxembourg. A stakeholder has also commented that DWDM is not required in the core. Therefore, our model does not consider DWDM transmission in the core.

6.4 Outputs of the active network equipment module

The network equipment module calculates:

- The number of nodes, by type of node;
- The traffic which needs to be carried by each equipment type. This is further disaggregated by type of traffic so that costs can be allocated to each source of traffic;
- The number of chassis required for each equipment type;
- The number of cards required for each equipment type with a further distinction between different card types; and
- Software requirements for each equipment type.

Stakeholder question 6

Do stakeholders agree with the approach for modelling the active network equipment requirements? If not, please describe an alternative approach and the underlying rationale for suggesting such an approach.

Other comments

Could stakeholders please provide any additional comments they might have on this section.

[17] A further advantage of using DWDM rather than separate fibre pairs is that it reduces repeater requirements. .

7 Costing

The main inputs to this module are:

- Asset prices and asset lives;
- Forecast asset price trends;
- Network equipment requirements (from the access network module and the core network module);
- Demand (from the demand module); and
- Other assumptions.

The costing module consists of two main calculation steps:

- Network costing – determining the cost of the network as a whole (see Section 7.1); and
- Service costing – allocating the cost of the network as a whole to individual services (see Section 7.2).

These calculation steps are discussed in the rest of this section. Section 7.3 describes the outputs of this module (the total and unit costs of network services and products).

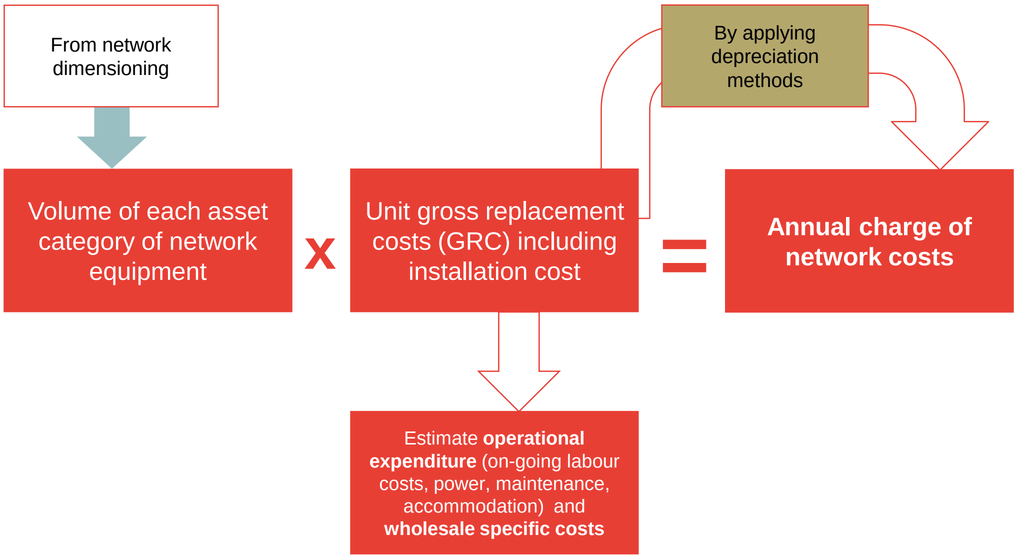
7.1 Network costing

The costing of network elements consists of the following steps:

- Calculation of GRC of network equipment;
- Estimation of non-network capital costs;
- Annualising network costs; and
- Adding operating costs to calculate total network cost.

This is illustrated in the figure below and described in further detail in the rest of this sub-section.

Figure 15. Estimation of network costs



Source: Frontier Economics

7.1.1 Gross replacement costs

There are two main steps to estimate the total capital expenditure in each year modelled.

First, the unit cost of every network element is calculated for each year modelled. This unit cost is based on the current (2012) price adjusted by forecast asset price trends. The unit cost includes both installation and capital costs. This is based on forward looking costs based on current price data from stakeholders, forecast trends and benchmarks. Where list prices are used, these should reflect any discounts available to operators in Luxembourg.

Second, the unit cost is then multiplied by the annual equipment required (from the access network requirements module and the core network requirements module).

7.1.2 Annualisation of costs

The model reflects how an efficient operator would recover the cost of capital investments over the useful lifetime of the assets. This is not necessarily equivalent to the asset life used for statutory accounting purposes since these tend to be quite conservative and do not necessarily reflect how long assets are actually in service for. Economic asset lives take account of the rapid development of technology in the industry and how assets are often replaced as new technology becomes available while the asset is still technically usable. The model reflects how asset lives vary across different categories of assets.

