Conceptual approach for the LRIC model for fixed networks

Final model specification

11 February 2010

Post- og teletilsynet

Contents

1 Introduction

The Norwegian Post and Telecommunications Authority ('NPT') has commissioned Analysys Mason Limited ('Analysys Mason') to develop a LRIC model for interconnection on fixed networks (Markets 2 and 3) and for full and shared access to fixed access networks (Market 4).

Analysys Mason and NPT have agreed an approach to deliver these cost models, which will be used by NPT to inform its own pricing decisions in the future. The agreed approach presents industry participants with the opportunity to contribute to the project. This paper presents the conceptual approach to the bottom-up models.

Modelling principles are presented throughout this paper and summarised in Section 6.

In this section we provide:

- the overall timeline of the project and opportunities for industry to contribute
- an explanation of the scope of the project
- the structure of this paper.

1.1 Timeline

An overview of the four phases of the project timeline is shown in Figure 1.1 below.

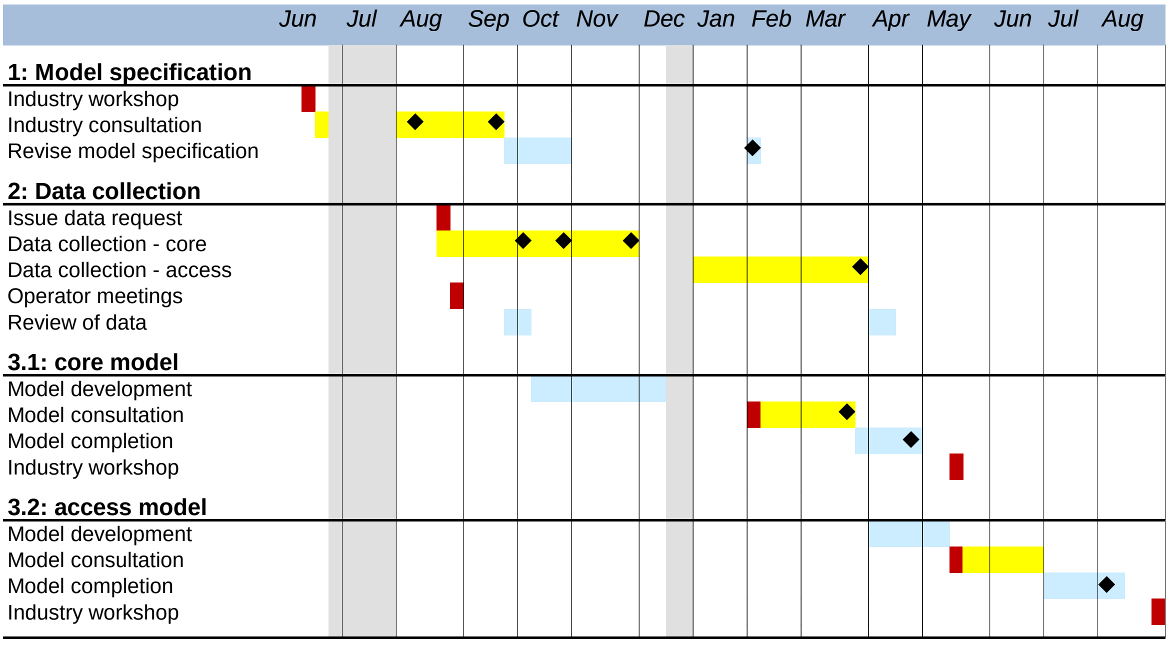

Figure 1.1: Project timeline [Source: Analysys Mason]

Industry participants have been invited to contribute to three phases of this project:

- **Model specification**: The draft version of this paper presented the proposed conceptual approach to developing the LRIC model. Industry was asked to submit comments on the recommendations in the paper. Comments received from industry have been used to develop this final paper.
- **Data collection**: In the next phase, data requests were provided to operators. From SMP operators, information was sought on their network configuration and size, service volumes, and cost data. Other industry participants were also invited to contribute to this phase.
- **Model consultation**: Following development of both the draft core LRIC model and the draft access LRIC model, reference models will be issued to industry for consultation.

1.2 Scope of project

NPT has chosen to undertake a project to address both the core and access networks.

In an incumbent fixed network, there are a number of areas of the network that are common to both markets, and therefore consistency can be achieved by tackling both at the same time. However, it may not be the case that there will be a single model or a single workbook, as our approach has been to accommodate significant uncertainty over the speed of migration to next-generation solutions.

It is also worth noting that no decision has been made on wholesale products under future network deployments. Accordingly, the modelling of these will be purely for the purpose of gaining additional understanding of their costs.

A modular approach to LRIC model development will be used, as summarised below in Figure 1.2.

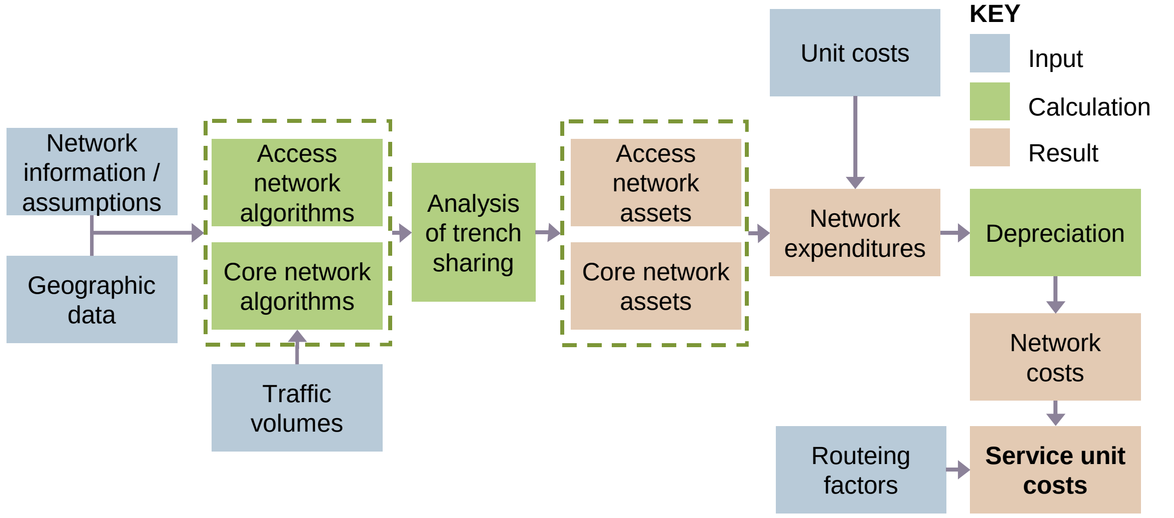

Figure 1.2: Modular approach to bottom-up LRIC models [Source: Analysys Mason]

A summary of the scope of the models is provided below for Markets 2 and 3, and for Market 4. An explanation of how the models will be calibrated and reconciled with top-down data to '*hybridise'* the models is also provided below.

Markets 2 and 3 (voice origination and termination)

For Markets 2 and 3, bottom-up core model(s) will be developed to understand the cost base of a number of operators designated as having SMP. The approach to accommodating a range of operators with SMP in Market 3 is explained in Section 4. Currently only Telenor is designated as having SMP in Market 2 (origination). The core model(s) will be of the same fundamental structure, and adapted through a 'parameterised' approach to accommodate different operators with different scales and scopes to Telenor.

The core model(s) will adopt two technology paths:

- a TDM based voice platform, referred to as a 'current' deployment
- an IP-based voice platform, referred to as a next-generation network (NGN) deployment.

The current deployment will reflect Telenor's current voice platform.

It may be the case that the NPT may choose to use results from either or both platforms to inform future decisions.

Market 4 (wholesale access to the local loop)

For Market 4, a bottom-up model will be developed to understand the cost base of Telenor's access network, since Telenor is designated as having SMP in this market.

Co-location services are also identified as a necessary product to support Market 4, and therefore we will develop a bottom-up module to address these services. This module may be part of the core model or stand alone, but in either case consistency with other modules will be ensured.

To provide an understanding of the cost of next-generation access (NGA) services, we will adapt our analysis of the access network. The technologies options to be considered are discussed in Section 5.2 and include the following:

- fibre to the node (FTTN) using very high bitrate digital subscriber line (VDSL)
- fibre to the home (FTTH) using point-to-point Ethernet (PTP)
- fibre to the home (FTTH) using a Gigabit passive optical network (GPON).

Hybrid models

Both the bottom-up models developed for Markets 2 and 3 (voice origination and termination with current network technology) and Market 4 (local loop unbundling) will be *hybridised* to improve the robustness of our approach. This process involves comparing top-down cost information from Telenor to the bottom-up model to ensure a satisfactory reflection of actual operator costs. This top-down validation will be undertaken in conjunction with Telenor, in order to understand the current cost base of the in-scope products.

The adapted bottom-up core model addressing other operators designated with SMP can also be *hybridised*, albeit to a lesser extent. In this case, we will compare the results of our modelling with data provided by operators during the data collection phase.

The conceptual design paper for the top-down validation is provided in a separate document, as it is specifically focused on Telenor. It will however be publically available for reference.

1.3 Structure of this paper

The remainder of this document is laid out as follows:

- Section 2 describes important principles of long-run incremental costing and our approach to dealing with these
- Section 3 defines the services to be included in the bottom-up models
- Section 4 addresses how SMP operators of different scale and scope will be accommodated
- Section 5 provides our model reference design for the bottom-up models
- Section 6 summarises the principles of the LRIC model for fixed networks identified in this paper.

This paper also includes a number of annexes containing supplementary material:

- Annex A explains the principles of the algorithms to be used for modelling aspects of the access and core networks
- Annex B provides a glossary of the acronyms used in this document.

2 Principles of long-run incremental costing

Long-run incremental costs (LRIC) based on an efficient deployment of a modern asset reflect the level of costs that would occur in a competitive and contestable market.

Competition ensures that operators achieve a normal profit and normal return over the lifetime of their investments (i.e. over the long run).

Contestability ensures that existing providers charge prices that reflect the costs of supply in a market that can be entered by new players using modern technology.

Both of these market criteria ensure that inefficiently incurred costs are not recoverable and that a forward-looking assessment of an operator's cost recovery is required (since a potential new entrant is unconstrained by historical cost recovery).

Efficient costs in a competitive and contestable market are set according to the following principles:

- the LRIC of the service
- often including a mark-up to recover common costs
- earning a normal return on investment
- allowing only efficiently incurred costs
- reflecting the costs of supply using modern technology
- assessed on a forward-looking basis.

These principles can be considered to be intrinsic to a LRIC-based cost calculation, although there is some flexibility and interpretation in their application. The remainder of this section discusses each of these principles in turn.

2.1 Long-run incremental costs

We discuss the principles in considering the *long-run costs* and defining the relevant *incremental costs*.

Long-run costs

Costs are incurred in a fixed operator's business in response to the existence or change in service demand, captured by the various cost drivers. Long-run costs include all of the costs that will ever be incurred in supporting the relevant service demand, including the ongoing replacement of assets used.

Consideration of costs over the long run can be seen to result in a reliable and inclusive representation of cost, since all of the cost elements would be included for the service demand supported over the long-run duration and averaged over time in some way. Therefore, in a LRIC method, it is necessary to identify all of the cost elements that are incurred over the long run to support the service demand of the increment.

Incremental costs

Incremental costs are incurred in support of the increment of demand, assuming that other increments of demand remain unchanged. Put another way, incremental costs can also be calculated as the avoidable costs of not supporting the increment.

There is considerable flexibility in the definition of the increment, or increments, to apply in a costing model, and the choice should be suitable for the specific application. Possible increment definitions include:

- marginal unit of demand for a service
- total demand for a service
- total demand for a group of services
- total demand for all services in aggregate.

Figure 2.1 below illustrates where the possible increment definitions interact with the costs that are incurred in a generic five-service business.

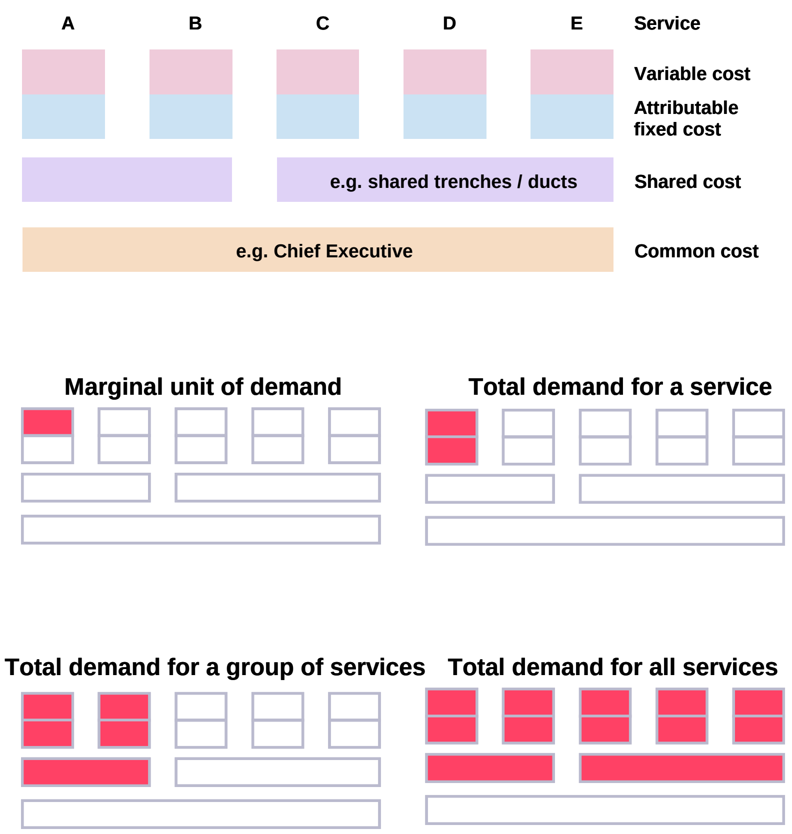

Figure 2.1: Possible increment definitions [Source: Analysys Mason]

The application of large increments maximises the incremental cost and minimises the common cost. This approach also requires the large incremental cost to be shared out (allocated) among its constituent services in some way.

The application of small increments to a cost model with economies of scale means that the calculated incremental costs reflect the economies of scale at current volumes, for each increment applied. The costs related to the growth of the network to current volumes (economies of scale) then need to be considered separately to the incremental costs – i.e. as a common cost, which may be recovered by a mark-up.

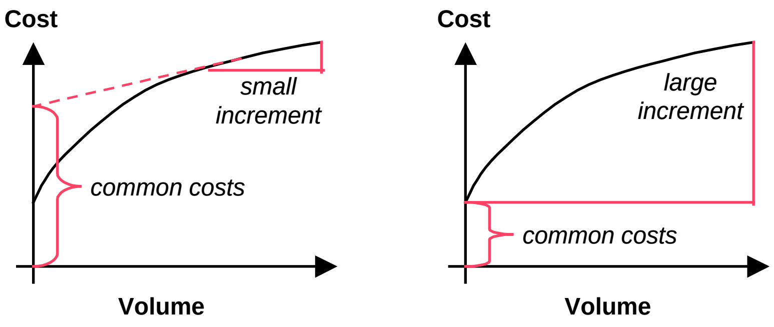

Figure 2.2: Large and small increments [Source: Analysys Mason]

The adoption of a large increment – in the case of a fixed network, all services using the access network – means that all of the services that are supplied are treated together and 'equally'. Where a subset of those services may be regulated (as in the current situation), the regulated services neither bears excessively, nor benefits excessively from, the higher (or lower) costs arising from economies of scale.

Definition of increments

We will define separate increments for the access network and core network, to cost the services in Markets 2 and 3, and those in Market 4. In assessing an incumbent operator's cost base, separate increments will lead to the identification of costs common to both increments, as illustrated in Figure 2.3. The treatment of these common costs is discussed below.

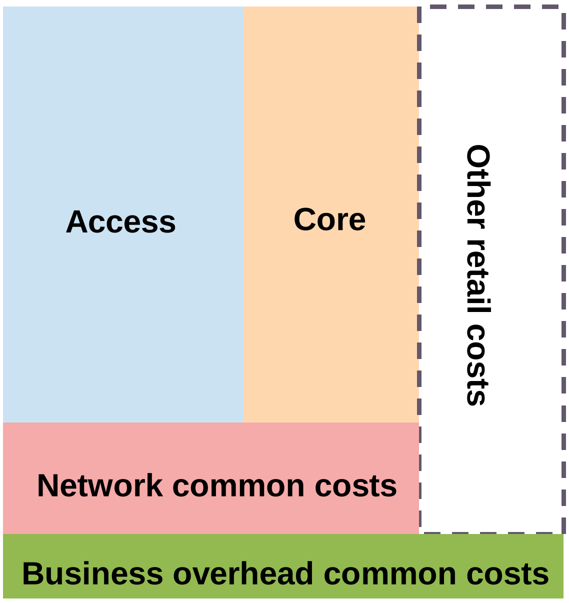

Figure 2.3: Access and core increments and common costs [Source: Analysys Mason]

In the current network, the definition of the border between access and core networks will be between the equipment side of the main distribution frame and the PSTN concentrator. In an NGN, the border may be similarly located between the access line and the active electronics using the line. This is further explained in Section 5.2.5. It is worth noting that some elements of core networks can be recovered in access products. For example, the line card in the concentrator is recovered in line rental charges for PSTN retail and wholesale line rental (WLR) services.

Applying separate access and core increments implies that focus is required on:

- the routeing factors that distribute traffic costs across services, particularly the degree to which data traffic loads the network
- the definition of a network element as being core or access (or common to both).

The level of costs recovered in total is not affected by the definition of increments – the increment definition affects which services recover those costs.

► *Increment for Markets 2 and 3*

In the European Commission's recent recommendation ('EC Recommendation'),[1] it is recommended that the increment for Market 3 is defined as the wholesale voice call termination service. Paragraph 6 states:

"Within the LRIC model, the relevant increment should be defined as the wholesale voice call termination service provided to third parties. This implies that in evaluating the incremental costs NRAs should establish the difference between the total long-run cost of an operator providing its full range of services and the total long-run costs of this operator in the absence of the wholesale call termination service being provided to third parties. A distinction needs to be made between traffic-related costs and non-traffic-related costs, whereby the latter costs should be disregarded for the purpose of calculating wholesale termination rates…"

Adopting this recommendation for Market 3 would require the definition of two increments for the voice platform:

- wholesale voice call termination service provided to third parties
- other services using the voice platform (including origination and other services such as on-net calls).

The EC Recommendation explicitly excludes non-traffic-related costs, which may correspond with any identified fixed costs attributable to the increment, as illustrated in Figure 2.4 below. Supporting these two increments will be common costs from the voice platform, common costs from the network and common costs from the business. If the non-traffic-related costs and common costs are excluded, then a "pure LRIC" cost of the increment can be calculated.

It should be noted that the use of pure LRIC for Market 3 may mean that common costs need to be recovered over a subset of services. For this subset of services, including origination (Market 2), this could lead to results that are above long-run average incremental costs (LRAIC). The model will be able to accommodate this eventuality.

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1 Commission Of The European Communities, *COMMISSION RECOMMENDATION of 7.5.2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU*, 7 May 2009

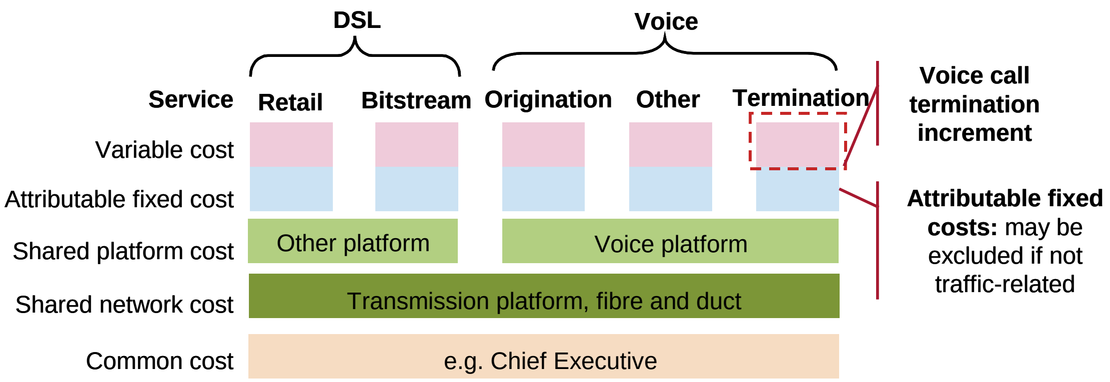

Figure 2.4: Illustration of voice call termination increment [Source: Analysys Mason]

An alternative approach is to define the increment as all traffic through the network. This would allow an understanding of the cost of providing voice origination and termination, considering the whole cost of the network. In this case the increment would include costs down to and including the shared network costs, as illustrated in Figure 2.4. Such an approach would allow for reconciliation of the costs produced by the top-down model and is consistent with previous approaches of LRAIC.