Annualised capital costs also include a return on capital employed equal to the cost of capital. The cost of capital is the minimum rate of return necessary to attract capital to an investment (i.e. just sufficient to compensate investors for the opportunity cost of investing, this is also known an "economic profit"). This makes it the appropriate level of profit to allow on regulated assets. The cost of capital is typically measured using the weighted average cost of capital (WACC). The WACC methodology is described in further detail in an annexe to this specification document.

As a base case, we follow a tilted annuity approach as this gives constant allowable revenues in real terms. The tilt in the annuity formula takes account of how input costs change over time and therefore how costs would be recovered in a competitive market. In particular, where asset prices are increasing (decreasing) over time, an operator would tend to front load (back load) its cost recovery as entry to the market by another operator becomes less (more) costly.

Using a tilted annuity approach helps to avoid accounting distortions and better reflects the recoverability of costs compared to accounting forms of depreciation (i.e. straight line depreciation). Another advantage is that the annual charge does not depend on the age of the asset. This means that the fact that the bottom-up model includes new assets is less of an issue. This approach is also used extensively in bottom up models used for regulatory purposes.[18] Long term asset price trends for different categories of assets are an input to the tilted annuity formula when calculating annualised network costs.

As described in Section 7.1.2, working capital associated with network investments is reflected in the annuity formula. The model also includes the functionality to consider a standard annuity depreciation profile.

Economic depreciation introduces the demand side into the calculation of depreciation and results in smoother unit prices where demand is changing. While there are theoretical benefits of such an approach, there are various practical limitations associated with implementation. In particular, such an approach requires forecasting demand side characteristics over the full life of the assets and this may introduce subjectivity.

Special treatment of certain assets may be required for the final drop. This is because it is operated and maintained by the operator but the initial installation of new connections is paid for by the end customer (although the operator will

18 Tilted annuity is also consistent with the financial capital maintenance (FCM) approach recommended by the European Commission in its "Recommendation on interconnection in a liberalised telecommunications market – part 1 – Interconnection pricing", 15 October 1997. That is the tilted annuity approach allows the investor to recover the full cost of the asset in present value terms (using the cost of capital as a discount factor).

pay for any subsequent replacements). The annualisation method is set such that the operator is able to fully recover costs over the expected customer lifetime;

7.1.3 Annual direct operational expenditure

Annual direct operational expenditure relate to the on-going costs of running the network. This includes on-going staff and non-staff related costs. These are described in further detail below. Direct operating costs can be estimated as a percentage mark-up over GRC or as a cost per line. While it is theoretically possible to estimate operating costs using a bottom-up approach (e.g. estimating the hours required to perform various activities and then estimating the cost per hour of different types of labour), this does not necessarily lead to more robust results in practice. This is because such an approach would require a large amount of data and subjective judgements about input assumptions.

The exceptions to this are space, power and air-conditioning costs associated with specific network equipment. These requirements are dimensioned within the model as these costs are driven by the type and quantity of specific types of equipment.

The model contains the flexibility to apply different mark-ups and assumptions for operating costs to different categories of network equipment.

Corporate taxes are not included here as they are included in the cost of capital (see below).

Pay costs

Pay costs include salary costs (including overtime), pension costs and benefits (such as medical and dental insurance). These should relate to both employees and management. This would not include any labour costs that relate to the installation of network equipment since these costs are included in the capital costs.

Non-pay

Non-pay costs relate to costs such as staff training, payments to contractors, and so on.