Principle 1. Two cost increment approaches for the core network will be modelled:

Defining separate increments for wholesale termination and other services using the voice platform (including wholesale origination) – a "pure LRIC" approach.

Defining one increment as all traffic throughput on network – a LRAIC approach.

The pure LRIC increment is only applicable to the calculation of the termination service (i.e. Market 3), as implied in the EC Recommendation. The LRAIC approach is applicable to both Markets 2 and 3.

► *Increment for Market 4*

For Market 4, and the costing of the unbundled copper local-loop service, it is reasonable to include other services delivered over the copper network that use shared resources. This implies that all services using the access network duct and trench, including copper loops, fibre links and duct access itself, should be costed and included in the increment. Such an approach will allow cost-causality principles to lead to the allocation of costs on a per-line basis. This can be considered a LRAIC approach – there are no recommendations regarding the increment for Market 4 services.

Principle 2. The increment in the access network will be defined as the total volume of all services using the access network - a LRAIC approach.

2.2 Common cost mark-ups

As highlighted previously, the calculation of incremental costs for a fixed operator will identify some costs as common to the increments. These are likely to include:

- network common costs – parts of the deployed network that are common to all network services (e.g. the voice platform for a small increment approach; local exchange space, which is common to core and access, for the larger increment definitions)
- non-network common costs, or 'business overheads' – activities that are common to all functions of the business (e.g. the CEO).

For some services (and depending on the pricing approach to be taken by NPT, which is outside the scope of this paper) common costs may be allocated to the increments. Where rational allocations cannot be made on cost-causality principles, then mark-ups are required.

If all common costs are borne by one increment, the increment's LRIC is marked up to the efficient stand-alone cost (SAC) of providing that increment. The SAC therefore represents the ceiling to the marked-up cost of any increment: in such a situation, the mark-up on the LRIC of other increments would be zero by definition. In the situation where organisation-level common costs are shared among increments, a mark-up mechanism needs to be defined that will produce the relevant marked-up LRIC (i.e. the LRIC+). These situations are illustrated in Figure 2.5 below.

Figure 2.5: Illustration of LRIC, SAC and LRIC+ [Source: Analysys Mason]

Equi-proportionate mark-up (EPMU) is a commonly adopted approach for the allocation of common costs. In the EPMU approach, a unique percentage is used as an uplift for the incremental cost of all the increments. The percentage is calculated as the ratio of total common costs to total incremental costs. Applying an EPMU is straightforward, results in uniform treatment of all of the service costs in the business, and does not require any additional information to calculate.

Use of mark-ups

In assessing the cost of services, the implications of both recovering directly attributable costs (pure LRIC) or all efficiently incurred costs (LRIC+) should be considered. Therefore, where costs are not rationally allocable, an alternative allocation mechanism is required in the model (whether NPT chooses to allow these costs or not is outside the scope of this model specification).

EPMU is supported on the grounds that it is objective and easy to implement. It is also consistent with regulatory practice elsewhere.

Principle 3. Where required, an EPMU approach will be employed for marking-up common costs.

2.3 A normal return on investment

A requirement of prices in a competitive market is that the operator earns a normal, rather than super-normal, return on investment. This must be earned over the long run, rather than over the short run, since there would need to be a consideration of a terminal value and its associated earning power in a short-run return calculation.

The weighted average cost of capital (WACC) represents the opportunity cost of capital invested in the business, and therefore the return on investment required to compensate for this opportunity cost.

NPT has separately appointed an external advisor to determine the approach and the appropriate value for the WACC to be used in the model.

Recommended approach

The model will include WACC as a parameter. The value of the WACC to use for the access and core networks will be determined by the NPT-appointed external advisor.

Principle 4. A WACC will be used in the model in order to provide a return on investments. The approach to defining the WACC will be determined by an advisor.

2.4 Efficiently incurred costs

In order to set the correct investment and operational incentives for regulated operators, it is necessary to allow only efficiently-incurred expenditures in cost-based regulated prices. The specific application of this principle to a set of cost models depends significantly on a range of aspects:

- detail and comparability of information provided by individual operators
- detail of modelling performed
- ability to uniquely identify inefficient expenditures
- stringency in the benchmark of efficiency that is being applied[2]
- whether efficiency can be distinguished from below-standard quality.

Cost inputs are collected in the data collection phase (Phase 2 in Section 1.1) and compared against available benchmark costs. Costs used will be available for industry assessment during model consultation (Phase 3c), subject to confidentiality limitations.

Where possible in the model, bottom-up costs will be reconciled with top-down costs identified in operator accounts.

2.5 Costs of supply using modern technology

In a contestable market, a new entrant that competes for the supply of a service would deploy modern technology to meet its needs. This is because this should be the efficient network choice. This implies two ‘modern’ aspects: the price of purchasing that capacity, and the costs of operating and maintaining the equipment. Therefore, a LRIC model should be capable of capturing these two aspects:

- the modern price for equipment should represent the price at which the modern asset can be purchased over time
- operation and maintenance (O&M) costs should correspond to the modern standard of equipment, and represent all the various facility, hardware and software maintenance costs relevant to the efficient operation of a standard modern network.

The definition of modern equipment is a complex issue. Operators around the world are at different stages (from initial plans to fully deployed) of deploying next-generation, IP-based networks. Conversely, a significant proportion of customers are still served through conventional PSTN networks. Therefore in the timeframe being considered, both approaches may be considered reasonable.

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2 For example, most efficient in the Europe versus most efficient in the world.

NPT has chosen to develop a model that can consider both conventional PSTN and next-generation IP-based services. The model reference designs are explained in Section 5.

In the EC Recommendation, it is proposed that a fixed voice termination model could consider NGN deployments.

2.6 Forward-looking costs

Forward-looking costs determine the level of cost recovery now and in future periods, according to:

- current levels of expenditure
- projected future changes in demand volumes
- projected future changes in equipment prices
- projected future changes in the deployed technology (if any).

Forward-looking costs should not take into account the costs actually recovered by an operator to date. In a LRIC model, the depreciation algorithm embodies the forward-looking principle. Some, but not all, depreciation methods project cost recovery in a forward-looking manner. The methods that rely on historical levels of expenditure or cost recovery may or may not be consistent with a forward-looking calculation. This depends on whether the historical periods are consistent with forward-looking costing over the entire duration considered.

Depreciation methods are discussed in more detail in Section 5.5.3.

3 Service definitions

Section 3.1 describes the full service set that will be considered in the model, distinguishing between services that drive the dimensioning of the access and core networks.

Section 3.2 defines the charging structure of the wholesale products to be costed in the model.

3.1 Definition of services carried

The principal requirement of the model is to understand the costs of services related to Markets 2, 3 and 4: call origination, call termination and full/shared access to the network.

However, fixed networks typically convey a wide range of services. The extent to which the modelled fixed network can offer services to locations within its network footprint determines the treatment of economies of scope. Economies of scope, arising from the provision of both voice and data services across a single infrastructure, will result in a lower unit cost for voice and data services. This is particularly true for networks built on next-generation architecture, where voice and data services can be delivered via a single platform.

As a result, a full list of services must be included within the model, as a proportion of network costs will need to be allocated to these services. The service set may also need to vary by region. For example, broadband services available in the urban areas may be significantly different to those in the most remote areas of Norway.

Assessing both voice and data services in the model increases the complexity of the calculation and the supporting data required, and is expected to result in a lower unit cost for voice services due to economies of scope. Excluding costs relevant to services outside Markets 2–4 is equally complex.

3.1.1 Access services

The following sections discuss the access-related services that are relevant to both the current and NGA architectures.

Current access services

The basic architecture of the current access network is shown below in Figure 3.1.

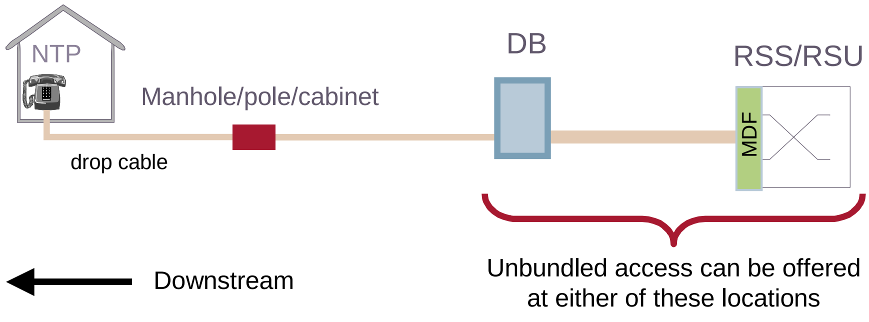

Figure 3.1: Outline of current access architecture [Source: Analysys Mason]

Copper (or fibre) loops connect the network termination point (NTP) in the customer premise to a remote switching stage/unit (RSS/U). There is a point of aggregation used in the network, referred to as a distribution box (DB); the copper cable downstream of this node is referred to as the sub-loop.

Service	*Service explanation*
PSTN/ISDN end-user access	Provision of a line suitable for voice and sold through Telenor's retail arm. May be provided over copper pair, fibre (where multiple services may be provided over the same line) and wireless solutions.
Wholesale line rental (WLR)	Provision of a line suitable for voice and sold through operators other than Telenor's retail arm. May be provided over copper pair, fibre (where multiple services may be provided over the same line) and wireless solutions.
Full local loop unbundling (LLU)	The full service for LLU allows an access seeker to provide services, including voice and xDSL, over the copper loop using its own equipment co-located with the termination block at Telenor's MDF. Co-location at the MDF is offered by Telenor as a separate product Telelosji. The unbundled copper pair runs from the NTP to a terminating block at the MDF.
Shared LLU	As for full LLU, except that an access seeker can only use the high frequencies. In addition, the access seeker must provide splitters at both the MDF and the NTP.
Full sub-loop unbundling (SLU)	The full service for SLU allows access seekers to provide services, including voice and xDSL, over the copper sub-loop using its own equipment deployed in the vicinity of Telenor's DB. Internal connections in the DB are established using the Telelosji service. The unbundled copper pair runs between the NTP at the premises and a terminating block in the DB. If the distance from the DB to the MDF exceeds 1.5km, then xDSL transmission systems cannot be used due to technical limitations.
Shared SLU	As for full SLU, except that an access seeker can only use the high frequencies. In addition, the access seeker must provide one splitter in the vicinity of the DB and another at the customer's NTP.
DSL access	Provision of a line suitable for data and sold through Telenor's retail arm. May be provided over copper pair or fibre (where multiple services may be provided over the same line). Costs may be recovered through use of shared access or naked bitstream DSL.
Bitstream	Provision of a data service to an end user, where a connection of specific quality can be set up from the subscriber to an access point in Telenor's network, from where the access seeker can route traffic to its own network. Telenor carry traffic over the copper line, installs and operates the necessary xDSL equipment, and ensures transmission up to the access point. Costs may be recovered through use of shared access or naked bitstream DSL.
Leased lines	Provision of one or more local tails for a permanent connection from a location, for either retail customers, other operators, or internal use.
Access lines	In addition to the above services, other copper lines in the access network which may be deployed can be quantified.

Figure 3.2: Services over which access network costs can be recovered [Source: Analysys Mason]

The three primary issues in the service definition are:

- consistency with top-down operator data
- impact on the dimensioning of the access network over time
- inclusion of other services.

► *Comparing with top-down operator data*

Volumes in the bottom-up model will be aggregated in terms of copper/fibre access lines. This is because the access network is dimensioned in terms of physical lines, rather than rentals (which can use the same physical line). Comparison of the bottom-up active access line volumes with top-down data requires care to avoid double counting since there is not a one-to-one mapping between active services (e.g. PSTN, ISDN2) and active physical lines (e.g. copper, fibre).

In addition, double-counting of leased lines used internally by Telenor services will be avoided.

Principle 5. In the bottom-up model, active access line volumes will be aggregated by copper and by fibre. These volumes will then be compared to top-down data.

► *Dimensioning of the access network*

The size of an access network over time should not be dimensioned purely based on changes in service volumes. This would imply that major components such as the trench/duct deployed are changing over time in response to demand. In fact, the size is largely fixed at the time of initial deployment and is driven by the number of buildings passed. Hence, a projection of demand, rather than the actual demand carried, will be used to dimension the access network that reflects the number of buildings that are passed over time. Functionality will be included in the model to change this projection over time, if an access network whose size varies over time is deemed appropriate.

However, the number of access lines over which the cost of the access network is recovered, as a default input, will be projected to vary over time based on an appropriate forecast.

Principle 6. A variety of access-related services will be modelled. However, the size of most assets in the access network over time will not be varied on the basis of demand, but rather a forecast driven by locations passed. However, the costs of access will be recovered over the forecast demand.

► *Other services*

Fibre and duct access are important services that contribute economies of scope to the modelled operator since they are sharing assets deployed for the copper-based access networks, and hence should be allocated some of the associated costs. These services are described below.

Service	*Service explanation*
Duct access	Provision of dedicated capacity within duct in the access network, where an access seeker can deploy its own cabling.
Fibre access	Provision of access to a fibre (or fibres) link between two locations. The access seeker can deploy its own electronics at these locations in order to 'light' the fibre and use for its own point-to-point transmission.

Figure 3.3: Other services over which access costs can be recovered [Source: Analysys Mason]

Principle 7. Services covering access to both ducts and fibre in the access network can be included in the Market 4 service set.

NGA services

The three main candidate architectures for an NGA network in Norway are shown below in Figure 3.4. These are:

- FTTN/VDSL, where the DB is upgraded and the copper back is replaced by fibre
- FTTH/PTP, where a dedicated fibre is deployed from the switch to the premises
- FTTH/GPON, where fibre is deployed through the access network in a tree topology, using splitters as distribution nodes.

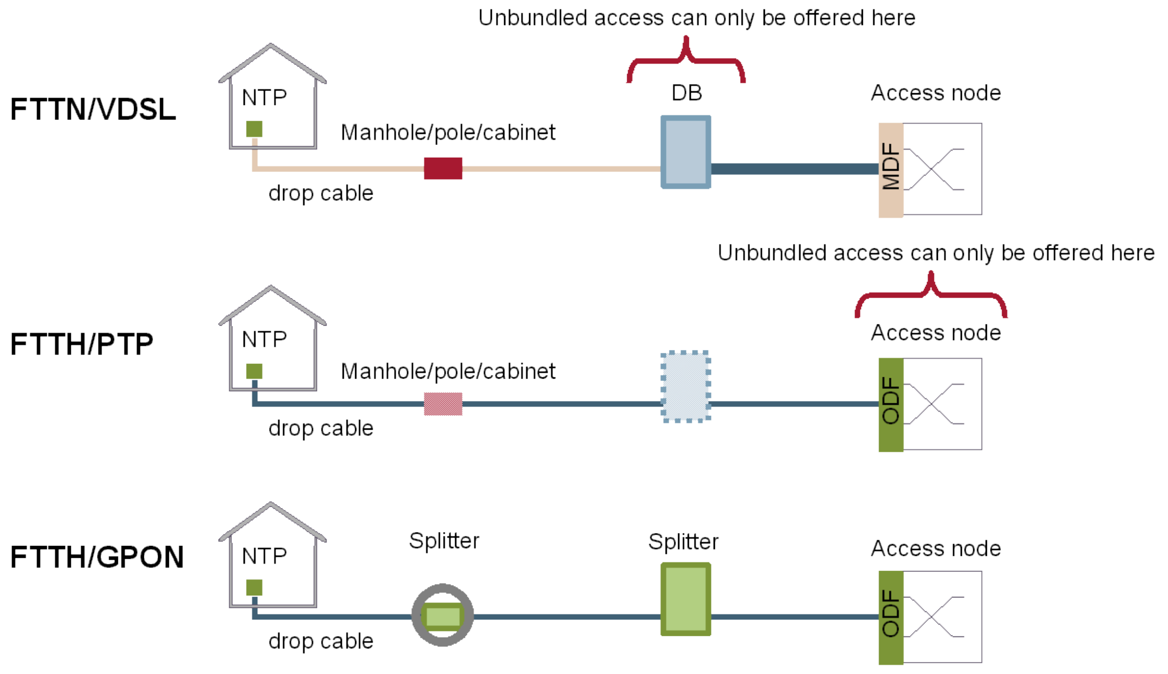

Figure 3.4: Outline of NGA architectures [Source: Analysys Mason]

An NGA network could be partially or fully deployed in Norway. The services described above do not explicitly change to next-generation services as the migration occurs.

The principal aim of the model is to inform NPT and industry in pricing decisions for full and shared access services. It is unclear at this time what services may exist under next-generation network architectures, since these architectures are conjectural. Therefore, the next-generation version of the model is intended to inform NPT how access service costs may change.

For access services, including LLU/WLR, the main driver of service costs would be the costs of the new access network deployment and the number of access lines over which the access network (albeit a modified network) costs are recovered.

Certain access services would change for NGA. For the architectures described above:

- SLU would be feasible for FTTN/VDSL (LLU will no longer be possible)
- fibre unbundling (the equivalent of LLU) would be the feasible for FTTH/PTP
- a bitstream product would be feasible for FTTH/GPON. We will not explicitly model an unbundled FTTH/GPON, as methods for unbundling GPON remains unclear.[3]

However, it is the total number of active access connections in use that will impact the unit costs of NGA.

Principle 8. Consistent with the approach for the current network, the costs of NGA connections will be determined through the recovery of the total cost of a NGA architectural deployment over the active access connections in that architecture.

3.1.2 Core services

Both retail and wholesale voice services will be modelled so that the voice platform is correctly dimensioned and costs are recovered. The services identified are those currently available. An explanation of how these services will be accommodated in a next-generation (NG) core model is provided later in this section.

Current core services

A number of voice services that contribute to the deployment of the core network are listed in Figure 3.5 below.

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3 One example proposition for GPON unbundling is to define a maximum number of access seekers, so that a known number of assets, including optical splitters and backhaul fibres, is replicated. This may not be consistent with an open access model.

Service	*Service explanation*
Local on-net calls (retail)	Voice calls between two retail subscribers of the modelled fixed operator within the same call charging zone.
National on-net calls(retail)	Voice calls between two retail subscribers of the modelled fixed operator not in the same call charging zone.
Outgoing calls to international (retail)	Voice calls from a retail subscriber of the modelled fixed operator to an international destination.
Outgoing calls to mobile (retail)	Voice calls from a retail subscriber of the modelled fixed operator to a domestic mobile operator.
Outgoing calls to other fixed operators (retail)	Voice calls from a retail subscriber of the modelled fixed operator to a domestic fixed operator.
Outgoing calls to non-geographic numbers (retail)	Voice calls from a retail subscriber of the modelled fixed operator to non-geographic numbers, including 08xx numbers, directory enquiries, and emergency services.
Local incoming calls (wholesale)	Voice calls received from another international, mobile or fixed operator and terminated on a retail subscriber of the modelled fixed operator, with no transit on another core switch of the modelled fixed operator.
Tandem incoming calls (wholesale)	Voice calls received from another international, mobile or fixed operator and terminated on a retail subscriber of the modelled fixed operator, after transiting on another core switch of the modelled fixed operator.
Local outgoing calls (wholesale)	Voice calls originated by a wholesale subscriber of the modelled fixed operator and terminated on-net or off-net, with no transit on another core switch of the modelled fixed operator.
Tandem outgoing calls (wholesale)	Voice calls originated by a wholesale subscriber of the modelled fixed operator and terminated on-net or off-net, after transiting on another core switch of the modelled fixed operator.
Local transit calls (wholesale)	Voice calls received from another international, mobile or fixed operator and terminated on another international, mobile or fixed operator, with no transit on another core switch of the modelled fixed operator.
Tandem transit calls (wholesale)	Voice calls received from another international, mobile or fixed operator and terminated on another international, mobile or fixed operator, after transiting on another core switch of the modelled fixed operator.
Dial-up Internet traffic	Circuit-switched calls made by customers for Internet access.

Figure 3.5: Voice services [Source: Analysys Mason]

As in the case of Market 4, these services have been included in order to accurately estimate total costs and allocate these among the services using the network. It is not implied that their prices might be regulated as a result.

Principle 9. Traffic generated by ISDN lines will be included in the above voice services i.e. there will not be specific ISDN voice services.

The services relating to Internet access that will be included in the model are listed in Figure 3.6. These services are included to capture backhaul requirements from the local exchange towards the core network. These services are applicable to the model of

Telenor and may be applicable to operators who have deployed their own fibre backhaul to exchanges.

Service	*Service explanation*
xDSL retail	Provision of a digital subscriber line (xDSL) Internet service, sold through the modelled operator's retail arm.
xDSL wholesale (bitstream)	Provision of an xDSL Internet service, resold by other operators.

Figure 3.6: Internet access services [Source: Analysys Mason]

In addition, a number of 'other' services, shown in Figure 3.7 below, have been identified as relevant for the core model.

Service	*Service explanation*
Leased lines	Includes leased line services provisioned for either retail customers, other operators, or internal use
Data transmission services	Transmission bandwidth between the different layers of the network (e.g. access nodes, distribution nodes, core nodes) is used by services identified above and other services (e.g. ATM, FR, VPN, connections to hybrid fibre-coax (HFC) and mobile networks, etc.). This excludes the leased line services defined above.