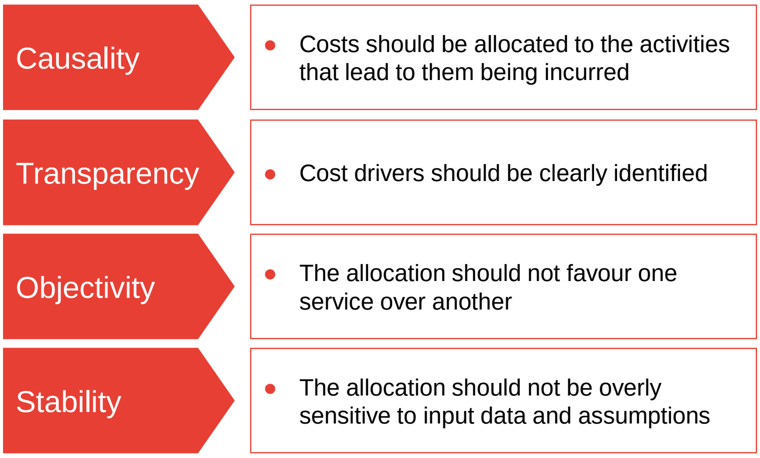
7.1.4 Wholesale specific costs

Wholesale specific costs relate to interconnection and other specific activities not directly related to the network. These include to wholesale billing and product management. However, as these costs are not generally incremental to call termination, they are not considered when calculating the pure LRIC of wholesale call termination.

7.2 Service costing

The next step in the model is to allocate the annualised capital and annual operating costs of the network to the individual services modelled. The model adopts the principles set out in the figure below.

Figure 16. Principles for cost allocation



7.2.1 Routing and service factors

Based on the principles described above, the model first combines the cost of individual pieces of network equipment into larger asset groups that are used uniformly by services (e.g. line cards, modules and routers that are all used by the same access service). This is to avoid dealing with individual asset cost lines.

Routing factors are used to calculate the demand volumes of each network element category. They describe how often a particular network element category is used in providing a given service. While there is a partition of the network dimensioning modules (cable and duct network and other network), the routing factors determine which products and services use network elements from both networks (e.g. access services use both cable and duct network elements as well as active network equipment).

The volume of each service is multiplied by the routing factor or service factor for each network element that the service uses to give factored volumes. The total cost of that network element category is then divided by the total factored volume for all services using that network element category.

7.2.2 Common costs

Common costs are costs that are not incremental to any individual increment. They include costs such as overhead costs (corporate overheads, human resources, finance and support systems). These relate both to capital and on-going operating costs. This also includes licence and regulatory fees.

As described in Section 2.1.3, common costs may be allocated to services based on EPMU. The model calculates common costs as a percentage of the total cost base (annualised capital costs including a return on capital employed and all operating costs). This percentage is used to mark-up the cost of individual services. The exception to this is the calculation of the pure LRIC of termination where, by definition, there is no allocation of common costs.

7.2.3 Calculation of pure LRIC and impact on other costs

Under the pure LRIC methodology, the relevant increment is wholesale termination services only. Under the definition of incremental costing, this means that the pure LRIC of wholesale call termination would be the costs avoided if this service were no longer provided. Therefore, in order to calculate it, the model is run twice:

- First to calculate the total costs that would be incurred if all services were provided; and
- Second to calculate the total costs that would be incurred if all services except for wholesale call termination were provided.

The difference between the total costs under each run of the model is the total pure LRIC of the service. This is then divided by the volume of calls in order to calculate the unit cost.

In order to ensure that the modelled operator is able to fully recover its efficiently incurred costs, the model re-allocates the common costs that would have been recovered from wholesale termination under the LRAIC approach. These are re-allocated to call origination and on-net calls based on the volume of these calls.

7.3 Outputs of the costing module

The outputs of the costing module are the final results of the model. These include:

- Total cost per product (see annexe for full list of products) for each year modelled;
- Unit cost per product for each year modelled.

The model is sufficiently flexible for the ILR to be able to run scenario testing and sensitivity analysis.

Stakeholder Question 7

Do stakeholders agree with the approach to costing? If not, please describe an alternative approach and the underlying rationale for suggesting such an approach.

Other comments

Could stakeholders please provide any additional comments they might have on this section.

8 Quality assurance

There are four main ways in which we assure quality of the model itself and that its outputs are fit for purpose.

- During the model build:
  - Through detailed planning of the model build and specification of the model; and
  - Ensuring best practice throughout the model build.
- After the model build:
  - Detailed model documentation and deliverables; and
  - Final testing of the model.

These are described in further detail in the rest of this section

8.1 During the model build

8.1.1 Planning and specification

Developing a model specification allows wider participation in the design of the model. In particular, it allows those not directly involved in building the model to comment on the modelling principles and model structure in order to determine whether the model is fit for purpose. In particular, the model specification allows the identification of any issues before the model is built. This includes ensuring that the model reflects the operating environment in Luxembourg as well as international best practice.

The model specification document forms a point of reference at various stages of the model development and allows the consideration of consistency with respect to:

- The model itself – the model developer can check that the model meets the defined requirements;
- The model documentation – the person writing the documentation will do so in reference to both the model itself and the documentation and therefore can pick up any inconsistencies; and
- The final testing – the person reviewing the model can identify whether the model achieves its stated objectives.

8.1.2 Model build

In developing the model, it is important to follow modelling best practice. These include the following elements.

- **Model control and defined interfaces between modules**
  - The model uses the same modelling principles throughout the different modules. These range from the level of detail (e.g. defining the unit of measurement for a service consistently across the model) to whether the model is using real or nominal costs.
  - The model uses common classifications across the different modules (e.g. a common forecast period, a common list of services). Where data is used across different calculation steps, it may be appropriate for the model to define named ranges in MS Excel to ensure consistency.
  - There are defined interfaces between the different files and modules that make up the model.
- **Clear separation of inputs, stages of calculation and outputs**
  - There should be a clear separation of the different steps of the model. Using clear formatting (see below) and providing written descriptions within the model itself helps both in the model development and in the model review (e.g. descriptions of input data and calculations allows someone reviewing the model to ensure that the coding meets the stated objective).
- **Splitting complex stages of calculations**
  - Complex calculations should be split into smaller stages in order to make the model easier to follow and to identify any issues both during the model development and final testing. This makes it easier to review the coding of calculation. Providing written descriptions (e.g. annotation of macros and explanations typed into Excel cells) or graphical illustration within the model allows the checking of these calculations (see below). Providing visibility of intermediate results also allows the checking of these results.
- **Use of cross-checks**
  - In developing the model, it is important to use knowledge of the telecoms industry and the specific Luxembourg operating environment to check outputs and intermediate calculations. The model also includes built in cross-checks to ensure robustness (e.g. checking that proportions sum to 100%, that costs are not negative and so on)

Quality assurance

- **Sensitivity analysis**
  - The model contains sufficient flexibility to consider the impact of changing key input assumptions. This allows the model developer to determine whether changing an input assumption changes results (either at final or intermediate calculation steps) that are consistent with expectations (e.g. increasing subscriber volumes should lead to an increase in traffic volumes and increase total costs, but given the presence of high fixed costs this would be likely to lead to lower unit costs).
- **Colour coding and formatting**
  - Using clear colour coding and formatting allows the model developer, the model reviewer and the model user to quickly identify different types of information (e.g. inputs, active calculations, calculations from other model modules, outputs, user defined assumptions, cross-checks and descriptions). This makes the model easier to develop, review and use.

8.2 After the model build

8.2.1 Documentation and deliverables

The model documentation consists of the specification document, model manual (describing the practical implementation of the model) and the model results. Providing detailed documentation of the model structure and dependencies between the modules, details of algorithms used, and data and transformations used allow the model reviewer to assess whether the calculations have been correctly implemented.

8.2.2 Final testing

Final testing ensures that the model meets requirements, is technically accurate and sufficiently detailed. Each module is checked by someone who did not develop the module.

As described throughout this section, the final testing consists of:

- Review against documentation and original specification;
- Review model structure;
- Sense checking of intermediate and final results; and
- Calculations in individual cells.

Annexe 1: Summary of stakeholder questions

Table 5. Stakeholder questions and reference to relevant sections of specification document

	Question	Relevant section in specification document
1	Do stakeholders agree with the time period modelled? If not, please provide evidence and justification to support an alternative time period.	Section 2.2
2	Do stakeholders agree with the scorched node approach? If not, please describe an alternative approach and the underlying rationale for suggesting such an approach.	Section 2.3
3	Do stakeholders agree with the technologies modelled in the core and access networks? Where stakeholders propose that alternative technologies should be modelled, please describe the rationale for doing so.	Section 2.4
4	Please comment on the proposed approach to forecasting demand.	Section 4
5	Do stakeholders agree with the approach for modelling the cable and duct network requirements? If not, please describe an alternative approach and the underlying rationale for suggesting such an approach.	Section 5
6	Do stakeholders agree with the approach for modelling the active network equipment requirements? If not, please describe an alternative approach and the underlying rationale for suggesting such an approach.	Section 6
7	Do stakeholders agree with the approach to costing? If not, please describe an alternative approach and the underlying rationale for suggesting such an approach.	Section 7