Figure 3.7: Other services [Source: Analysys Mason]

We will seek to quantify these other services in the core model to reasonably dimension the transmission network.

Principle 10. Leased lines and other transmission services reasonably identified will be captured within the core network model.

NG core services

It is envisioned that the core services in the NGN will be based on existing services. Therefore future services, which do not exist as of yet, will not have to be projected without precedent. The services described above would still be available within an NG core but delivered differently. For example:

- voice services would be equivalent to those on the current network, but would be delivered with VoIP protocols
- IP–PABX would be the NGN equivalent of PR–ISDN, through replacement of the PABX when connected to an IP service

- broadband would have an equivalent NGN service, although its backhaul provisioning (in terms of kbit/s per sub) may change[4]
- business connectivity services would migrate to IP–VPN and Ethernet
- IPTV services (both linear and video-on-demand (VoD)) could be introduced, which could also be considered to be available in the current network.

Principle 11. NG-specific core services will not be separately defined and modelled: the same service definitions will be used as with the current network.

3.2 Definition of output wholesale products

3.2.1 Market 2 and 3 wholesale products

Current core wholesale products

We understand that Telenor provides wholesale voice products with three interconnect port variants, as shown in Figure 3.8 below.

Product	*Product explanation*
2Mbit/s circuit switched	This conventional interconnection product is used for both origination and termination interconnections.
155Mbit/s SDH	This current interconnection product is used for both origination and termination interconnections.
155Mbit/s ATM	This evolved interconnection product consolidates 2Mbit/s ATM streams from other core nodes and can be used for both origination and termination interconnections. However, this product is being phased out and is not available for new operators.

Figure 3.8: Wholesale interconnect products [Source: Analysys Mason]

It is believed that the principal product used is 2Mbit/s interfaces. Therefore, the focus of the model will be on the costing of 2Mbit/s interfaces. If evidence arises during model consultation that a 155Mbit/s SDH product is important for the market, then it may be considered in the future. It is understood from the current Telenor Reference Interconnect Offer[5] (Telenor's standard 'samtrafikkavtale') that ATM 155Mbit/s ports are being phased out and are no longer available for new operators.

4 Dial-up Internet traffic will not be appropriate in exchange areas with NGA deployed.

5 Avtale om samtrafikk mellom Telenor Norge AS og tilbyder; Issued 03.2009. Annex 2, page 19.

It is assumed that other operators will provide interconnect products to their own networks using a 2Mbit/s circuit switch port.

It is assumed that voice interconnection products can be charged using the four aspects of a fee structure (or a subset of these options):

- a port establishment fee
- a monthly port fee
- a per-call set-up fee
- a per-minute conveyance fee (the fixed origination or terminate rate).

It may be reasonable to disaggregate the cost of interconnect along these aspects where cost-based reasons exist for such disaggregation (e.g. where specific assets are clearly driven by call set-up or call conveyance). However, cost orientation can also be demonstrated at a higher-level (e.g. examining the average cost of a minute without the call set-up and conveyance disaggregated).

Principle 12. The same fee structure (namely a port set-up fee, a monthly port fee, a per-call set-up fee and a per-minute conveyance fee) will be used where clear reasons exist for disaggregation. The 2Mbit/s port interface will be modelled as a minimum.

It should be noted that the conveyance charge is the fixed termination rate and will hence not vary between the port types used.

NG core wholesale products

The move to NGN will herald the introduction of Ethernet-based interconnect products. It is assumed that three port variants of 10Mbit/s, 100Mbit/s and 1Gbit/s may be viable, and flexibility is allowed in the core model to accommodate these. It may be appropriate to test the level of demand for a 1Gbit/s interconnect product, given that the largest port available today is 155MBit/s. Charging mechanisms will be structured as in the current network.

Principle 13. Three NGN-interconnect products will be defined corresponding to connections based on 10Mbit/s, 100Mbit/s and 1Gbit/s Ethernet.

3.2.2 Market 4 wholesale products

Access loops

► *Current wholesale products*

The wholesale products for Market 4 that will be costed in the model will be unbundled access to both shared and full copper loops and sub-loops, as described previously in Figure 3.2.

Currently, the price of the full loop is set by Telenor to be the same as the price of the sub-loop. The costs of these service will be separately derived in the model. The treatment of the cost recovery of primary cable may form part of the market review decision, which is outside the scope of this model specification.

Allocation of full access copper costs to shared access loops can be undertaken externally to the model, as part of a pricing decision. This is also outside the scope of this model specification.

Principle 14. The costs of both full and shared access to both copper loops and sub-loops will be calculated for the current network.

► *NGA wholesale products*

There are currently no wholesale products explicitly defined for Market 4 in an NGA deployment. Therefore this version of the model is intended to inform NPT how access service costs may change. It is currently understood that certain types of unbundling will practically be possible[6] in certain NGA architectures:

- copper SLU will be possible in an FTTN/VDSL deployment
- fibre unbundling will be possible in an FTTH/PTP deployment.

In addition, bitstream access would also be possible in all three architectures. The costs of the access elements for these three services will be calculated, which will allow comparison with the costs of the equivalent services in the current network. The cost of end-to-end bitstream services over these architectures will not be calculated.

Principle 15. The costs will be calculated for copper SLU for a FTTN/VDSL deployment, and fibre unbundling for a FTTH/PTP deployment.

6 Issues on whether certain types of unbundling are economically feasible are outside the scope of this specification paper.

Co-location

Telenor currently offers co-location services, called Telelosji, at both the MDF location and also the distribution boxes at the sub-loop level. These services include:

- location, mounting and installation of equipment
- station wiring
- power, ventilation and cooling.

Modelling co-location services requires a different approach to the rest of the cost model. This is because the focus is not on network asset dimensioning, but rather on constructing a bottom-up calculation of the component costs associated with co-locations.

Hence, we will construct a self-contained co-location module that calculates the cost of co-location services for locations in Norway. From the perspective of Market 4, the most important co-location services are related to unbundled access (especially at the MDF location for LLU). However, the costs for this service will be shared with those of other co-location services (particularly overhead staff costs) and hence the co-location module will need to capture a range of co-location services.

Due to potentially radical changes in architecture with an NGA deployment, this module will need some separate consideration of an NGA network perspective and a current perspective, as explained below.

► *Current wholesale products*

The co-location module will need to calculate the costs associated with making space in Telenor locations suitable for co-location services, including component services such as:

- location, mounting and installation of equipment
- provision of station wiring
- provision of power, ventilation and cooling.

Given that costs of space are a primary driver of co-location costs, this part of the module will need to account for variation in costs with geography.

Co-location services consist of relatively few cost categories, being mostly stand-alone products that can be used by the access seeker to build up a co-location service. The inputs will therefore have to be more detailed than in the core and access models in order to capture costs at a sufficiently granular level.

► *NGA wholesale products*

The scope of co-location services may change in the NGA, depending on the architecture:

- for FTTN/VDSL, there would be greatly reduced requirements for co-location at the exchange, with the active electronics moved to the distribution boxes within the network. Co-location would be offered at either the distribution box or its near vicinity
- for FTTH architectures, the number of exchange locations may fall through rationalisation, reducing the availability of sites for co-location. Co-location at the sub-loop level will also not be relevant.

Principle 16. A separate co-location module will be constructed, which will calculate the costs associated with co-location in various types of locations in the Telenor network. Consideration will be made of the scope for co-location services in a current network compared with a next-generation architecture.

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4 Operator definitions

The model is required to provide an understanding of the cost of voice termination (Market 3) for operators designated as having SMP. Therefore, it must account for the fact that it could be used to inform the prices set for multiple operators in the future. Originally, only Telenor was obliged to have cost-oriented termination prices. However following an investigation by NPT (undertaken on a case-by-case basis), the operators were unable to justify their costs being materially higher than those of Telenor. Five of the operators with SMP have since been obliged to bring their charges down into line with those of Telenor. Currently, 12 operators are designated as having SMP in Market 3.

The modelling for the other operators is expected to be completed using the same calculations as the model developed for Telenor, with separate inputs to reflect the types of business models and different scale of operations. A key aspect of modelling the different operators is to understand any cost differences. The generic types of operators, based on the list of business models listed by NPT in its 2006 market review,[7] are described in Figure 4.1 below.

In order to analyse potential cost differences for different operator types, we will parameterise a number of alternative, hypothetical operators in the model. We expect that these hypothetical configurations will be designed to use only one type of access to a defined network footprint (e.g. an unbundler, an access owner, a reseller).

The parameters will be based around the following dimensions, of which access-related dimensions may not be applicable for some of the operator types:

- number and location of core nodes
- number and location of interconnect points
- number of access gateways
- average capacity, utilisation (and voice utilisation) on core links
- average capacity, utilisation (and voice utilisation) on interconnect links
- average capacity, utilisation (and voice utilisation) on access links network.

[7] P17, Annex 1, Analysis of the markets for call origination, call termination and transit services on the fixed network, NPT March 2006

Operator type	*Operators list*	*Description*	*How model will be adapted*
Telenor	Telenor	Telenor uses its access network to offer: • PSTN (Business Model A “Traditional”) • both broadband and VoB to the same end users (Business Model F “VOB with own/leased lines”) • broadband	This will be the base model.
Access leasers	Ventelo, TDC, Tele2, NextGenTel	These operators lease access circuits from Telenor and use them to offer: • PSTN (Business Model D “Leased access”) • both broadband and VoB to the same end users (Business Model F “VOB with own/leased lines”) • broadband based on LLU	The model will have a small core similar to Telenor’s NGN. It will also include a backhaul network to aggregate services from the access/ distribution nodes to the core nodes. Geographical expansion of the modelled network will be based on actual deployment achieved by a typical operator.
Access owners	Get, Hafslund, Lyse Tele	These operators have their own, alternative access network (e.g. cable, fibre) and use it to offer: • VoB and broadband to the same end users (Business Model F “VOB with own/leased lines”) • broadband based on own access	The model will have a small core similar to Telenor’s NGN. It will also include a backhaul network to aggregate services from access nodes to the core nodes. Geographical expansion of the modelled network will be based on actual deployment achieved by a typical operator.
Access independent	Telio	These operators neither own nor lease infrastructure. They rely on service-based access to offer: • PSTN (Business Model B “Carrier pre-selection operator (CPSO)” and business model C “Indirect interconnection”) • VoB to the end users (Business Model G “VOB without own/leased lines”)	The model will have a small core similar to Telenor’s NGN. It will not include any backhaul network. Geographical expansion of the modelled network will be limited to the core network and driven by the requirement for different points of interconnect.

Note: operators might fit under one or more business models

Figure 4.1: Generic operator types [Source: Analysys Mason]

Principle 17. The model will be capable of reflecting a number of network configurations, which are modelled using separate sets of parameters.

Only Telenor will be modelled for voice origination (Market 2) and for wholesale access to the local loop (Market 4).

5 Model reference design

5.1 Overview

This section provides the model reference design for the bottom-up LRIC model addressing interconnection on fixed networks and for full and shared access to fixed networks.

Section 5.2 describes the access network model specification, including current and NGA network architectures and methods to inform the asset calculations. The access network model will principally inform Market 4 decisions and is limited to Telenor.

Section 5.3 describes the core network specification, including current and NG network architectures. The core network model will be applicable to Telenor in wholesale voice origination and termination (Markets 2 and 3) and, potentially in a reduced form, to other operators designated as SMP in wholesale voice termination (Market 3).

Section 5.4 provides the reference design for the co-location module. This module will be applicable to Telenor, due to its requirements to support Market 4.

Section 5.5 describes the costing parameters to be used in the bottom-up LRIC model.

Section 5.6 explains the period that the model will cover.

Section 5.7 summarises the planned documentation to support the bottom-up LRIC model.

5.2 Access network specification

This section outlines the specification for the access network model, which will be required to consider the costs of both current and next-generation architectures. These architectures are introduced below, followed by a summary of the structure of our approach.

Current architecture

An illustration of Telenor's copper access network topology is shown below in Figure 5.1.

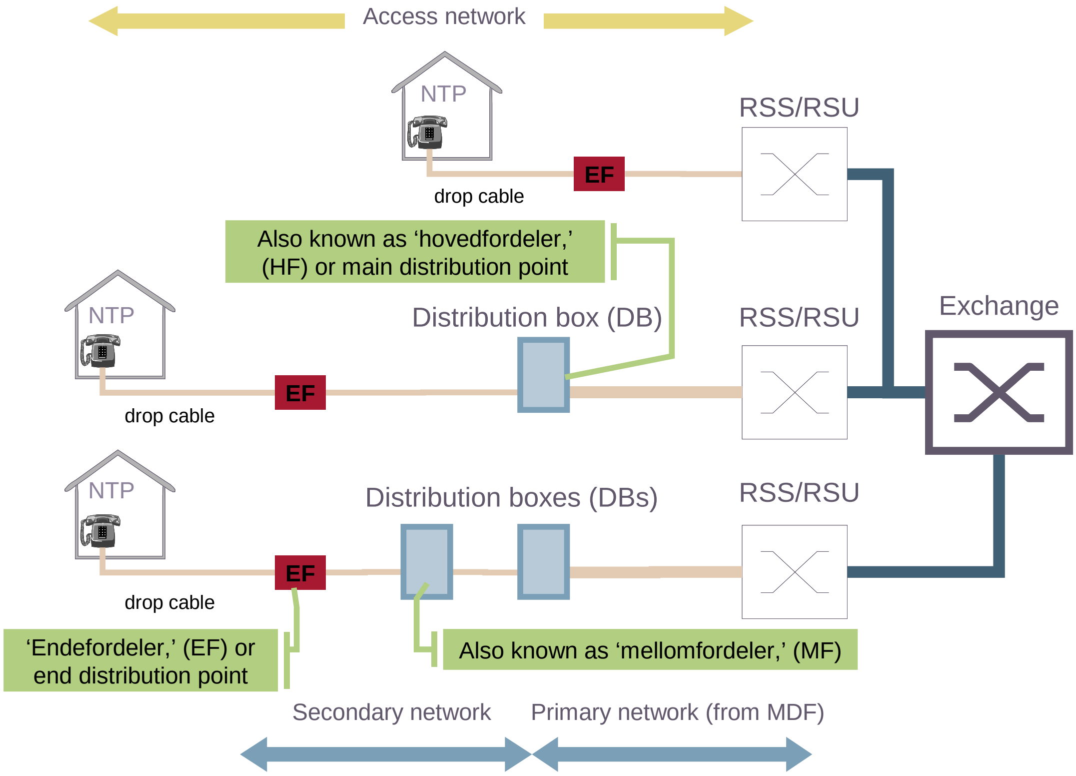

Figure 5.1: Topology of the copper access network [Source: Telenor, Analysys Mason]

Access lines terminate in the MDF, which are usually located at the network nodes called the remote subscriber stage (RSS), or the remote subscriber unit (RSU)[8] – collectively referred to as RSX. These nodes can be deployed in accommodation (i.e. a building), or as a field deployment. These nodes are routed back to an exchange: this cable not included in the access network.

The last distribution point in the network, where the so-called ‘drop cable’ arrives from the network termination point (NTP) of the end-user, is called the end distribution point or ‘endefordeler’ (EF). This can be deployed either in a manhole, on a pole, or in a cabinet. Between the MDF and the EF, there may be:

- no other distribution points
- a distribution box (DB), also called a ‘hovedfordeler’ (HF)
- a DB and one or more additional distribution points, or ‘mellomfordeler’ (MF).

The primary network is the part of the access network from the MDF to the first distribution point. The secondary network is the access network from the first distribution point to the last distribution point. Hence, customers connected directly to the MDF (via

8 These are vendor-specific terminologies: RSSs are provided by Ericsson and RSUs by Alcatel-Lucent.

an EF) have no secondary segments. All segments between HF and EF are included in the secondary network. Cable links between EF can be branched.

This topology can vary depending on the geography. Fibre connections can be deployed to buildings with high demand, while in remote areas of Norway, a mix of copper, radio and satellite links can be employed.

Next-generation architecture

There are three main NGA architectures to consider for operators in Norway: FTTN/VDSL, FTTH/PTP and FTTH/GPON. These are illustrated below.

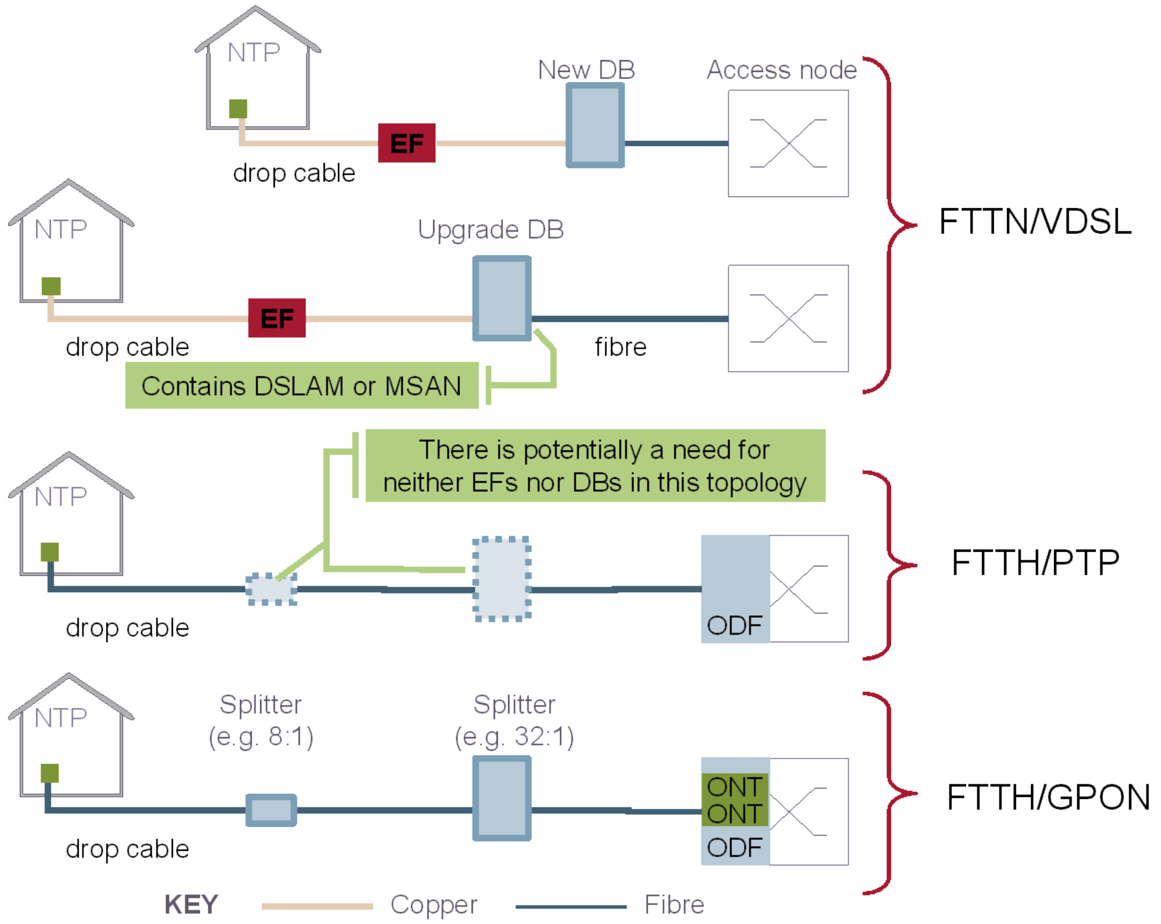

Figure 5.2: NGA architectures [Source: Analysys Mason]

► *FTTN/VDSL*

FTTN using VDSL involves laying fibre-optic cables to the DB. These are typically within a few hundred metres of the end-user's premises. New, larger DBs would be needed to house the active equipment: most likely a VDSL multi-service access node (MSAN) or digital subscriber line access multiplexer (DSLAM). The existing copper sub-loop would be retained. New DBs may also need to be deployed for lines previously served directly by exchanges, but that are too long to be used for VDSL, as shown above.

An alternative to the tree-based topology shown above would be to place the DBs on fibre rings. This involves shorter distances to connect all the DBs, but does not allow re-use of as much existing infrastructure.

► *FTTH/PTP*

FTTH can be deployed using point-to-point (PTP) Ethernet fibre connections. By using this technology, each premise would have a dedicated fibre pair. An optical Ethernet switch would be required at the switch building to terminate the fibre connections and the fibre is assumed to terminate on an ODF. Specialised customer premises equipment (CPE) would be required at the end-user location.

► *FTTH/GPON*

FTTH using GPON involves laying fibre directly to the customer premises in a tree topology. The final drop cable to houses would only be installed when customers connect. All other fibre would be installed in the initial roll-out.

The fibre is assumed to terminate on an optical line terminator (OLT) in the switching building, with several OLTs on an optical distribution frame (ODF).

Passive splitters would be installed in the access network at the location where DBs and EFs are currently located. There are several possible topologies for these splitters: the split (of 8:1 and 32:1) illustrated is only one possible topology.