Annexe 2: Glossary

Acronym	Definition
BHCA	Busy Hour Call Attempts
BHE	Busy Hour Erlang
BHT	Busy Hour Traffic
CCU	Co-located Concentrator Unit - Concentrator unit located at the Local Exchange
DP	A Distribution Point is a physical point at which different cables are "joined" together to form one continuous and longer cable (or a cable is split into smaller cables). Distribution Points can come in the form of either streetside cabinets, telegraph poles, manholes/footway boxes, joint boxes, distribution boxes, etc
Easement/wayleave	Right to do something or the right to prevent someone else from doing something over the real property of another.
GPON	Gigabit Passive Optical Network
ISDN	Integrated Services Digital Network
ISDN BRA	ISDN Basic Rate Access
ISDN PRA	ISDN Primary Rate Access
LE	Local Exchange
LEA	Local Exchange Area
MDF	Main Distribution Frame
MDF	Consists of a two-sided metal frame. Copper cable pairs from the D-side of the frame terminate horizontally on connection modules. There is then a jumper cable that connects to another connection module on the E-side of the frame. Connection modules on the E-side of the MDF are arranged vertically.
MEA	Modern Equivalent Asset
MSAN	Multi-Service Access Node
ODF	Optical Distribution Frame
OLT	Optical Line Terminator
P2P	Point to Point
PoP	Point of Presence
PSTN	Public Switched Telephone Network
RCU	Remote Concentrator Unit - Concentrator unit that can be located away from the Local Exchange
SDH	Synchronous Digital Hierarchy
VPN	Virtual Private Network

Types of morphology	Description
City Centre	Refers to the business district of a metropolitan area. The buildings in such an area are generally 10 floors or above and consist of office buildings and high-rise apartment blocks. Population density of > 5,000 per square kilometre.
Metro	Refers to areas where buildings are generally five (5) to 10 floors high. Population density of 2,001 - 5,000 per square kilometre.
Urban	This morphology refers to a mix of business and residential properties up to five (5) floors high, but mainly consisting of one (1) to two (2) floors. Population density of 201 - 2,000 per square kilometre.
Rural	This morphology refers to sparsely populated largely open areas. Buildings are usually no more than two (2) floors high. Population density of 0 - 200 per square kilometre.

Annexe 3: Services modelled

This annexe sets out the products considered and the output that is estimated under the following headings:

- Voice calls;
- Wholesale line rental services;
- Wholesale infrastructure access services;
- Wholesale broadband access services; and
- Data transmission services.

Voice calls

The list below presents the wholesale voice calls that are included in the model. This includes voice services provided over IP:

- Call origination – a blended cost across all technologies;
- Call termination – a blended cost across all technologies;
- Call transit.

Costs for call origination and call termination do not differentiate between regional and national call as the modelled network has only one layer of interconnection.

Wholesale line rental services

The model considers the costs of the wholesale line rental services (revente de l'abonnement téléphonique) covering the cost of the access network and the subscriber sensitive element of the access node. The cost is presented as a blended cost across the different access technologies (MSAN at MDF, FTTC, FTTH-GPON and FTTH-P2P).

ISDN 2 and ISDN 30 costs are not calculated as they rely on legacy TDM technology which is not implemented in the modelled network.

Wholesale infrastructure access

The model considers local loop unbundling for the following technologies and services:

- Copper local loop unbundling from the MDF to the user premises;
- Copper sub-loop unbundling from the cabinet to the user premises;
- Fibre unbundling from the access node site to the user premises;

- Fibre unbundling from the DP to the user premises; and
- Duct access.

Wholesale broadband access

The model considers the following wholesale broadband services:

- Resale of wholesale line with access provider defined bandwidth and quality of service;
- User defined bitstream with separate access and bandwidth charges;
  - Access charges on voice enabled lines and for "naked" bitstream (i.e. broadband only lines) separately across the different access technologies (ADSL/SDSL at MDF, FTTC, FTTH-GPON and FTTH-P2P) and as a blended cost;

    Bandwidth charges based on different qualities of service (VoIP, IPTV, etc.) and MONO-VC

Data transmission services

The model considers the following data transmission services:

- Ethernet access services (equivalent to terminating segments of leased lines); and
- Ethernet transmission across the core network (10Mbps, 100Mbps and 1Gbps).

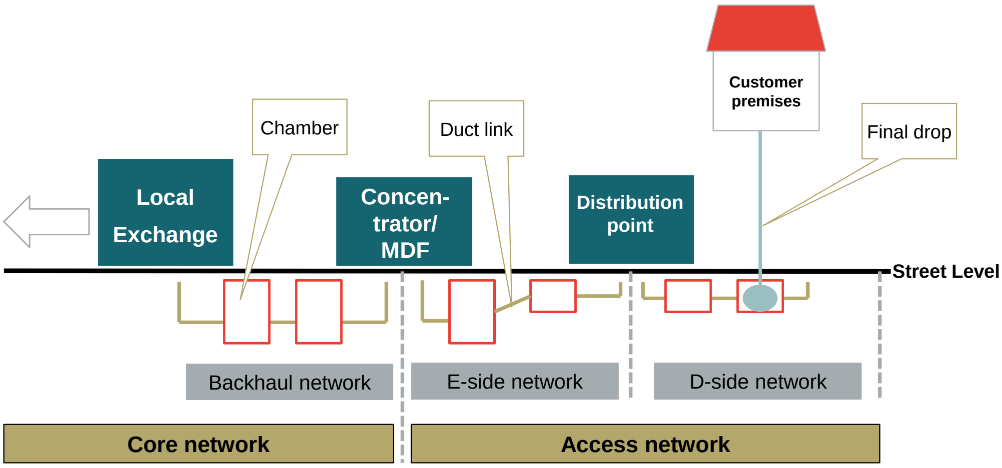
Annexe 4: Division of core and access networks under different technologies

In this annexe, we describe how the division of the core and access network depends on the technology used in the access network.

Division in traditional copper access network

In EPT's current copper based access network, the distribution point marks the boundary between the E-side (exchange side, also known as feeder) and D-side networks (distribution side). In this network, the concentrator is the first active network element. This is illustrated in the figure below.

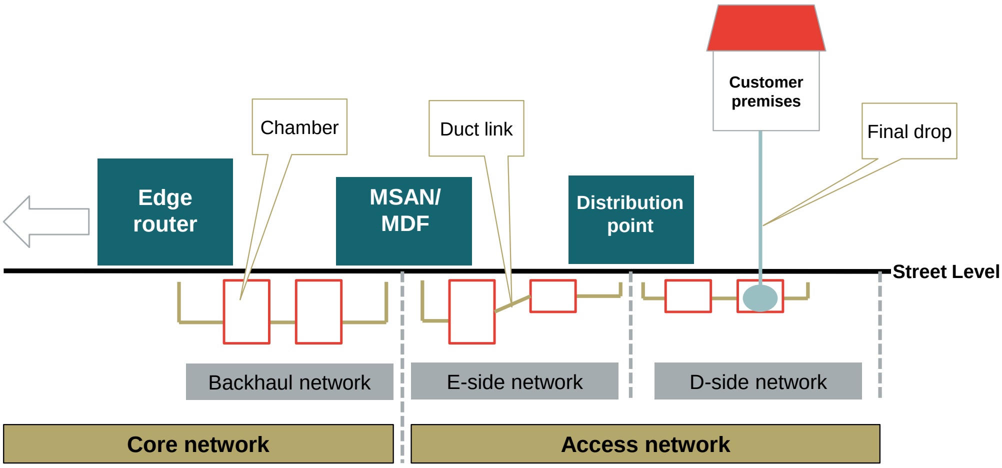
Figure 17. Copper access network and TDM based core network



Source: Frontier Economics

While one of the scenarios considered in the model is a copper-based access network only an NGN-based core network is modelled (see Section 2.4.2). The figure shows a copper based access network in combination with an NGN core network. In this figure, the concentrator is replaced by an MSAN (although other options could be selected) and the local exchange is replaced by an EDGE router. In between the MSAN and EDGE router there is likely to be one and perhaps two levels of aggregation switches.

Figure 18. Copper access network and NGN based core network

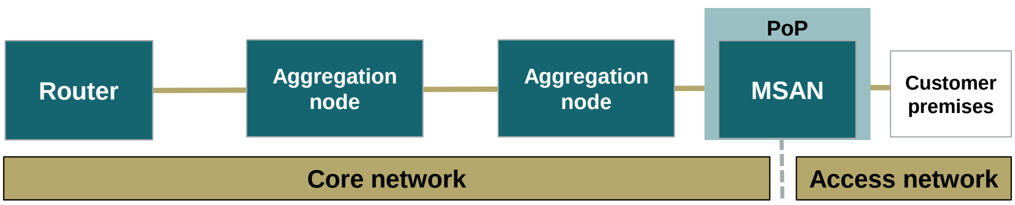


Source: Frontier Economics

Division under FTTC

In an FTTC access network, fibre is rolled out to either the distribution point (DP) or, more usually, a cabinet, which is located near to the DP. The MSAN is placed within the DP or cabinet (which becomes the point of presence – or POP). Alternatively, an MSAN can be installed for broadband subscribers, while a traditional concentrator is used for voice calls. The link between the MSAN and the customer's premises is provided over fibre. FTTC is also referred to as VDSL.