As with PTP, specialised CPE would also be required at the end-user location.

Structure of our approach

A modular approach will be taken to enable flexibility in the end-to-end model design. The output will be the volumes of each asset in order to serve the demand profile selected. This output will feed into the cost module in the same manner as the equivalent outputs from the core network model.

The access network calculations will require two phases, as shown below in Figure 5.3.

- an ‘**offline’ calculation** phase, which derives values for various input parameters based on a geographical analysis of Norway
- an ‘**active’ calculation** phase, which will calculate the output asset volumes using the parameter values derived in the offline calculation phase.

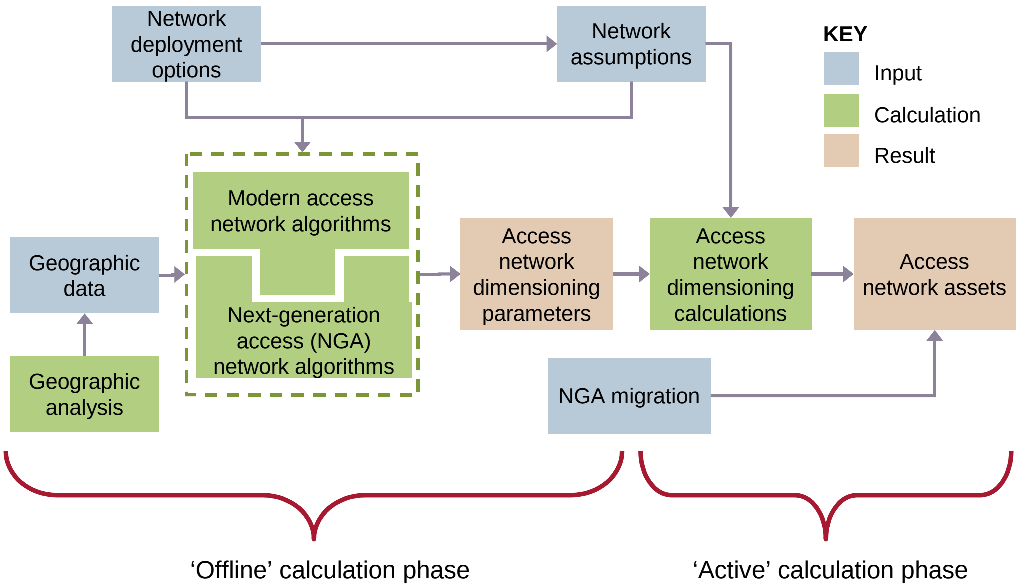

Figure 5.3: Model modular approach [Source: Analysys Mason]

The principal purpose of the offline calculation phase will be to undertake geographical analysis of Norway in order to understand aspects such as the road distances between locations and demand density. These calculations will be data-intensive and may require a variety of software packages. Hence, they will not fall within the calculations of the Excel model, but will be pre-calculated to provide input values for the Excel model.

Calculating the total volumes of network assets explicitly required across the whole of Norway requires far too much computation. Instead, our approach will allow the explicit calculation of volume requirements for a (statistically significant) sample of regions, which can then be extrapolated to derive the total asset requirements for the whole of Norway.

As shown above, the components required to complete the offline calculation phase are:

- geographical analysis, including the design of geotypes, described in Section 5.2.1
- understanding of access deployments used in Norway, described in Section 5.2.2
- network design algorithms to calculate the asset requirements in a sample of areas, described in Section 5.2.3
- a series of calculations that derive values for a set of parameters, based on the outputs of the sampled regions, described in Section 5.2.4.

For the active calculation, there is also a separate set of calculations to derive the assets for a national access network, using the outputs of the offline calculation phase. These are also described in Section 5.2.4.

Finally, for the purposes of both phases, a consideration of incorporating a migration to an NGA network is required. These principles are discussed in Section 5.2.5.

5.2.1 Geographical analysis and geographical data

Norway is a large country with considerable diversity in its demography and topography, which needs to be understood and captured within any model of fixed network services. The analysis required is described below and falls within the 'offline' calculations. The steps required are:

- understand available geographical data
- construct a database of locations and their demand requirements
- identify a partition of regions of Norway that allow a piecemeal treatment of the access network requirements
- group these regions on the basis of their geographical characteristics
- construct a representative sample of these regions.

Geographical data

The geographical analysis will make use of the following data:

- **StreetPro Norway**, which contains the national road and railway network, represented as line segments. Other information within this dataset includes:
  - co-ordinates of business locations and other points of interest
  - administrative boundaries and all major bodies of water
- **Bygningspunkter**, which contains locations of buildings in Norway.[9]

Network-related geographical data will be requested from industry stakeholders as part of the data collection phase. This will include locations of major network nodes, such as exchanges and points of interconnect, as well as information about the areas of Norway that these nodes serve. Any such data made available will allow the network modelling to reflect existing deployments where appropriate.

Location database

For a bottom-up LRIC model of an access network, one would ideally have knowledge of the location of every access line required in Norway and the services required, as both quantities will be heterogeneously distributed across Norway. An access network could then be dimensioned to serve this demand.

In the absence of data from operators on demand at a location level, we will construct a reasonable proxy using alternative sources.

9 There is a related dataset called DEK (Digitalt Eiendomskart), which contains land parcel boundaries. While we do not expect to use this data, it may be beneficial in the modelling of the final drop in the network.

The Bygningspunkter ('Building Points') contains a wealth of information about every building in Norway. We understand that the dataset has full coverage of the country and is able to geocode buildings in the ETRS Transverse Mercator (ETRS89) co-ordinate system. This allows us to associate locations to fixed demand in Norway, since the access network is built to reach premises.

The Bygningspunkter will be used as the basis of a database of locations for Norway, by:

- removing buildings assumed to have no demand (e.g. garages, monuments)
- identifying buildings to get higher demand (and quantifying that demand), including:
  - multi-dwellings, e.g. using the number of flats and building type
  - business locations, using building type, number of floors
- geocoding our final set of buildings, since the co-ordinates are geocoded to within the building. These co-ordinates can also be mapped onto the roads using StreetPro.

Principle 18. A commercially available database of Norwegian building locations will be used for the access network modelling.

Service areas

A partition of the land mass is required to analyse national access network requirements in a piecewise fashion. This partition should reflect the real distribution of demand in Norway, which suggests two main options:

- the service areas of Telenor's switching units/stages, as described in Section 5.2.2
- administrative boundaries, such as the municipalities or postcode areas in Norway.

The advantages and disadvantages of these options are summarised below.

Data set	*Advantages*	*Disadvantages*
Telenor service areas (i.e. those served by the switching units/stages)	These areas will have been arranged to best support the population centres of Norway. Population centres have not significantly shifted, so these arrangements still have merit today	These areas are tied to the existing incumbent network
	Telenor may be in a position to provide network and demand data at this level of granularity, which would aid the top-down calibration and reconciliation of the model	These areas can still have population heterogeneity, with a population centre surrounded by sparsely populated land
Administrative boundaries (e.g. municipalities or postcodes)	Postcode areas will be more granular than exchange areas, although municipalities will not be more granular	A switch will likely serve several postcodes, while a municipality would be served by multiple switches. In either case a mapping would need to be constructed and it may not be well-defined
	Administrative boundaries are likely to be designed with some reference to population centres	Operator data may be harder to map onto these areas, which will make the top-down calibration and reconciliation of the bottom-up model more difficult

Figure 5.4: Advantages and disadvantages of the options for a partition [Source: Analysys Mason]

Telenor's service area boundaries will be the first-choice option for splitting up the country, since they provide a good guide to the population centres in Norway, and top-down data could perhaps be provided at this level to aid the hybridisation of the bottom-up model.

Principle 19. Telenor's service area boundaries will be used as a partition for Norway.

Geotyping

The diverse topography of Norway cannot be accurately captured in a bottom-up model using a single value for each parameter in the asset dimensioning calculations. At the other extreme, to calculate parameter values using data for the whole of Norway would be computationally expensive. Therefore, we will use geographical classifications, or *geotypes*, in the model, which take a partition of the Norway land mass and then group together the regions which have similar geographical characteristics. The parameter values in the model can then be varied by geotype where necessary.

In order to design an appropriate set of geotypes, we will investigate:

- a set of regions covering Norway, such as postcode areas or exchange areas
- geographical information associated to each region (e.g. population, buildings, area)

- what model inputs would vary by geotype in the model or, at the very least, what factors drive these inputs.

Geotypes are defined according to metrics calculated using the geographical information and then each region is categorised as one particular geotype. A simple, illustrative example of this process would be to split Norway into four geotypes, using postcodes and their average building density:

- **Step 1:** Calculate the building density of each postcode
- **Step 2:** Define a postcode to be:
  - *urban* if the density is >250 buildings per km^2
  - *suburban* if the density is between 50 and 250 buildings per km^2
  - *rural* if the density is between 5 and 50 buildings per km^2
  - *remote* if the density is <5 buildings per km^2.

For the avoidance of doubt, this segmentation is illustrative only and is not what we are proposing to use in the bottom-up LRIC model.

► *Implications of using geotyping in the LRIC model*

The benefit of such a classification is that, for each geotype, average values of each parameter required can be derived by analysing only a sample of the areas in the geotype. The similar geographical characteristics within the geotype would indicate that these derived values would be representative of the whole geotype.

As a result, the Excel model containing the active calculations would only need to store geographical information or other inputs on a geotype basis. The benefits of this model structure are that:

- calculation run-time is shortened
- model structure is simplified
- performing sensitivity analyses is more feasible.

In addition, the access network deployment can be varied by geotype, which allows different NGA migration paths to be considered in the model, as described in Section 5.2.5.

► *Defining the geotypes to be used in the LRIC model*

As previously stated, a database of locations and demand will be constructed using the Bygningspunkter. For our selected partition of Norway, we can then define the 'average road per location' for each area in the partition, by using StreetPro Norway. We will use this metric as the basis for our geotyping, since we believe it to be closely related to the average trench per location passed by the access network, which is itself linked to the access network costs in any given area.

There are other metrics that can refine this geotyping. Depending on what is made available, such metrics could include:

- area within the service area boundary
- population/address density of the service area
- density of businesses in the service area
- distribution of straight-line distances from buildings to the network node within the service area.

Principle 20. Geotypes will be defined on its selected geographical areas using average road per location. This geotyping may be refined, where appropriate, using additional geographical data related to these areas.

Sampling methods

In order to use a sample of areas to derive parameters for the active calculations, a representative sample must be selected. There are several sampling methods available.

► *Simple random sampling ('Monte–Carlo')*

A sample of a fixed size is taken at random from across the entire population of service areas. This would be unwise, since there may be geotypes that are not represented within the sample.

► *Stratified sampling*

The population of service areas is split into classes (or strata) of elements. For a given sample size, it is then pre-determined how many elements of each stratum should lie within this sample. A random sample of each particular size is then taken for each stratum.

At its simplest, the pre-determined sample sizes for each stratum are proportional to the relative number of elements in the stratum. This is proportionate stratified sampling. However, if the variances of a particular variable differ significantly across strata, then sample sizes should be made proportional to the stratum standard deviation as well.

Stratified sampling will be used, with the strata being the defined geotypes.

Until the geotypes have been properly defined, the exact size of the sample that will be employed remains undetermined. It will be influenced by several competing factors:

- *level of confidence* – larger samples improve confidence levels
- *calculation time* – it is important that the run-time of the LRIC model is short enough to enable scenarios to be run. One way to reduce calculation time is to reduce the

sample size, but this should not be done to the extent that the accuracy of the model is compromised. A sample size will be agreed following the geographical analysis.

Certain 'sanity checks' will be initially performed on the area data. These checks will include confirming that the number of locations for sampled areas is in alignment to the number of households/businesses (as relevant) in corresponding areas from the 2001 Norwegian census.

Principle 21. As part of the offline calculation, a stratified sample of areas from each geotype will be used to calculate representative access deployments using the network design algorithms. The outputs of this sample will be used to derive the input parameters for the active calculation phase.

5.2.2 Deployment of the access network

This section describes the issues surrounding the modelling of an access network in Norway. In particular, we discuss:

- topology of the final drop, which connects buildings to the access network
- topologies modelled in the access network
- extent of node scorching
- geographical scope of the access model.

Topology of the final drop

Figure 5.5 below displays the nature of the final drop in Norway where fixed-line solutions are used. Since this part of the network is dedicated to individual buildings, this part of the network can contribute a significant proportion of the access network costs.

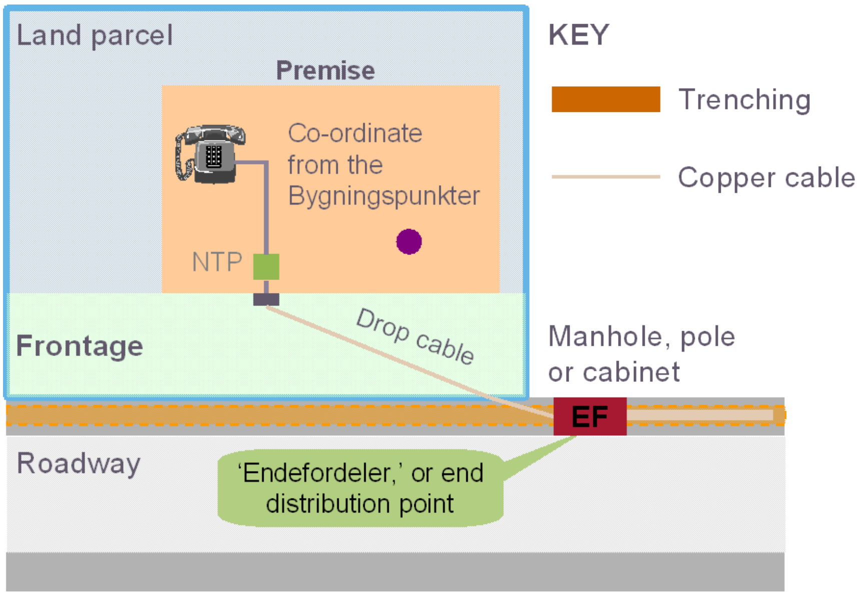

Figure 5.5: Final drop topology [Source: Telenor, Analysys Mason]

Telenor provides the network termination point (NTP), usually a RJ45, within a building. In addition, it provides screw termination and insulation displacement connection at the interface to any internal subscriber-owned cabling. The NTP will be included as a network element within the model.

The final drop cable leaves the property, going across the frontage of the land parcel either to:

- trenching underneath the pavement/road
- a deployed pole.

At regular intervals (every few households), these cables reach an end distribution point ('endefordeler,' or EF), which is a fitting that aggregates cabling. Where cabling is underground, there are also access points along the street where engineers can access the ducts and cabling via manholes. Cables continue to be aggregated further as they go up the network hierarchy. Figure 5.5 also illustrates the co-ordinate from the Bygningspunkter, which can be used as the geographical identifier for a building.

Topologies modelled in the access network

► *Current network*

As described above (and shown below in Figure 5.6), a hierarchical copper/fibre deployment is the current architecture in urban areas. It is expected that Telenor provides direct optical-fibre connections to several thousand locations (businesses, universities and municipal premises) in the major cities in Norway.

For simplicity within the model of the current network, we will only use EF and HF (i.e. exclude MF) in our topology to connect locations back to the switches.

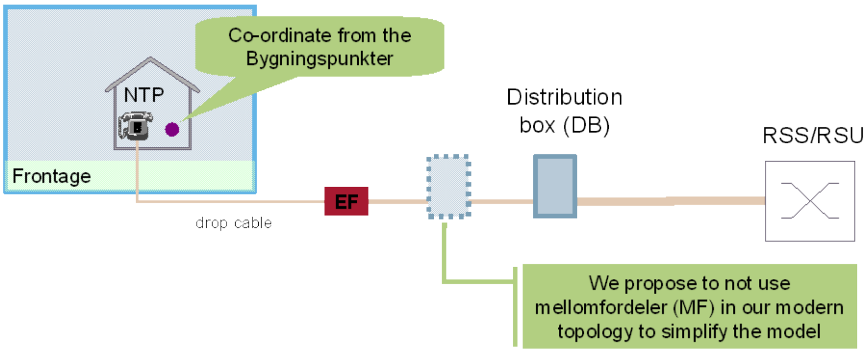

Figure 5.6: Proposed current network deployment [Source: Telenor, Analysys Mason]

In the remotest areas, where the cost of deploying copper is too prohibitive, a variety of wireless solutions could be employed:

Currently deployed access technologies — The connection of remote areas to the PSTN uses a variety of technologies, including satellite and radio.

Modern technological solutions — Recent technological developments, such as WiMAX, can be modelled in addition to the current access technologies. A large proportion of Norway is very sparsely populated. In these areas, fixed wireless technologies (such as WiMAX) are likely to be less expensive than cable and digging. Telenor could use its 3.5GHz spectrum holdings to deploy WiMAX services to help reach locations outside its DSL coverage footprint.

However, it is understood that the proportion of locations served by wireless access is negligible. From the perspective of calculating a cost for unbundled access, it is appropriate to calculate the cost of a network with copper/fibre deployments reflecting the actual network footprint. This means that the modelled access network will use wireline access (i.e. copper/fibre) to every building requiring connectivity[10] in Norway, excluding those areas identified in Principle 25.

Principle 22. For the current architecture, a copper deployment will be used (with some fibre) that uses EF and HF to connect all buildings requiring connectivity back to the switch.

► *NGA network*

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[10] A ‘building requiring connectivity’ will be a residence or business site, i.e. not a holiday home, barn, garage, etc.

Principle 23. The access network model will include the capability to consider the deployment of FTTN/VDSL, FTTH/PTP and FTTH/GPON for a given set of areas, as described at the beginning of Section 5.2. Issues related to capturing migration to an NGA network are discussed in Section 5.2.5.

Extent of node scorching

When modelling an efficient network using a bottom-up approach, there are several options available for the level of detail used to capture the existing network. The greater the level of granularity/detail that is used directly in the calculation, the lower the extent of network 'scorching' that is being used.

Scorched node	The scorched-node approach assumes that the historical locations of the actual network node buildings are fixed, and that the operator can choose the best technology to configure the network at and in between these nodes to meet the optimised demand of a forward-looking efficient operator. For example, this could mean the replacement of legacy equipment with best-in-service equipment. Scorching at the node also allows a better comparison with top-down data. The scorched-node approach, therefore, determines the efficient cost of a network that provides the same services as the incumbent network, taking as given the current location of the incumbent's nodes. Scorched-node models are common internationally. The regulators in New Zealand, the USA, the UK, Austria, Switzerland, Denmark, the Netherlands and Ireland have all adopted the scorched-node approach.
Modified scorched node	The scorched-node principle can be reasonably modified in order to replicate a more efficient network topology than is currently in place. Consequently, this approach takes the existing topology and eliminates inefficiencies (for example, this may involve simplifying the switching hierarchy).
Scorched earth	The scorched-earth approach determines the efficient cost of a network that provides the same services as the incumbent network, without placing any constraints on its network configuration, such as the location of the core nodes. This approach models what an entrant would build if no network existed, based on the location of customers and forecasts of demand for services.

This approach gives the lowest estimate of LRIC, because it removes all inefficiencies due to the historical development of the network. In practice, it is almost unknown to adopt a scorched-earth approach; certainly for modelling the costs of standard interconnect conveyance and other access services.

Principle 24. A modified scorched-node principle will be used, in which the level of scorching is clearly defined as an a priori assumption at the building locations of the MDF in the network. Consequently, in the current network deployment, all of the concentrators and switching elements in such accommodation are assumed to be deployed in efficient locations.

Nodes below the level of RSX will not be retained for scorching, i.e. actual locations of MF/HF/EF in Telenor’s network will not be retained. In addition, any RSXs that are not field deployed will also not be retained. Instead, during the offline calculations for the access network, the network design algorithms will derive locations for any intermediary nodes, as described in Section 5.2.3.

Universal service obligations (USO) and relevant market for access services

Telenor is designated as a USO provider and has an agreement with the Norwegian government defining the scope of its USO, which commenced in September 2004. The agreement requires Telenor to provide public fixed telephony at an affordable price to all households and enterprises. In addition, leased lines and certain data services must continue to be accessible to all enterprises.

According to the Electronic Communications Act of 2003, the relevant geographical area of Norway includes Jan Mayen, the dependencies, Antarctica and Svalbard. However, according to the latest market analyses for Markets 4 and 5:

- Svalbard is excluded from the perspective of these markets as an exception
- Jan Mayen, the dependencies and Antarctica are assumed to not have any significant impact on the market analyses.

Principle 25. The scope of the access network model will be limited to exclude Jan Mayen, the dependencies, Antarctica and Svalbard.

5.2.3 Network design algorithms

The algorithms used in the offline calculations for the access network will be provided in Microsoft Excel Visual Basic. For the locations in each of the sampled service areas, these algorithms will calculate the network assets required to deploy an access network to serve all locations from an RSX.

The algorithms will only use copper and fibre as access technologies and will calculate the requirements for trench, cable duct, manholes and jointing using best-practice engineering rules. Fibre will be deployed using either point-to-point or ring architectures to satisfy high-demand nodes such as large business premises.

The attributes required by these network design algorithm are to:

- group the locations so that they can be effectively served by a hierarchy of nodes
- calculate how to link the locations back to the RSX with trench and cable in order to provide each location with fixed network services
- employ a distance measure to derive trench/cable lengths, for tapered and non-tapered cabling
- make other assumptions about trench, duct and other aspects of the modelled network.

These are described in turn below.

Grouping of locations

The design of service areas by the network nodes is complex since it considers both the general distribution of locations and engineering constraints, specifically constraints of:

- capacity – only a certain maximum number of lines can be served by the node
- distance – the properties of access technologies mean that if distances increase beyond a critical value, then service quality is degraded. This is particularly true with copper-based technology.

Consequently, two broad approaches can be considered:

Grid-based approach	This method divides Norway up using a grid without consideration of the *a priori* distribution of locations. For this approach to be accurate, customers must be located in a relatively uniform pattern across the area under consideration. In reality, people tend to live in congregated areas. Furthermore, the grid may sub-divide areas artificially generating low-density grid-cells.

Top-down clustering algorithm

The objective of a clustering algorithm is to generate a more accurate number of feasible serving areas. Such algorithms have been used in previous fixed LRIC models, such as the hybrid cost proxy model (HCPM) used by the FCC.

This algorithm may still derive clusters that are not realistic: for instance, a cluster may be derived that lies on both sides of a river or fjord. The feasibility of enhancing the algorithms to avoid such outcomes will be investigated.

Principle 26. A clustering algorithm will be employed to determine the locations served by network nodes. The algorithm will be flexible and able to determine clusters according to a range of capacity and distance constraints. It will use straight-line distance for simplicity, although means to increase the geographical awareness of the algorithm will be investigated, so that the occurrence of unreasonable clusters can be minimised.

Determining the trench/cable network

In order to determine the arrangement of trench/cabling in the access network within any area served by a network node, various algorithms can be used. The two main groups of algorithms generate minimum spanning trees and minimum Steiner trees respectively.

► *Minimum spanning trees*

There are several distinct flavours of this class of algorithms to derive a minimum spanning tree for a set of locations. These effectively calculate the lowest cost amount of duct/cable to link a set of points (i.e. premises) together. There are many algorithms available.

Some algorithms effectively derive the shortest trench network to link all premises. However, such a process may lead to deceptive results, since focusing on minimising the trench network may lead to inefficient cable deployments. A simple example is illustrated in Figure 5.7 below.

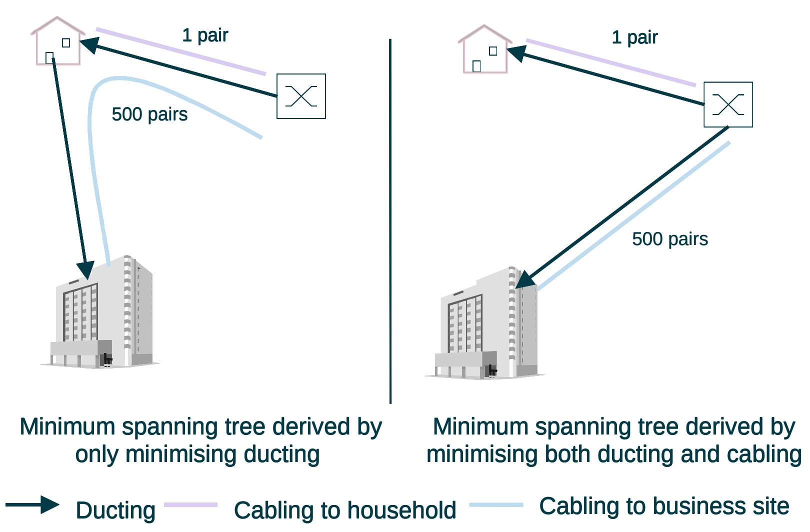

Figure 5.7: Difference in optimising duct alone and both duct and cabling [Source: Analysys]

This shows a very simple case of a household, a large business and a switch. The left side shows the deployment when only trench is optimised. The shortest route of trench is to connect the business via the house. However, since the business site needs 500 pairs, significantly more cable is required in this scenario than that on the right, which has a marginally longer distance of trench. Although, an over-simplification, this does demonstrate that, for more complex clusters, the cost of cabling should also be considered.

There are slightly more complex algorithms that improve on this, by minimising a cost function including the costs of both cabling and trenching/ducting. Although the object that this generates indeed may not be a minimum spanning tree, it is the configuration of lowest cost. However, this cost function needs to be designed and calibrated using geographical analysis of the specific case of Norway.

► *Minimum Steiner trees*

Steiner tree algorithms are an enhancement of minimum spanning trees, in that they permit the creation of new intermediate nodes to be created in order to generate the shortest network architecture. This is analogous to adding an additional junction box (for example) to the existing set of points. The minimum Steiner tree is always shorter than (or in the very unlikely case, equal to) the length of the minimum spanning tree. It has been demonstrated that Steiner trees are typically up to 13.4% shorter than the minimum spanning tree, although in practice it is often only a few percent shorter.[11] Calculating the minimum Steiner trees for a network the size of Telenor's would be highly computationally expensive.

11 *Cost of the BT UK local loop network*, Analysys, February 2005.

In addition, at the level within an area served by a network node (e.g. a distribution box, or HF), most PTP links will lie along a small number of roads, where there is little scope for inserting intermediate nodes.

Therefore, the use of a minimum spanning tree algorithm is recommended instead, for which there exist tested implementations that are computationally feasible. We will use modified versions of the Prim and Dijkstra algorithms, which minimise cost functions to determine a spanning tree. These algorithms are described in Annex A. This function balances both minimising trench length (and therefore cost) and the cost of cabling concurrently, by attempting to minimise a cost function incorporating both component costs. This allows a network to use less cable in its topology, by using a slightly longer trench network. This use of a cost function also allows:

- maximum distance between the RSX and building location to be controlled
- inclusion of cable tapering in the network.

Principle 27. Modified Prim and Dijkstra spanning tree algorithms will be used to determine the layout of cabling in the access network. The intention is to use the algorithm to determine a spanning tree for each cluster of locations in the service area. Although not Steiner tree methodologies, these algorithms have several improvements on a simple minimum spanning tree algorithm; in particular they can account for cable tapering.

Distance measures for trenching and cabling

It is crucial for an efficient network design to optimise the deployment costs associated with trenches, ducts and cabling. These costs are driven by the amount of civil works required, which is directly linked to the following elements:

- total length of trenches dug and ducts deployed
- length of the copper and fibre cables laid within the ducts.

The latter, however, can be complicated by the use of distribution points and tapering (i.e. where the numbers of pairs in a cable decreases along its length). As a result, the cabling cost may not be purely proportional to the length of cable. Where customer access is done through copper pairs, it is necessary to deploy an end-to-end copper pair between the customer premises and the exchange.

When modelling the distances required for trench and cable, there are several options:

- straight-line versus Manhattan distance
- calibrating a ‘p–function’

- street distances
- distances incorporating terrain elevation.

► *Straight-line or Manhattan distance*

The straight-line (or Euclidean) approach calculates the direct distance from one node to another node, effectively ignoring topography and street-level clutter.

In contrast, the Manhattan approach quantifies distances based on a square grid layout. While this method provides some proxy for urban deployment, it significantly distorts real-life distances in more rural areas, where the road layout is not grid-like.

Using either of these two methods on their own could result in a dramatic miscalculation of the deployed trench and cable lengths.

► *Calibrating a 'p–function'*

A general p–function is defined by two parameters *k* and *p* and defines the distance between two points $\underline{x}=(x_1,x_2)$ and $\underline{y}=(y_1,y_2)$ by:

$$\left\|\underline{x}-\underline{y}\right\|_{k,p} = k\left(\left|x_1 - x_2\right|^p + \left|y_1 - y_2\right|^p\right)^{\frac{1}{p}}$$

Euclidean straight-line distance uses k=1, p=2; while rectilinear 'Manhattan' distance uses k=p=1. Different pairs of values can be used to account for the fact that, in reality, trench and cable will follow roads and this will not be captured by either straight-line or Manhattan distance alone. With regard to identifying suitable values for *k* and *p*, a paper by Love et al[12] concluded that "it is inappropriate to simply assume a convenient value for *p* in a location study." This is because experimental data finds that there are several values of *p* that can lead to good approximations. Also, different values of *k* can be used to scale distances to be a better approximation.

The treatment of the lengths of cable and trench need to be slightly different, as a single trench can actually hold multiple cables, as illustrated below.

12 Love, Morris and Wesolovsky,(1988) Facilities location models and Methods, Ed Saul J Goss, North Holland.

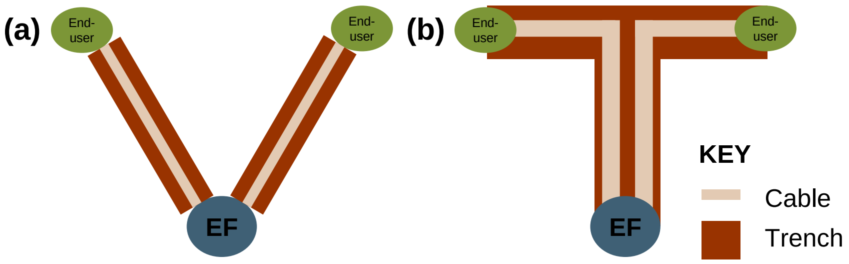

Figure 5.8: Demonstration of trench sharing between links [Source: Analysys Mason]

Figure 5.8 above shows two links joining end-users to their parent EF. Diagram (a) indicates how these links would be viewed links if trench and cable used the same distance measure. Diagram (b) shows what is happening between these links for the example in reality: they are sharing part of the total trench as the locations lie across a junction. Although a calibrated p–function would get the cable lengths correct, it would over-estimate the actual trench. A separate trench sharing coefficient, *j*, will be included in addition to determining values of *k* and *p*. Cable length is calculated using the p–function, while the total trench lengths are calculated using the p–function and then scaling by *j*.

The p–function and value of *j* can vary by geotype, but requires the derivation of suitable *j*, *k* and *p*, which can be done using a sufficiently large set of sample point-to-point links.

► *Street distances*

This method uses actual street distance for point-to-point trench and cable deployments. While assumptions have to be made regarding the most direct way to lay cabling, it provides a realistic deployment of cables for an efficient network design. Analysis at this level of complexity is possible using StreetPro.

However, to use this metric in the actual calculation flow of the model would be computationally expensive and require the storage of huge amounts of data: namely the point-to-point road distances for a huge number of pairs of locations.

One way of controlling the required data storage would be to only calculate the road distances between points on a local basis (e.g. within 250m), with other point-to-point links calculated by a p–function.

► *Distances incorporating terrain elevation (topography)*

Given Norway's topography, it is arguable that any air distance between two points will not capture the actual distance of trenching required to account for this. However, this must be counter-balanced against the substantial amount of additional data and computing resource that would be required within the model to incorporate elevation into the distance calculations.

Therefore, instead, parameters will be included that can mark-up the trench and cable distances as a sensitivity. These will be set to zero in the base case, but calculations based on any available terrain databases for Norway could inform whether a non-zero mark-up should be included. This functionality provides that option.

This mark-up could be dimensioned on the basis of geotype and/or the network layer (i.e. final drop, access network, core network). This is because the effect on the longer trenches may be more pronounced than the shorter trenches.

Principle 28. For the trench and cable calculations for the access network, lengths will be calculated on the basis of p–functions, where the coefficients will be calibrated using geographic analysis of streets and households in Norway. The use of street-distances will take into account topological constraints on the network deployment. Equivalent calculations for the core network will be based on road/rail distances and will inherently take account of topological constraints. Elevation effects will be incorporated into the mode as a mark-up on the calculated distances.

Other design assumptions

The algorithms will need to make other assumptions regarding network design, related to:

- appropriate co-ordinates for building locations
- aerial deployments
- costs of trenching
- duct deployments.

► *Co-ordinates for building locations*

The database of locations used, whether from industry parties or constructed using the Bygningspunkter, may not be suitable for use by the network design algorithms without further processing. The locations provided may not relate to the building in a simple way: they may be inside, beside or only in the vicinity. If these co-ordinates were to be used directly, then the trench network derived by the spanning tree algorithms joining the locations together may not follow the roads. This can be significantly improved by using MapInfo to translate each building location onto the nearest street segment using StreetPro Norway, as shown in Figure 5.9 below.

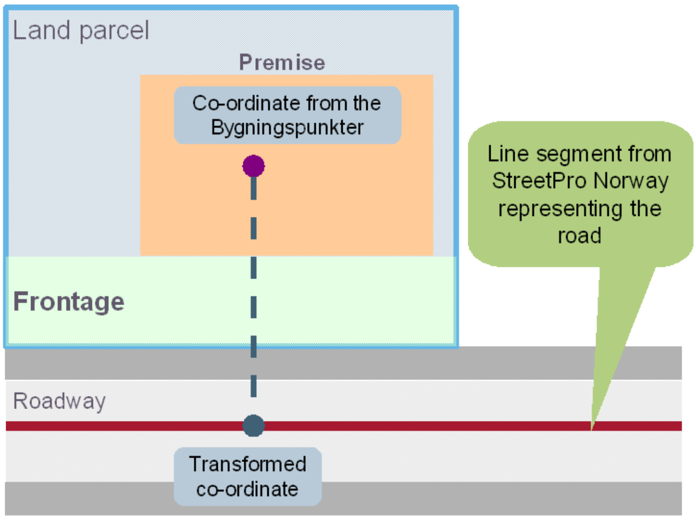

Figure 5.9: Illustration of mapping building locations onto streets [Source: Analysys Mason]

These translated co-ordinates can then be processed by the algorithms and will automatically follow the road more closely. In addition, the 'final drop' segment of the network can then be quantified separately.

► *Aerial deployments*

There are significant pole deployments in Norway and, given the topography, this can actually be the best-practice architecture to employ. In the active calculations, inputs will be included that allow a proportion of cabling to be aerially deployed, with poles dimensioned in place of duct.

Principle 29. Functionality will be included within the active calculations to assume some aerial deployment in the Norwegian access network.

► *Trenching costs*

It is known that the cost to dig trenches is dependent on the type of terrain (i.e. rock/soil type) in which it is being deployed. In order to capture this level of detail within the model, data has been requested on the proportion of trench deployed in each different terrain type at a distinct geographical level. Corresponding per metre costs for digging trench have also been requested.

Principle 30. Assuming sufficiently detailed costs and geographical data related to trenching is available, the data will be used to inform the costs of digging trench in an efficiently deployed network according to terrain.

► *Duct deployments*

All of the different types of duct (for example, according to the cable gauge size) in the network will not be modelled. As a simplifying assumption, a single diameter of duct in the access network will be modelled, although trench will be modelled as being able to accommodate a variety of combinations of duct.

Principle 31. We will model one size of duct used in the access network.

5.2.4 Access network dimensioning

Having run the deployment algorithms for the sample areas, the final stages of the calculations for the access model are to:

- derive values of input parameters to dimension a national access network: this is the last stage of the 'offline calculations'
- dimension the national access network using these parameters: this is the 'active' calculation.

Derivation of input parameter values

Having calculated the asset volumes for a sample of service areas, the final stage of the offline calculation will then be to derive average values, across each geotype, of the parameters to be used in the active calculations. Examples of these quantities and the asset they can be used to extrapolate are shown in Figure 5.10 below.

Cost driver	*Relevant asset*
Average road distance between locations	Length of trenching
Average lines per distribution box	Number of distribution boxes
Average trench per manhole	Number of manholes
Distribution of trench network by number of duct deployed	Length of duct required

Figure 5.10: Examples of key dimensioning parameters [Source: Analysys Mason]

Dimensioning the national access network

The parameters from the 'offline' calculations are average values calculated from the sampled service areas. These will then be used to extrapolate total volumes of assets required for each geotype as a whole, which total to give the volumes for the entire access network in Norway.

An example would be the calculation of duct requirements in a geotype. The requirements across Norway would be calculated for each geotype as shown below.

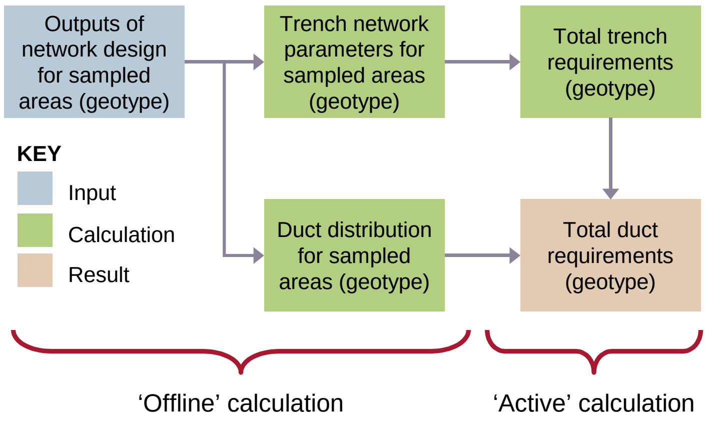

Figure 5.11: Calculation of total access network duct requirements [Source: Analysys Mason]

From the outputs of the design algorithms on the sample from the offline calculations, the distribution of duct for each geotype and the trench network parameter values will be taken as inputs. In the active calculations, the trench network parameters can then be used to extrapolate the total trench required by geotype. Finally, the duct distribution derived from the sample can then be applied to the total trench requirements to determine the total duct requirements by geotype.

5.2.5 Modelling of NGA migration

The access model will be capable of modelling both current and next-generation architectures. When modelling NGA deployments, there are several issues that need to be considered, which are discussed below in more detail. These are:

- the potential shift in the boundary between the core and the access network
- node rationalisation
- changes in the arrangement of points of interconnect
- re-use of trench and duct routes from the current network.

Access/core network boundary

In a legacy network, access-related costs are assumed to only occur downward of the first point of traffic concentration, within the MDF, as shown below.

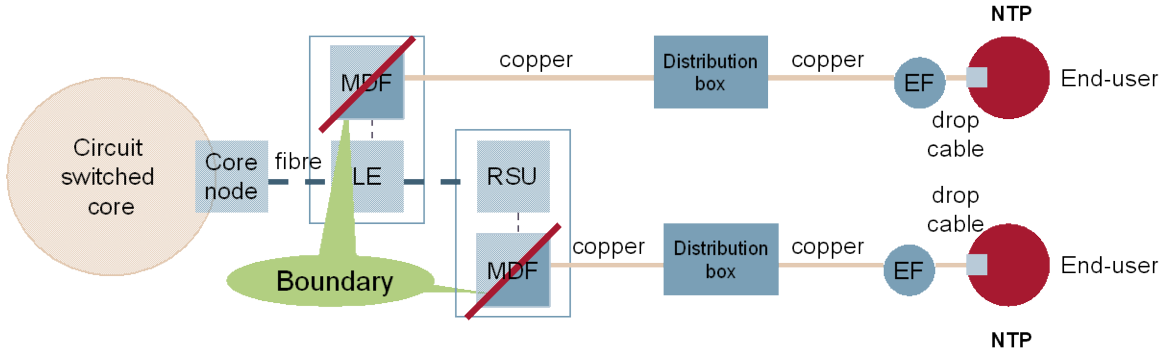

Figure 5.12: Boundary between legacy core and access network (red line) [Source: Analysys Mason]

However, the boundary may move within the network for an NGA architecture. In particular, the first point of traffic concentration would be:

- the distribution frame in the distribution box for FTTN
- the optical distribution frame (ODF) for FTTH, where the active electronics connect the fibre.

In the first case, the access network will end at the distribution box, meaning that the extent of the access network will shrink. Conversely, in the second case, the ODF will either be at a multi-service access node (MSAN) in a distribution box or perhaps back to a distribution node. These MSANs are capable of conveying both voice and data. In this case, a significant additional part of the trench network could be considered as access.

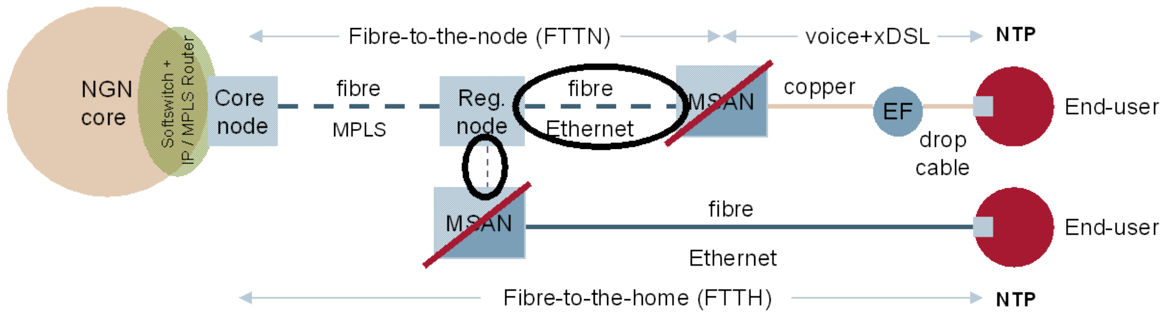

Figure 5.13: Boundary between the NG core and access network (red line) [Source: Analysys Mason]

Simple scenarios can be developed to test the impact of a significant change in NGA architecture (e.g. significant deployment of FTTN/VDSL). This would allow an understanding of the impact on the core model and cost of voice services. It will be necessary to take a simplified approach as results from the access network modelling will not be available during the consultation on the core model – therefore, not modifying the boundary definition is more reasonable as a default position for the next market review period.