Figure 19. FTTC



Source: Frontier Economics

The advantage of FTTC over a traditional copper network is that it allows for higher broadband speeds. However, since speeds are more sensitive to distance than under ADSL, the MSAN needs to be located in close proximity to the customer.

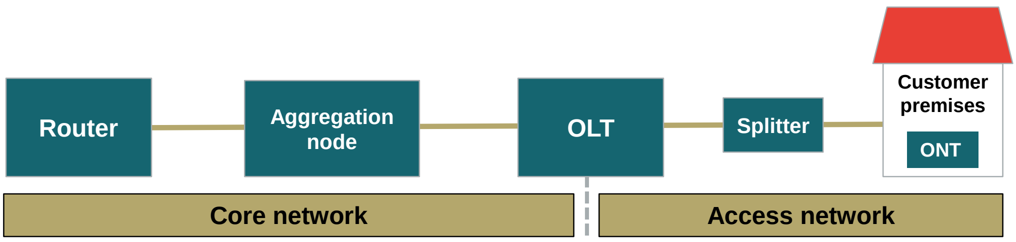
The provision of FTTC requires a relatively low level of investment compared to FTTH (perhaps in the order of 20-25%, depending on the characteristics of the network). Hence, it is a solution which may be adopted in the early stages of fibre roll-out, except, for example, in areas where the demand for high speeds is likely to be very high. On the other hand, it could mean that the MSANs become stranded costs if the demand for higher speeds results in a rapid move from FTTC to FTTH.

The fact that the first active network element is located at the cabinet (the boundary between the old E and D side networks) rather than at the end of the E side network means that in FTTC, the access network is longer than in a traditional copper network. By implication, the core network is shorter than in a traditional copper network. Hence, this has an impact on the relative costs of access and core services.

Division under GPON

FTTH can be provided either through a Passive Optical Network (PON) or an active optical network. In a GPON network, the fibre is split using a splitter allowing a single fibre can serve a number of customer's premises. The figure below shows a Gigabit PON (GPON), the most widely used form of PON.

Figure 20. FTTH-GPON



Source: Frontier Economics

The optical line terminator (OLT) contains the line cards and also the GPONs. Each GPON can provide downstream capacity of 2.5 Gbps and upstream capacity of 1.25 Gbps. Thus, in principle, each customer can have approximately 40 Mbps of downstream capacity under a 1:64 ratio. However, in practice, bandwidth can be allocated dynamically (some subscribers get more than others) and not all subscribers are using broadband at the same time (hence, achieved speeds would exceed 40 Mbps, if bandwidth is allocated equally).

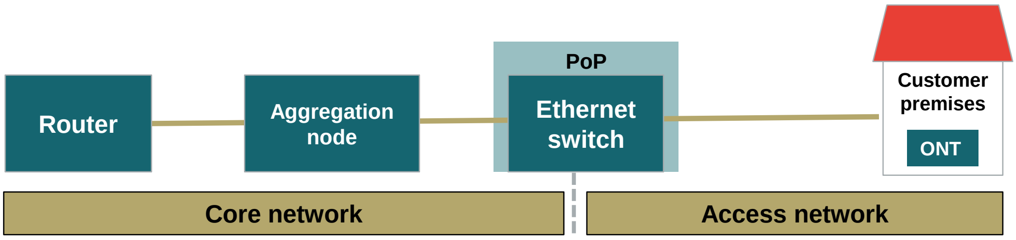
Over time, if customers require more bandwidth this can be provided by reducing the split ratio and/or by replacing GPONs by GEPONs (10 Gbps downstream capacity).

The OLT can be placed at the same node as the old concentrator. Alternatively, since the propagation characteristics of fibre are better than copper the number of nodes could potentially be reduced, implying that the length of the access network is increased (relative to a traditional copper network) while the length of the core network is decreased.