Principle 32. When modelling current and next-generation networks, the default assumption will be that the boundary between the access and core network will not be moved. Changes in the position of the boundary can be tested through simple scenarios.

Node rationalisation

In an FTTN/VDSL deployment, the number of RSXs remains unchanged, with distribution boxes upgraded or deployed at the sub-loop level. However, in an FTTH/GPON deployment, it may be possible to rationalise the RSX locations, as a technology such as long-range GPON would require fewer switching locations, as illustrated in Figure 5.14 below.

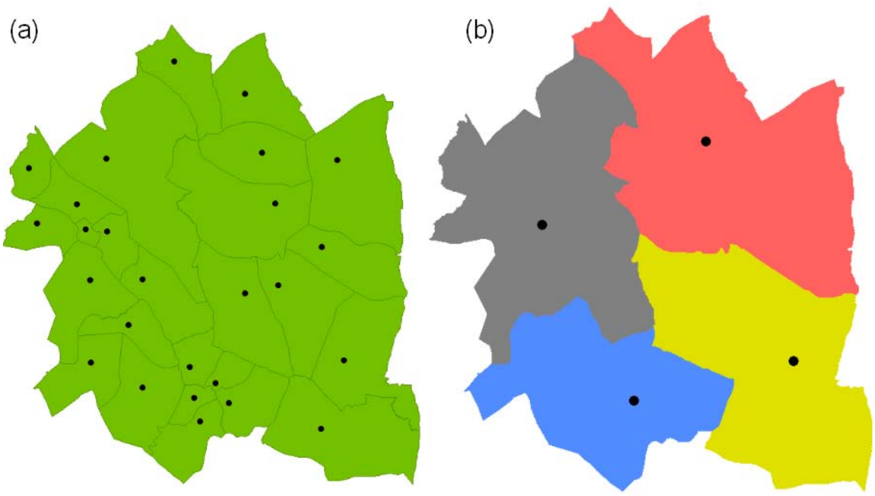

Figure 5.14: Illustration of node requirements and coverage capabilities in (a) the current access network and (b) an NGA network [Source: Analysys Mason]

This would remain consistent with the modified scorched node approach as discussed in Section 5.2.2, since all RSX locations could be retained, but the functionality at some of them could be reduced to that of an aggregation point (i.e. a splitter).

However, there are implications for the sampled service areas in the offline calculations. For the current architecture, areas served by current RSX locations intrinsically reflect the capabilities and scale of a copper deployment. These areas are likely to be smaller than those that could be served under GPON. There are several ways to treat this effect in the NGA model, as summarised below.

Continue to use the service areas	In this case, the same geotypes and sample of service areas would be used for both the traditional and NGA network architectures. In terms of modelling an incumbent NGA deployment, it is likely that the deployment would use existing node locations and routes wherever possible. Even if the GPON topology could handle larger areas, in reality the cost savings might be small and/or the quality of service might be increased.
Design a separate set of geotypes and sample	Alternatively, the service areas could be unified into a smaller number of larger "next-generation" service areas (see Figure 5.14), for which a separate set of geotypes could be defined for running the NGA model. Given that this effect is not present for all relevant NGA architectures (it is not the case for FTTN/VDSL), this may not be a sensible option to implement.
Account for the effect in the geotypes and sample for the current network	When defining the geotypes and sample for the current network, it could be investigated whether the service areas in a geotype form contiguous groups, which could then be unified into "next-generation" service areas for the NGA model. The sampled service areas could then be taken from the set of "next-generation" service areas. Each sampled "next-generation" area would then be put run through the network design algorithms: • as a single area in the NGA model • as separate service areas in the current network model. The benefit of this approach is that the geotypes and sampled areas would be consistent, in that the geotypes would contain the same service areas and the sample would always contain the same service areas. Although this possibility will be investigated, the service areas in each geotype may be too dispersed for unification to be practical.

The intention will be to retain the same geotypes and sample of service areas for use in both the current and NGA network architectures.

Principle 33. We will retain the same geotypes used in the current access network in the NGA model. This will support the cost of deployment of a specific NGA architecture across a geotype.

Changes in points of interconnect

Reconfiguring a core network using next-generation deployments could have an impact on the number of points of interconnect (PoI) in an efficient network, as discussed in a recent ERG Common Position.[13] This is based on the concept of an NG core moving towards fewer, large core switching nodes. Fewer nodes does not necessarily mean fewer PoI, as they can also be driven by factors such as:

- number and distribution of customers and traffic
- location of content servers and other network nodes
- capacity of PoI
- resilience requirements
- costs of transport.

There are currently 14 PoIs in 13 locations in Norway. It is understood that this number is unlikely to change in Norway, particularly as these locations have already undergone a phase of rationalisation in recent years.

Principle 34. The number of PoI in a NGN will be assumed to remain the same as current levels. Alternative values may be considered as sensitivities to the model.

Re-use of routes from the current network

Given the scale of deployment, the roll-out of NGA infrastructure will be an extended process. The two perspectives to consider when modelling an NGA network are those of:

- **the incumbent (Telenor)**: a deployment on top of an existing traditional architecture
- **a new entrant**: a greenfield deployment, which would inform NPT of the costs of an alternative operator such as a utility company.

The new entrant perspective would be modelled as a standalone deployment, with no migration necessary and there would be no parallel access infrastructure.

The Telenor perspective could also be modelled as a standalone deployment, which would give the standalone cost of a next-generation deployment.

However, it should also be considered that there will be some parallel access infrastructure and that Telenor will have the opportunity to re-use existing network (trench, duct and cable) to reduce the cost of deployment. These issues are considered for the three main architectures below.

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13 European Regulatory Group, *Supplementary Document to the ERG Common Statement on Regulatory Principles of IP-IC / NGN Core*, 2008

► *FTTN/VDSL*

This deployment needs few changes in the sub-loop, instead requiring:

- upgraded or new distribution box equipment
- installation of new fibre backhaul alongside the copper back to the RSX
- additional equipment at the exchange
- migrating the lines to the new distribution boxes.

All of these requirements mean that the trench and duct network can be re-used, on the basis that most installations are upgrades or replacements of existing assets.

The migration of lines could either be simultaneously as a single-event 'cut-over,' or gradually as customers move to VDSL-based services. The former would mean that there would be a minimal requirement for infrastructure to be operated in parallel. Such a migration, either for all or some geotypes, can be modelled exogenously, with a migration path for the activation of new assets and decommissioning of old assets. This would mean that a single model capturing the migration would not be necessary: two stand-alone models, consistently applied, could capture this migration.

A partial or incremental migration would lead to parallel infrastructure from the distribution box for a longer period of time, but even then an exogenous approach would be possible since most of the network costs will be in the (unaltered) copper sub-loop.

► *FTTH (PTP or GPON)*

These architectures would require more incremental network, with new duct required to accommodate some of the additional fibre. In particular, this would need to be deployed in parallel to the existing copper.

Telenor could choose to deploy a GPON placing splitters at or near to its existing nodes. However, were it to use a different topology, existing duct routes may not be suited to the new deployment.

Fibre could most likely be blown through existing duct, where it is present in the secondary network, as cabling is less congested in this part of the network. However, in the particular case of PTP, where all premises have a dedicated fibre pair, there would be increasing congestion approaching the RSX, meaning that additional duct would almost certainly be needed in these parts of the network. This is particularly the case since the cabling would need to be deployed in parallel to the original cabling.

In terms of incorporating this effect into the model, the options are to:

- run the NGA model assuming a greenfield deployment and then treat exogenously, by either:
  - specifying what proportion of trench for the NGA is new-build

  - specifying what proportion of new-build is deployed using micro-trenching
  - identifying which parts of the duct requirements could be accommodated by existing network (e.g. those lengths of trench that only require access to at most one duct)
  - comparing the NGA trench network with that derived for the current network
- design the NGA form of the network design algorithms to recognise the trench deployed for the current network, as well as its spare duct capacity and dimension the spanning trees on this basis. This would require complicated quantification of this spare capacity in the trench network and would add significant complexity to the spanning tree algorithms.

Principle 35. We will model the NGA architectures deployed (which may vary across geotypes) as standalone, with a reasonable utilisation profile over time, rather than modelling an explicit migration between the legacy and NGA architectures. Any potential savings in trench/duct would be calculated exogenously. The design algorithms will not be capable of either identifying or using duct from a legacy network.

5.3 Core network

This section outlines the specification for the core network models. Two functionally separate models are defined:

- a current network deployment, described in Section 5.3.1
- the full next-generation architecture, described in Section 5.3.2.

Controlling the migration between these deployments is explained in Section 5.3.3.

A modular approach will be taken so as to enable flexibility in the end-to-end model design. In the same way as the access model, the output of the core model will be the number of each asset type over time in accordance with the demand profile selected. This output will feed into the costing module in the same manner as the outputs from the access networks.

5.3.1 Core network platforms – current

The design of the current core network is based on a TDM architecture in which the voice and data platforms are carried and switched on separate systems, but both carried on the same transmission system, i.e. synchronous digital hierarchy (SDH), plesiochronous digital hierarchy (PDH) or dense wave division multiplexing (DWDM). The current network reference design is based on understanding of Telenor's current network.

This subsection outlines the model reference design of the current network deployment core asset deployment. It outlines the major network elements that will be modelled. Component parts of these network elements (e.g. port cards, chassis) will be modelled explicitly in the core model, and will be dimensioned according to known parameters and drivers such as voice minutes and call attempts.

Network nodes

Nodes in a current core network exhibit a hierarchical structure as shown in Figure 5.15.

Network asset	*Asset description*
Core nodes	Core nodes contain the main PSTN transit switches, core IP routers and switches, and the control and management platforms.
Distribution nodes	Distribution nodes contain the first, local level of switching.
Access nodes	Access nodes contain the MDF (that serves as the border between the access and core networks) and the remote concentrators.
	It may be the case that remote concentrators are also deployed below the access node level, subtended to a concentrator in an access node building. These are accommodated in the access network reference design.

Figure 5.15: Core network nodes [Source: Analysys Mason]

The three levels of nodes may physically exist at the same location. For example, a location may contain functionality for a core node, a distribution node and an access node.

Extent of node scorching

As with the access network modelling, there are several options available as to how faithfully the existing network is captured by the bottom-up model. The greater the level of granularity/detail that is used directly in the calculation, the lower the extent of network 'scorching' that is being used. Section 5.2.5 in the access network specification describes the different scorching possibilities.

Principle 36. A modified scorched-node principle will be used, in which the level of scorching is clearly defined as an a priori assumption at the location of the core nodes in the network. Consequently, in the current network deployment, all of the switching and routeing elements are assumed to be deployed in efficient locations.

Voice platforms

The structure of the current voice core network in Norway is outlined below.

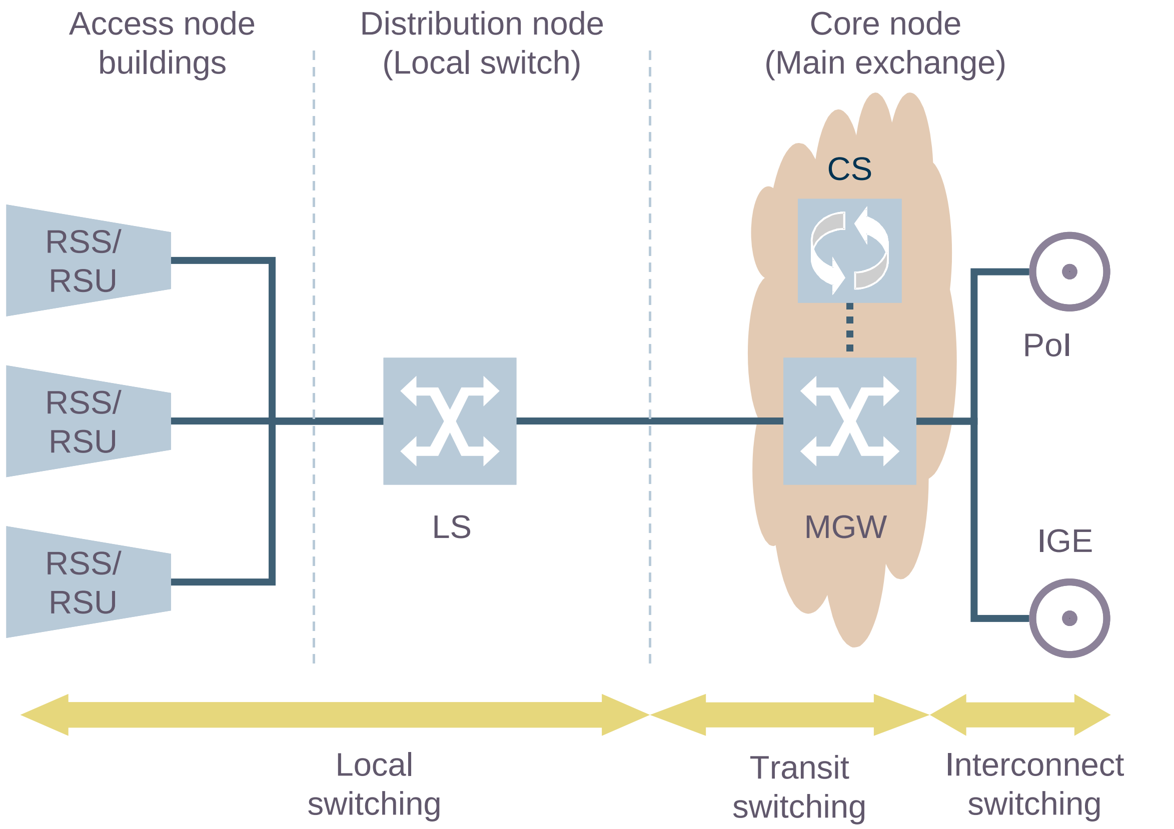

Figure 5.16: Current voice core network deployment in Norway [Source: Analysys Mason]

The major voice network assets in the current network deployment are:

- the RSX at the access node
- the local switch (LS) at the distribution node
- the media gateway (MGW), the call server (CS), the point of interconnect (PoI), and the international gateway (IGW) at the core node.

These major network units are discussed in detail below in Figure 5.17. Other important network elements such as intelligent network (IN) platforms, billing systems and network management centres, which also form part of the core network functions, will be modelled in a logical fashion. Specifically, at least one unit of each of these systems will generally be required, with software/licence upgrades in line with increasing use of capacity (e.g. calls per second on the IN).

Each LS unit is assumed to be linked to at least two MGW units for resilience purposes. The transit layer is assumed to be partially meshed, with logical links (possibly via intermediate switches) between each of the MGW and CS units, on a series of physical rings.

Network asset	*Asset description*
RSX	The digital remote concentrators (RSX) are located in the access node. The MDF at the access node serves as the border between the access and core networks. In the current network, the RSX multiplexes voice circuits back to the distribution node.
LS	Active switching occurs for the first time at the LS. All calls go to as LS. The LS itself is responsible for the routeing and switching of voice traffic and, therefore, provides the PSTN service features. It also aggregates traffic from the RSX, returns all local calls and passes on the trunk calls either to other LS or to the MGW and CS.
MGW and CS	MGW and CS are the network elements that perform transit switching in a layered architecture. Traditional architecture relied on monolithic transit switches, that were designed to interconnect local switches and to connect the network of local switches to the long-distance trunk network. This function is now split between the MGW that handles the user traffic and the CS that handles the call control.
PoI	Domestic PoI are provided via MGWs that interconnect directly with other operators' networks. The MGWs are under the control of a CS.
IGW	IGWs are traditional monolithic transit switches that are used to interconnect with foreign operators. Alternatively, they can be MGWs controlled by CS with appropriate international functionality.

Figure 5.17: Voice platform assets [Source: Analysys Mason]

Data platforms

The structure of the current data core network in Norway is outlined below.

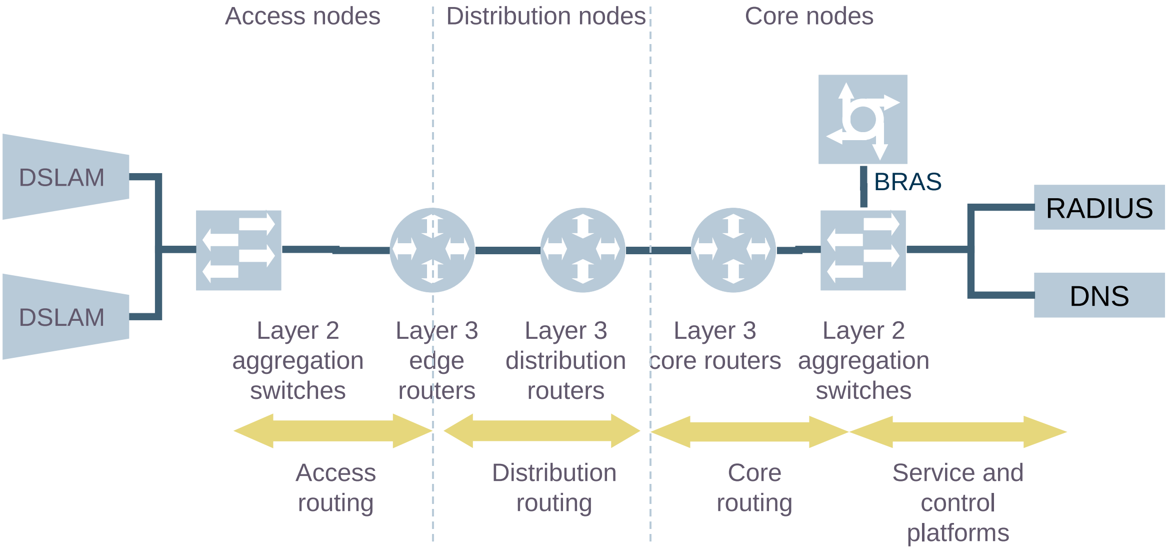

Figure 5.18: Current data core network deployment in Norway [Source: Analysys Mason]

DSLAMs may or may not be linked to two edge routers. Edge routers are assumed to be linked to two distribution routers for resilience purposes. Distribution routers are assumed to be deployed by pairs and linked to a pair of core routers for resilience purposes. The core routeing layer is assumed to be fully meshed.

The major network assets for data services are discussed in detail below in Figure 5.19.

Network asset	*Asset description*
DSLAM	The DSLAMs are located in the access node in the same way as the voice remote concentrators described above. Their role however is different in that they switch the data (ADSL and SDSL) traffic onto the IP network. DSLAMs may not be located in every exchange, dependent on the operator's deployment strategy.
Layer 2 aggregation switches	Ethernet switches are used to aggregate the traffic and are located within the access nodes.
Layer 3 edge routers	IP routers may be located in the access nodes on the edge of the IP network and used for routeing between the DSLAM and distribution routers.
Layer 3 distribution routers	IP routers are located in distribution nodes and used for routeing between the DSLAMs (or edge routers, if deployed) and the core routers.
Layer 3 core routers	IP routers are located in the core nodes in the core of the IP network and are used for routeing, both between distribution and core nodes and between core nodes.
BRAS	The broadband remote access server (BRAS), located at the core node, routes traffic to and from the DSLAMs located at the access node. The BRAS is also the interface to authentication, authorisation and accounting systems (such as RADIUS).
RAS	Specific to dial-up Internet services, a dial-up remote access server (RAS) is included at each core node to route dial-up traffic to the Internet. The RAS is also the interface to authentication, authorisation and accounting systems (such as RADIUS).
DNS	The domain name server (DNS) translates human-readable computer hostnames, e.g. www.example.com, into the IP addresses, e.g. 208.77.188.166, to which network equipment needs to deliver information. It also stores other information such as the list of mail exchange servers that accept email for a given domain.
RADIUS	The remote authentication dial-in user service (RADIUS) is an authentication, authorisation and accounting (AAA) protocol for controlling access to network resources. It is used to manage access to the Internet or internal networks across an array of access technologies including modem, DSL, wireless and VPNs.

Figure 5.19: Data platform assets [Source: Analysys Mason]

Modern switches and routers can be fitted with optical adapters or with traditional electrical ports.

Principle 37. Switches and routers in current data networks will be assumed to have traditional ports and not optical adapters.

Control platforms

The major network control assets are discussed in detail below in Figure 5.20.