Division under FTTH P2P

As described above, under a GPON the fibre is split. Under a P2P system, each subscriber is supplied with one or two fibres. FTTH P2P can provide higher speeds than GPON with potential speeds of 1 Gbps per subscriber, depending on the technology used. However, it requires more fibre and may also result in higher trench and duct costs than GPON and is therefore the more expensive option.

Figure 21. FTTH - P2P



Source: Frontier Economics

As shown in the figure above, the dividing line between the access and core networks is at the Ethernet switch which would be located in the old concentrator building or even further from the subscriber as under GPON technology. It should be noted that EPT has argued that rolling out FTTH in its network will result in an increase of POPs relative to its TDM network rather than a reduction. In EPT's view, this is necessary for security reasons since if a fibre cable is damaged it will take longer to repair than a copper cable. EPT's proposed strategy differs from those adopted by some other operators where the introduction or proposed introduction of FTTH is likely to result in a reduction in the number of POPs. Hence, the model has the flexibility to model different numbers of POPs.

Annexe 5: Depreciation methodologies

Standard annuity function

Tilted annuity function

A tilted annuity function calculates an annuity charge that changes between years at the same rate as the expected change in the price of the asset. This means that the annual charge will consist of proportionately more financing costs in early years compared to later years. Where asset prices are falling, this results in falling annualisation charges over time. The tilted annuity approach allows the recovery of the asset price plus financing costs after discounting. This gives the following formula.

$$\text{Annual capital charge} = (CoC + Depr) = GRC \times \frac{WACC - trend}{1 - \left(\frac{1 + trend}{1 + WACC}\right)^{Asset\ life}}$$

Where trend= price trend. When the price trend is set to zero, this gives the standard annuity function.

Annexe 6: Estimation of WACC

The cost of capital, like operational and capital expenditure, is a cost of doing business. It is the minimum rate of return necessary to attract capital to an investment. Unless expected return on investment can cover the cost of capital, the company is unable to attract the investment capital it requires.

The cost of capital is also the appropriate rate of profit to allow on regulated assets. Since the cost of capital is the rate of return that just compensates investors for their opportunity costs (i.e. for forgoing their next best investment alternative), it is consistent with a normal rate of economic profit, which is what firms operating in competitive markets would expect to earn. Therefore, cost oriented regulatory pricing must provide investors with an expectation of earning a return that is commensurate with the cost of capital, but no more.

The cost of capital is typically measured using the Weighted Average Cost of Capital (WACC). The WACC takes into account two main sources of possible funding for a company, debt and equity, and the relative proportions of these (gearing), in order to determine a (weighted) average cost of capital for the business.

The WACC is expressed in nominal terms to take account of inflation. This is because the model results is used to assess the SMP operators' prices based on estimates of the current level of capital employed. Further, the model calculates depreciation charges on a financial capital maintenance basis.

The WACC is expressed without an adjustment for corporate taxation since this is not included in the model as a separate cash flow item.

The pre-tax real WACC can be expressed formulaically as:

$$\text{pre-tax real WACC} = \frac{1 + \text{pre-tax nominal WACC}}{1 + \text{inflation rate}} - 1$$

Where:

$$\text{pre-tax nominal WACC} = \frac{\text{Post-tax nominal WACC}}{1 - \text{corporate tax rate}}$$

And:

$$\begin{aligned}\text{post-tax nominal WACC} &= \big(\text{nominal cost of equity} \times (1 - \text{gearing ratio})\big) \\ &+ \big(\text{nominal cost of debt} \times \text{gearing ratio} \\ &\times (1 - \text{corporate tax rate})\big)\end{aligned}$$

The values of these individual parameters take account of number of factors.

- The approach adopted by the ILR in previous regulatory decisions in order to ensure a consistent approach. This helps to provide greater regulatory certainty for stakeholders.
- Consideration of the risk of investment in Luxembourg and how this may be different to the risk in other operating environments.
- The methodology adopted by other European regulators and the results in comparable operating environments. Again, this helps to ensure a consistent approach and will help to provide greater regulatory certainty for stakeholders.
- The EC NGA recommendation makes provision for specific risk of investments in new NGA technologies versus legacy copper access networks.[19] Therefore, the estimation of these parameters needs to consider whether such a differential would be appropriate in the Luxembourg context.

[19] Commission Recommendation of 20 September 2010 on regulated access to Next Generation Access Networks (NGA) (2010/572/EU)

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