Network asset	*Asset description*
Network synchronisation equipment	Many services running on current digital telecommunications networks require accurate synchronisation for their correct operation. For example, if switches do not operate with the same rate clocks, then slips will occur degrading performance. Telecommunications networks rely on the use of highly accurate primary reference clocks which are distributed across the network using synchronisation links and synchronisation supply units (SSU).
STP	This is a router that relays SS7 messages between signalling end-points (SEP). The STP is connected to adjacent SEPs and STPs via signalling links. Based on the address fields of the SS7 messages, the STP routes the messages to the appropriate outgoing signalling link. In order to meet resilience requirements, STPs are deployed in mated pairs at each node.
Network management system	This equipment is a combination of hardware, software, and accommodation facilities to monitor and administer a network.
IN	It allows operators to provide value-added telephony services, such as tele-voting, call screening, telephone number portability, toll-free calls, prepaid calling, account card calling, virtual private networks, etc.

Figure 5.20: Control platform assets [Source: Analysys Mason]

5.3.2 Core network platforms – NGN

This section outlines the reference design of the NG core asset deployment. As per the current network deployment, it outlines the major network elements that will be modelled. Component parts of these network elements (e.g. port cards, chassis) will be modelled explicitly in the core model, and will be dimensioned according to known parameters and drivers such as voice minutes and call attempts.

The choice of the control layer in an NG core is influenced by the access network architecture. However, the long-term evolution of the NG core architecture is to have a converged IP-based platform, which will aggregate a variety of different access nodes. In the short-to-medium term, this network could be used in conjunction with exchange-based MSANs providing PSTN services through use of a VoIP server gateway. An exchange-based deployment is required for consistency with Principle 32. The transport layer from the MSAN towards the core would be based on Ethernet and IP/MPLS switches and routers. It is this type of network that is consistent with the EC Recommendation relating to Market 3.

In the future, this core network could support the different NGA architectures, though the treatment of voice would be different:

- where the planned NGA deployments in Norway is orientated towards retaining some of the copper access network (FTTN/VDSL), then an MSAN could provide PSTN services through equipping it with a VoIP server gateway. As well as broadband access, they may incorporate IP multicast capabilities for video delivery. Upstream connectivity would be Ethernet-based, directly accessing the converged core
- where the access upgrade strategy is more orientated towards FTTH (either PTP or GPON), then all traffic could be transported as IP from the customer premises to an Ethernet access node, with voice services enabled by analogue telephone adapters (ATA) and then later IMS applications.

The list of assets required for the deployment of an NG core is shown in Figure 5.21.

Network asset	*Asset description*
MSAN	The MSAN is used to connect the copper pairs for each customer, with the MSAN then converting the voice, ISDN and xDSL into a single IP-based backhaul to the distribution and core nodes. MSANs include multi-service provisioning platforms (MSPPs) which are used for providing other services such as fibre based Ethernet and E1 access services, usually to business customers.
TGW	The trunk gateway (TGW) translates the TDM-based voice coming from other network to IP for transit over the NG core. Traffic from the legacy local switches (LS), which are not included as part of the NGN, would also be connected to the TGWs.
Session border controller	In a converged service access network, the session border controller (SBC) is used to police the IP connection between the common access network and the call server controlled core voice network. It provides security between the different networks domains (e.g. network address translation, stopping denial of service attacks, etc.) and controls the per-call (or per-session) bandwidth allocation at the network border.
Bandwidth manager	Bandwidth managers or resource and admission control elements are used in multi-service networks where requests are made by multiple service applications for specific (usually guaranteed) bandwidth requirements. The bandwidth manager controls resource reservation and admission control across multiple applications.
Layer 2 aggregation switches	Ethernet switches are used to aggregate the traffic and are located within the access, distribution and core nodes.
Layer 3 edge routers	IP routers may be located in the access nodes on the edge of the IP network and used for routeing between MSAN and the routers in the distribution nodes.
Layer 3 distribution routers	IP routers are located in distribution nodes and used for routeing between the edge and the core routers.
Layer 3 core routers	IP routers are located in the core nodes in the core of the IP network and used for routeing between distribution and core nodes and between core nodes.
CS	A call server (CS), is located in the core nodes and used to oversee the voice traffic.
DSL specific services	Equipment specific to DSL services (i.e. BRAS, mail servers, user authentication (RADIUS) servers and DNS) is also present in the NG core nodes.

Figure 5.21: Assets required for an NG core [Source: Analysys Mason]

An all-IP/Ethernet NG core will be modelled with no legacy TDM or SDH. This is consistent with the EC Recommendation,[14] which proposes that a fixed voice termination model could consider such NGN deployments.

Principle 38. The NG core model will be an all-IP/Ethernet core with no legacy TDM or SDH. This will be the long-term deployment and would be consistent with the deployment of a new entrant.

Equipment connectivity

Switches and routers can be fitted with optical adapters or with traditional, electrical ports.

Principle 39. The switches and routers in the NGN networks will be assumed to have optical adapters and not electrical ports.

Nodes

The move to NGA/NGN may trigger a rationalisation of core nodes, e.g. deployment of GPON may imply aggregating smaller local exchanges areas into larger exchange areas. It is noted that this remains consistent with the scorched node principle, as discussed in Section 5.2.5. If a reasonable assessment shows that some access nodes will be removed in the future, then interconnection will not be required at these nodes. The cost of those nodes can therefore be excluded.

At the distribution node level, an assessment will be made to understand if they become distribution aggregation nodes or are downgraded to access node functionality. It is less likely that the core nodes are to be rationalised, as there are around 14 locations currently used in Telenor's network for voice interconnection. However, the issue will be investigated.

Principle 40. The impact of an evolution to NGA/NGN on an efficient core network nodes architecture will be investigated.

5.3.3 Core network – Migration between platforms

This section outlines the treatment of core network technology generations. Indeed NPT seeks to capture not only a modern IP-based NG core deployment, but also to consider

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14 Commission Of The European Communities, *COMMISSION RECOMMENDATION of 7.5.2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU*, 7 May 2009

the transition from the current network deployment. Two possible approaches have been identified in which to address this in the model: exogenous and endogenous.

Exogenous approach

For the exogenous methodology, the approach would be to apply a glide path to derive the termination rate through logical steps:

- construct two standalone models of the core network – one of the current network and one of a full NG core
- the current fixed termination rate (FTR) cost would be based on the forward-looking deployment of the current network
- the FTR model for the NGN would be based on a future forward-looking deployment, including phase-in of the NG core
- a glide path could be derived over several years, by blending the current FTR with the modelled forward-looking cost using a migration profile of interconnected traffic from traditional to NG platforms.

Figure 5.22 illustrates how the unit cost / demand profiles for both technologies may look.

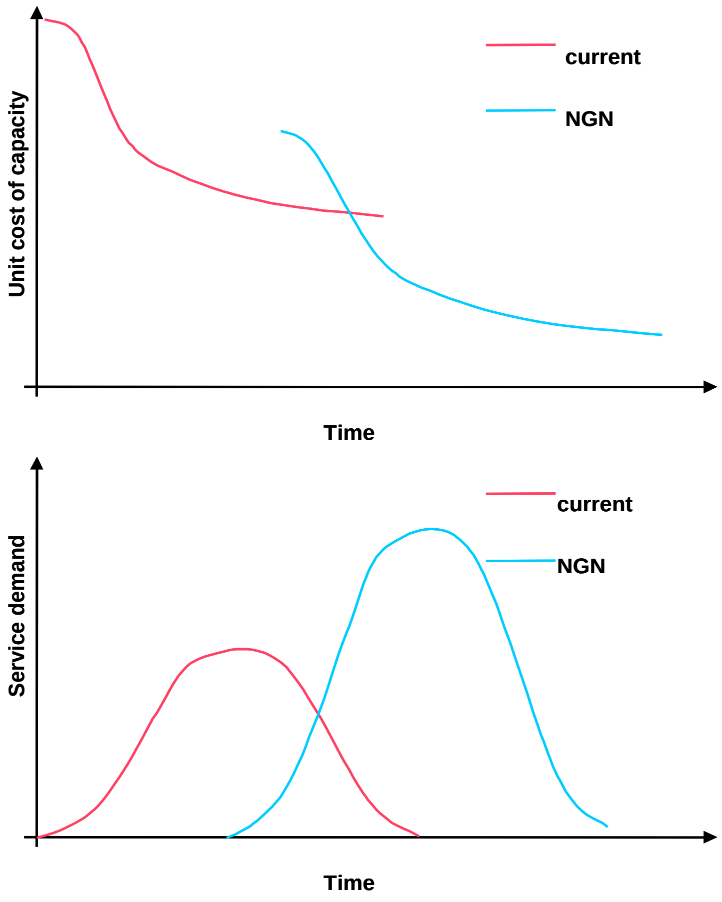

Figure 5.22: Demand and cost proxies for multiple generations [Source: Analysys Mason]

Endogenous approach

For the endogenous approach, the NG core can be phased in directly. In a mobile network technology migration, this can take five to ten years, with significant parallel infrastructure for much of that time (due to slow handset migration, spectrum scarcity, the amount of time required to carry out thousands of site upgrades, etc.). In a fixed deployment, migration of the core network alone can be a much faster process, with perhaps around 100 core and distribution nodes in which to conduct upgrades. It also benefits from end-user services being independent from the transport mechanism. In fact, the incentive is to minimise the migration period, subject to realistic cash flow funding requirements and technology reliability.

For the endogenous approach, a series of migration profiles would be included in the model. It is clear that the rate at which Telenor, as well as the other operators, migrate between the two core technologies is a critical factor. However, it is unclear, now and for the foreseeable future, when this migration will happen. Hence the trade-off between the two approaches is summarised below.

Exogenous approach	*Endogenous approach*
Allows users to easily test the cost implications of the rate of migration	May better capture some of the migration costs
Simpler approach may allow more scenarios or range over which scenarios will work	More complex approach may limit the number of scenarios that can be validated

Figure 5.23: Differences between exogenous and endogenous approaches [Source: Analysys Mason]

Principle 41. We will use an exogenous approach, with consistent parameters migrating services from the current network model to the NGN model. A set of migration rate scenarios will be used to show the sensitivity of service costs. The model will be capable of generating unit cost outputs for single networks (i.e. current and NGN).

5.3.4 Core transmission routes

In addition to assessing an efficient number of core network nodes and the assets within each location, the most important part of the network to understand is the trench/cable network linking these locations together.

Three methods for defining the core network transmission routes will be investigated, as shown in Figure 5.26.

Option	*Method*	*Activities*
1	Operators provide asset volumes of the network directly	Minimal, but the network routes will be historical and will require evaluation of efficiency
2	Operators provide the nature of the core node links and realistic network links are derived	Given the point-to-point links, distance-minimising street routes can be plotted using geographical information software (GIS). Some intrinsic inefficiency between the specified links may still remain
3	Use bottom-up design rules to first dimension the actual links between the nodes and then calculate the properties of the realistic network	As in Option 2, except the optimum link configurations are calculated algorithmically. This is fully forward-looking

Figure 5.24: Comparison of options for understanding core network links and the processing required [Source: Analysys Mason]

Each of the above options will be pursued, with Option 3 providing an assessment of the efficiency of routes determined from Options 1 and 2.

It is expected that core transmission routes will remain static for any one operator, over the period of examination of an operator. This will remain the case for the migration between current and NGN However, the capacity of the routes can be quantified over time.

► *Determining link configurations algorithmically*

An algorithm in Visual Basic will be used that is capable of taking the access node layer in a fixed network and deploying a set of backhaul links and resilient rings as part of a complete core network topology. Algorithms are necessary when defining a new network topology linking hundreds or thousands of nodes together based on bottom-up engineering principles.

The algorithm will be, in fact, a family of algorithms performing different tasks, including:

- **clustering** algorithms, grouping access nodes into access node clusters to be served by a single aggregation point
- **minimum spanning tree** algorithms, deploying tree architectures between nodes (such as in the access node layer)
- **'travelling salesman problem'** (TSP) algorithms, deploying resilient multi-ring architectures between nodes.

Core route distances will be modelled based on road and railway distances, using StreetPro Norway data, and route-optimising software (RouteFinder).

Modelling of route sharing

In fixed networks, where trenching is a very significant proportion of the total cost, there are significant cost savings to be found by sharing trenches. In the case of Norway, trenches could be shared with:

- the operator's core network
- another operator's network
- utility companies
- provisioned trench on new estates.

For the purposes of the bottom-up model, only the degree of trench sharing occurring in the cases where trench is shared within the network of the modelled operator can be estimated: namely between the access and core network layers. These estimates can be made on the basis of information from both industry parties, NPT and geographical analysis with MapInfo. This can then feed into the model in order to calculate the length of duct within each of these types.

Although the trenching required for the entire access network will be extensive, the core network links will still require trenching beyond that of the access network (e.g. in between remote concentrators and their parent switches). From a cost perspective for

Markets 2–4, deriving the amount of incremental trench required for each layer of the core network will be an important input to the model, simply because it will represent a large fraction of the core network costs, and there is likely to be little existing information. A parameterised approach can be used to accomplish this in a LRIC model, informed by:

- mapping links within each level in the core onto a street network using RouteFinder
- approximating access network trench using 'buffer' areas around each access node.

This approach is illustrated below in Figure 5.25. The blue, pink and green lines are core node links mapped onto actual road routes and the green areas are a proxy for the extent of the access network around the access node. Erasing the core links within the green areas enables an estimation of the incremental trench required for the core network. Examples of incremental trench are ringed in black below.

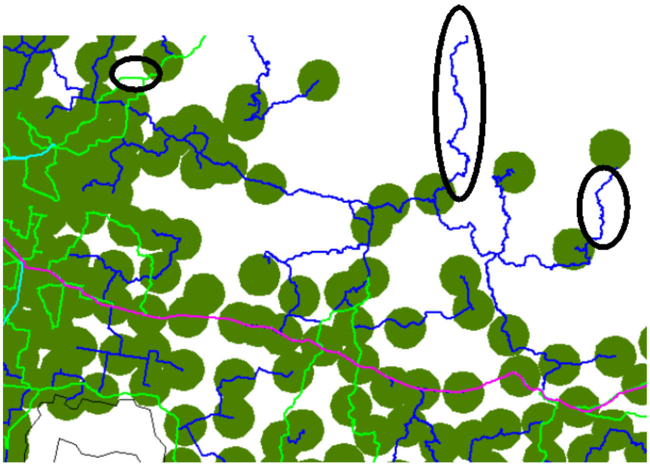

Figure 5.25: Identifying the sharing of routes between the access network and the core network [Source: Analysys Mason]

Principle 42. A parameter-based approach will be taken to quantify the level of trench sharing between the access and core network layers (and hence quantify the zero-cost trench), allowing testing of a range of inputs.

Core transmission route assets

Network asset	*Asset description*
Trench	Trenching is the action of digging the ground to lay ducts and fibre. As the access and core networks overlap in some regions, the same trench can be used to carry both access and core transmission.
Duct	Ducts are pipes laid in the ground following trenching to host the core fibre cables. Although the access and core networks overlap in some regions, separate ducts will be used for access services and for core fibre. Core ducts may support multiple core fibre links.
Fibre	Fibre is laid in the ducts and lit by equipment at each extremity. Individual core fibres provide point-to-point routes (though combined point-to-point routes may form ring structures).
Fibre regenerator	Fibre regenerators are installed along the fibre backbone and are used to amplify the signal. As the access and core networks overlap in some regions, the same fibre regenerator can be used to amplify the signals carrying access and core transmission.
ADM equipment	SDH add-drop multiplexers (ADMs) are active transmission equipment installed in each node served by a SDH ring and used to insert and/or extract information from the SDH bandwidth.
DWDM equipment	DWDM equipment has a function similar to SDH ADMs, i.e. to insert and/or extract information from the fibre. The difference is that DWDM equipment can deal with higher fibre-based bandwidth delivered using dense wavelength division multiplexing.

Figure 5.26: Core transmission assets [Source: Analysys Mason]

The capacities of transmission links will be calculated based on switch-to-switch transmission matrices.

5.4 Co-location module

As described in Section 3.2.2, Telenor currently offers co-location services (Telelosji) in Norway, which allow access seekers to use systems and space within Telenor's node locations. The main components of these services are:

- location, mounting and installation of equipment
- provision of station wiring
- provision of power, ventilation and cooling.

A separate co-location module for the LRIC model will be constructed, which will consider the costs incurred by a fixed operator offering these services at appropriate network sites.

For the purposes of Markets 2–4, the co-location services that require service costs to be calculated relate to switched interconnection and unbundled access. However, the module will need to capture additional co-location services (e.g. provision of retail access, or bitstream), since these will share certain costs with the co-location services relevant to Market 4.

The issues that are relevant to the specification of the co-location module are:

- derivation of service costs, as described in Section 5.4.1
- variation of costs by geography, as described in Section 5.4.2
- consistency of unit costs with other modules, as described in Section 5.4.3.

5.4.1 Derivation of service costs

In both the access and core network models, we will use a routeing factor methodology to assign costs to services. Co-location services, by comparison, are built up from individual components purchased by the access seeker. This requires the co-location module to capture costs at a greater granularity than in the other modules, which will also depend on receiving sufficiently detailed information from Telenor, requested during the data collection phase.

The costs of co-location services will be built up from four main sets of components, as shown below in Figure 5.28.

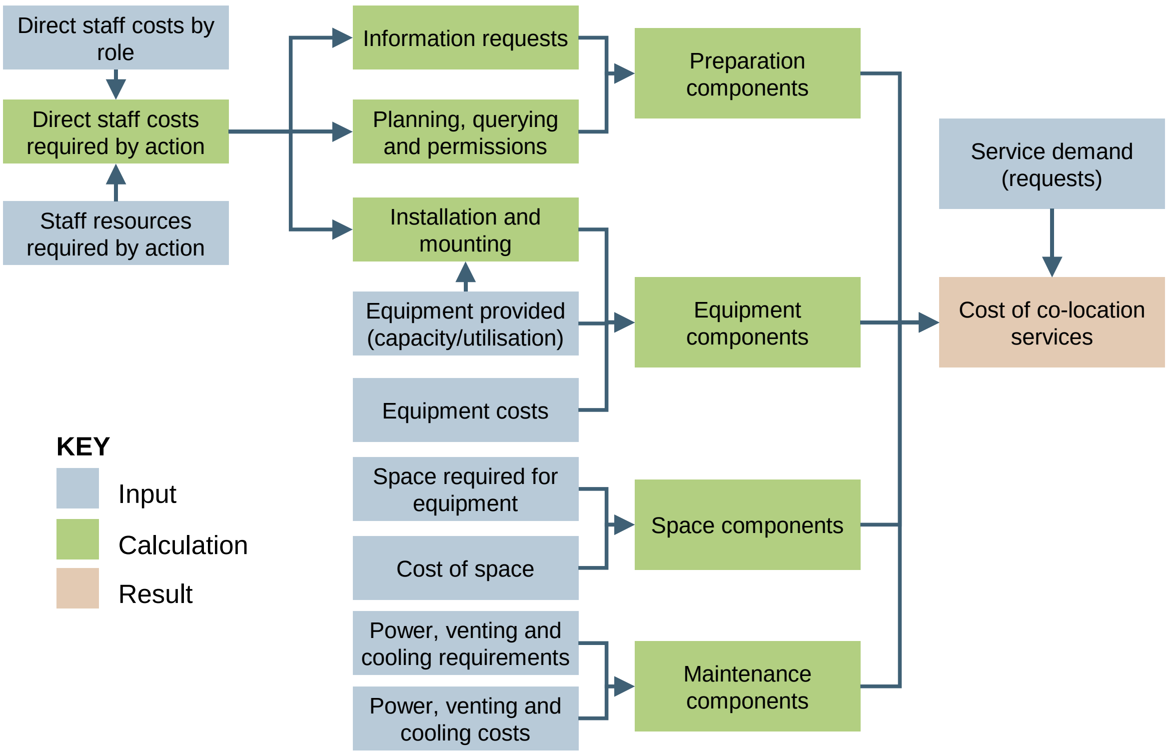

Figure 5.27: Derivation of costs related to co-location services [Source: Analysys Mason]

For example, the provision of providing co-located space in an RSS would be built up from:

- **Preparation:** staff costs related to administration of information requests, surveying, planning and confirmation
- **Equipment:** equipment costs of the rack for the access seeker to place their equipment, including connecting cables and duct if required, as well as necessary staff costs (including travelling costs)
- **Space:** cost of the space set aside for the access seeker's equipment (including free space)
- **Maintenance**: includes costs related to the powering, venting and cooling of the rack, as well as allowing staff from the access seeker to gain admission to the facilities.

In order to calculate the costs of the co-location services, the co-location module will also need to include the demand for each service from access seekers.

Principle 43. Costs of co-location services will be constructed by building up from individual cost components. Detailed cost information will be requested from Telenor for each of these components.

5.4.2 Cost variation by geography

There are several cost components which could vary significantly depending on the location in question. For example, it is understood that the price of conveyance of cabling through Telenor's duct network varies on a zonal basis. The three zones currently employed are:

- Oslo
- other cities/densely populated areas
- rural areas.

In addition, the cost of space is a significant component of the total cost and will vary based on the location within Norway. Hence, the co-location module will need to vary costs by geography. There are several options:

- variation of cost by the above zones
- variation of cost by site type e.g. DB, access node, distribution node, core node
- variation of cost by geotype
- a combination of these approaches.

The level of granularity that will be possible in this variation will be dependent on the data received during the data collection phase. Pragmatism is required as to where to vary costs by geography: for instance, power costs should not vary by geography.

Principle 44. Certain costs will be allowed to vary by geography in the co-location module. The split of geography will depend on the granularity of data received during the data collection phase and will be only used on those components where there is material variation.

5.4.3 Consistency of unit costs

The unit costs used in the co-location module (e.g. costs of cable, duct, trench provision) should be consistent with those used in the access and core modules. Direct links between these costs in their respective modules will be ensured.

5.5 Costing parameters

In this section, we discuss aspects of the costing calculations, as shown in Figure 5.28.

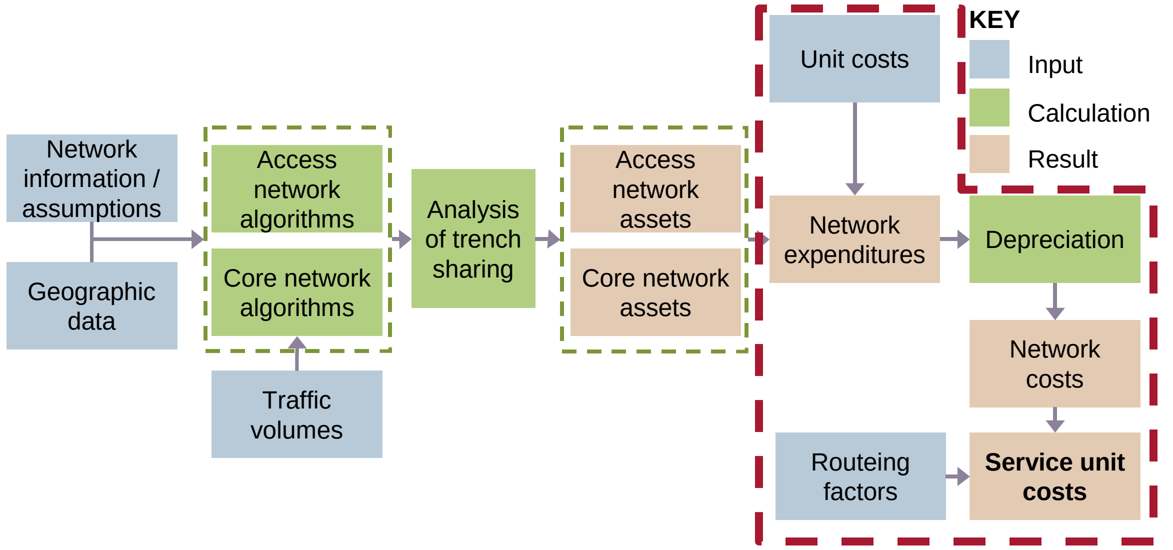

Figure 5.28: Costing calculations in bottom-up LRIC model [source: Analysys Mason]

The key aspects discussed are:

- input costs and lifetimes
- WACC
- depreciation methods
- routeing factors
- service costing and mark-ups.

5.5.1 Input costs and lifetimes

The operation of a fixed network is characterised by expenditures over time. These expenditures will be accounted for as either:

- **capital expenditures (capex)**, which are booked in the asset register and depreciated over time, also earning a return on investment due to the opportunity cost of tying up capital in the tangible and intangible assets. The level of these costs should be assessed on the modern basis. Specifically, these should reflect the level of expenditures prevailing at each point in time. We would expect that the capital investment cost of an asset should include the capitalisation of operating expenditures associated with its installation and testing. An asset type may also need to include an additional cost for spares which may be need to be held and a decommissioning cost associated with removing the asset from the network.

- **operating expenditures (opex)**, which are expensed in the profit and loss account in the year they are incurred, thus not tying up any capital (other than monthly ongoing working capital). Operating expenditures should relate to the level of rental, power, staffing, maintenance and other costs associated with an asset once it has been activated in the network.

Principle 45. Costs for each asset will be defined in terms of unit equipment costs, installation cost, cost of spares held and cost of decommissioning. The decommissioning cost will be set to zero by default unless a value can be substantiated. For each asset an operating expenditure will be defined relating to the operation and maintenance of that asset.

► *Trend in equipment unit costs*

The MEA price for purchasing and operating network elements will vary over time as the price of hardware capacity decreases, and other costs (e.g. rents) increase.

As such, the model should reflect the MEA trend of capital and operating expenditures, assessed in real terms to remove the underlying effects of inflation.

Principle 46. Cost trends will be defined for capital and operational expenses. Consideration of the cost-trends with and without inflation shall be made.

► *Lifetimes of assets*

Network asset lifetimes are used for replacement purposes and can be used for depreciation purposes depending on the type of depreciation method selected. Economic lifetimes will be used, which consider the following factors:

- financial lifetime
- estimated average physical lifetime
- other exogenous lifetime effects, such as early retirement, technology changes, etc.

Principle 47. Economic lifetimes will be defined for each asset.

5.5.2 WACC

The cost calculation will require a WACC to be specified. As noted previously in Section 2.3, NPT is appointing an external advisor to define the WACC approach and provide WACC values for operators.

5.5.3 Depreciation methods

The level of capital expenditure incurred by a business can be expressed in various ways over time:

- **cumulative capital expenditure**: the total of all capital investments made in the business
- **GBV**: the total of all capital investments made in the business, less the investments made in assets which have been replaced or retired
- **GRC**: the total capital expenditure which would be required to replace the entire network asset base today
- **NBV**: the GBV less accumulated depreciation on assets.

The efficiently incurred expenditures that are incurred in a fixed business must be recovered over time and any tied-up capital (i.e. expenditures which are not recovered in the year they are incurred) must earn a normal return on investment. The method by which these expenditures are recovered is, in general terms, the *depreciation method*.

There are four main depreciation methods:

- HCA depreciation
- CCA depreciation
- tilted annuities
- economic depreciation.

Each of these methods acts upon different measures of capital and operating expenditures and uses different calculation methods to produce the annualised cost in current and future years.

HCA depreciation

In HCA depreciation, the capital expenditure recorded in the asset register (the GBV) is depreciated over the defined financial lifetime of the asset at a uniform rate (a constant depreciation charge per year). As a result, the asset NBV decreases linearly over the lifetime as depreciation accumulates, and the corresponding cost of capital employed (the cost of tying up the remaining capital book value) also decreases linearly.

In HCA depreciation, operating expenditures are treated separately and expensed in the year they are incurred. Annualised cost is calculated by the formula:

$$AnnualisedCost = \left(\frac{PurchasePrice}{FinancialLifetime}\right) + (NBV \times WACC) + OperatingExpenditures$$

The example in Figure 5.29 (five-year asset purchased in Year 0, cost of 1000, lifetime of five years, operating costs of 100 per year increasing at 2% per annum, WACC of 12%) shows the features of HCA depreciation:

- constant depreciation charge
- declining cost of capital employed
- operating expenditures expensed in the year they are incurred.

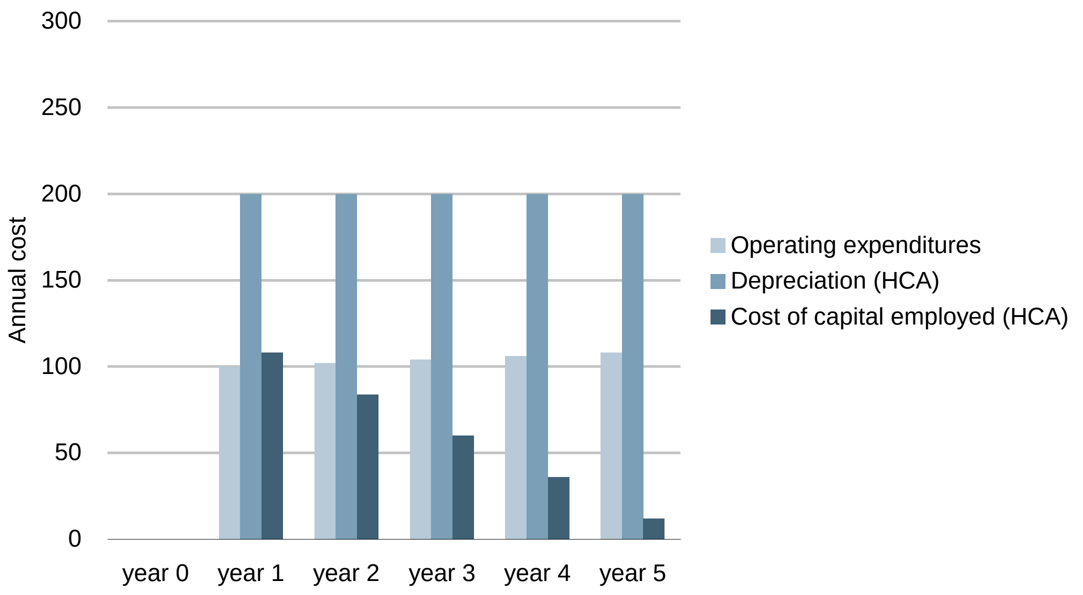

Figure 5.29: HCA depreciation [Source: Analysys Mason]

With HCA depreciation, the annualised cost in any year is not influenced by any future parameter and only by historical accumulation of book value and depreciation. HCA depreciation must be performed in nominal terms; operating expenditure recovery is not affected by HCA depreciation.

CCA depreciation

In CCA depreciation, the straight-line depreciation calculation is modified to take into account the changes in replacement cost for an asset (its MEA price). As the MEA price of an asset decreases, CCA depreciation is front-loaded because the replacement cost of the asset is declining (and its historically higher investment cost must be recovered earlier as the current price declines).

For CCA depreciation, the annualised cost is calculated by the formula:

$$AnnualisedCost = \left(\frac{GRC}{FinancialLifetime}\right) + HoldingGainLoss + (NRC \times WACC) + OpEx$$

When compared to the HCA formula, the first term of the equation differs in that it is the GRC that is spread over the lifetime, rather than the GBV. As a result, the additional term *HoldingGainLoss* must be added to reflect the gains or losses made by using an asset purchased in earlier (higher priced) years. The cost of capital employed is calculated by the *NRC* (or net replacement cost), which is simply the GBV minus accumulated CCA depreciation and accumulated holding gains/losses.

The term *HoldingGainLoss* is calculated as follows:

$$HoldingGainLoss = GRC \times Proportion\ Of\ Life\ Remaining \times MEA\ price\ decline$$

CCA depreciation is illustrated for the same example as used for HCA depreciation above. In this case, the MEA price decline is assumed to be 5% per annum. As can be seen in Figure 5.30, depreciation is front-loaded to ensure full cost recovery as the replacement cost of the asset reduces.

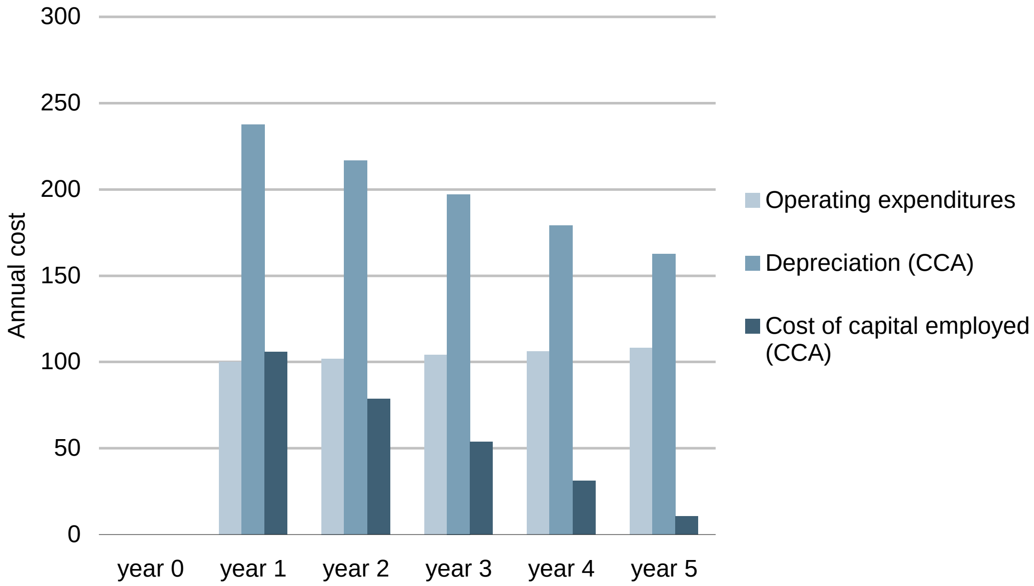

Figure 5.30: CCA depreciation [Source: Analysys Mason]

With CCA depreciation, the annualised cost in any year is not influenced by any future parameter, only by historical investments and price changes in the current period. CCA depreciation must be performed in nominal terms; operating expenditure recovery is not affected by CCA depreciation.

Tilted annuities

The annuity depreciation method calculates both the depreciation charges and the cost of capital employed, in such a way that the total (the annuity) is predictable over time. A flat annuity calculates a constant annualised cost per year that, after discounting, fully recovers the investment and return on capital employed. Operating expenditures are added to the cost recovery in each year they are incurred.

For many telecoms assets, the MEA price of the asset declines over time. In this situation, a tilted annuity is more appropriate. In a tilted annuity, the annualised cost of recovering the investment and return on capital is tilted with the forecast price trend of the asset, subject to still fully recovering investment and capital employed. As such, tilted annuities are sometimes used as a proxy for economic depreciation, particularly where the output of the asset does not change significantly over the period. This is the case in fixed networks, more so than in wireless networks.

The annuity charge formula is calculated as follows:

$$AnnuityCharge = \frac{WACC - MEApriceChange}{1 - \left(\frac{1 + MEApriceChange}{1 + WACC}\right)^{lifetime}} \times GRC$$

In this formula, the lifetime applied may be the financial lifetime or the economic lifetime (if different). Applied to the same example as above, the tilted annuity charge can clearly be seen in Figure 5.31 declining at 5% per annum.

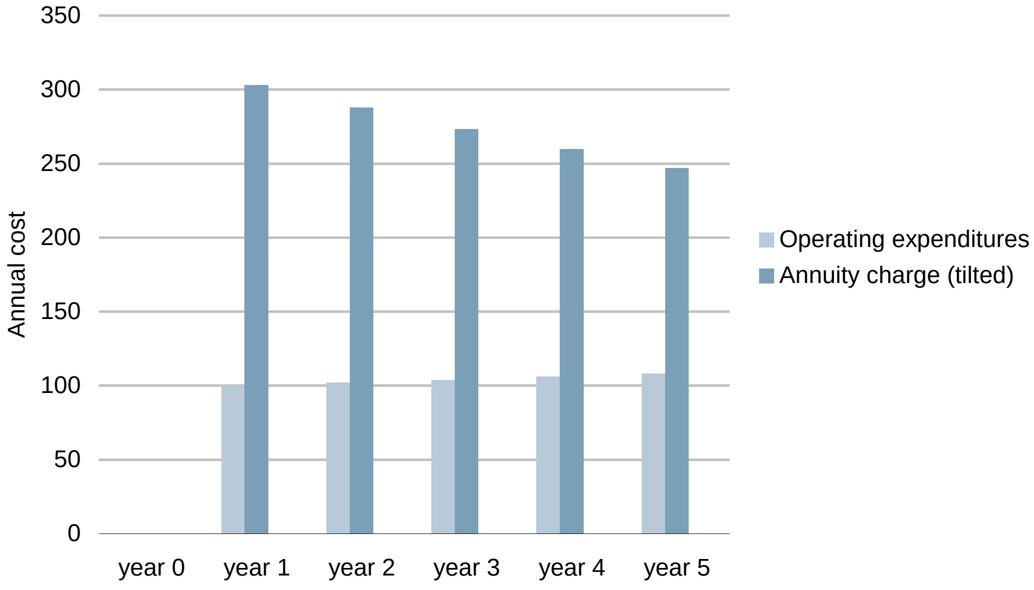

Figure 5.31: Tilted annuity depreciation [Source: Analysys Mason]

A tilted annuity calculation can be performed in nominal or real terms (using a real-term WACC and MEA price trend); operating expenditure recovery is not affected by annuity depreciation.

Economic depreciation

Theoretically, “economic deprecation” is the appropriate method for regulatory costing since it takes into account all the underlying factors influencing the economic value of an asset:

- projected trends in operating expenditures associated with the asset (MEA opex trends)
- projected trends in replacing the asset with its modern equivalent unit (MEA investment trends)
- the economic output (utilisation over time) that can be generated by the asset.

It is this third factor that specifically differentiates economic depreciation from the three previously discussed methods, since both CCA and tilted annuity depreciation take into account the MEA investment trend (albeit in different ways). However, in the situation where the output of an asset is not expected to change much over its lifetime, the result of an economic depreciation calculation is similar to a tilted annuity.

Economic depreciation can be implemented in many different ways with various formulaic calculations. However, all economic depreciation methods are likely to rely on an NPV calculation of some form. A NPV calculation ensures that the projected cost recovery profile (i.e. revenue) fully recovers expenditures plus the opportunity cost of tying-up capital. As such, it is possible to apply economic depreciation to operating expenditures, since these are business expenditures just like any other expenditure: whether they are accounted for by expensing or depreciating the expenditure is a matter for accountants. In the event that operating expenditures are recovered over time, they are also required to compensate for the cost of delaying the cost recovery (i.e. to earn a return on tied-up capital).

However, economic depreciation calculations are usually computationally expensive and therefore difficult to implement in a complex fixed network model. It may also be necessary to forecast cash flow for the lifetime of the longest asset model (e.g. of the order of 50 years for trench assets, would be expected). This posses real challenges in developing reasonable demand and cost profiles for such a duration.

Adjusted tilted annuities

A modified version of the titled annuity formula can be implemented, where an additional tilt is applied to front-load or back-load costs. A front-loaded tilt (a negative tilt) is appropriate where demand is falling to prevent under-recovery of costs over life of the asset. This approach will closely mimic economic depreciation where the economic output is not changing significantly.

The adjusted tilted annuity charge formula is calculated as follows:

$$AnnuityCh\arg e = \frac{WACC - tilt}{1 - \left(\dfrac{1 + tilt}{1 + WACC}\right)^{lifetime}} \times GRC$$

where *tilt* is defined as: $tilt = MEApriceChange + AdditionalTilt$

The additional tilt is a user input, and adjusted to load costs as required to ensure cost recovery.

Conclusions

Figure 5.32 summarises the factors, as discussed above, considered for the various depreciation methods:

	HCA	*CCA*	*Tilted annuity*	*Economic depreciation*	*Adjusted tilted annuity*
MEA cost today		✓	✓	✓	✓
Forecast MEA cost			✓	✓	✓
Output of network over time				✓	✓[15]
Financial asset lifetime [16]	✓	✓	✓	✓	✓
Economic asset lifetime			✓	✓	✓

Figure 5.32: Factors considered by depreciation methods [Source: Analysys Mason]

Economic depreciation (ED) is the preferred approach for regulatory costing. Moreover, changing utilisation over time is recognised to be an important factor for the voice platform, given a proposed migration from the current PSTN platform to an NG core. This changing utilisation of the platform can be captured in the core model by implementing an ED calculation. This will also lead to improved consistency with the mobile model used by NPT. An ED calculation requires clearly defining the start and end period of the assets useful life. Operators will be able to examine the implementation at consultation.

The same effect in the access network occurs through changing demand over time, which should be considered. However, the window of utilisation is less clear to define. Therefore it is not necessarily the case that the same ED algorithms will be used for the access network. It should be noted that while the (adjusted) tilted annuity approach is not the preferred regulatory costing approach, it is consistent with approaches adopted in other jurisdictions (see fixed LRIC models from NITA in Denmark and PTS in Sweden).

Principle 48. For the core network model, we will make explicit use of an economic depreciation calculation.

For the access model, we will investigate appropriate adjustments in the access network model to accommodate changing demand profiles. This will take the form of either a tilted annuity or an economic depreciation calculation.

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15 As discussed, the adjustment can allow correction for output of network elements over time. However, it is not implicit within the calculation.

16 Both tilted annuities and economic depreciation can use financial asset lifetimes, although the latter should strictly use economic lifetimes (which may be shorter, longer or equal to financial lifetimes).

5.5.4 Routeing factors

The application of a large traffic increment to the fixed network requires a matrix of routeing factors to be defined in the model. This matrix will then be applied to the incremental cost of traffic, by network element, to work out the individual incremental costs for each service modelled.

The dimensions of the matrix will be network elements and services. Each network element will need to be identified with a specific volume measure (e.g. minutes, calls, call events) to allow the numerical factor for each service to be identified.

In order to calculate the costs of set-up, rental and conveyance for a service, it may be necessary to apply divisions to network element costs prior to the application of routeing factors.

5.5.5 Service costing and mark-ups

The model will calculate the total economic costs for each network asset. Incremental costs per unit output will also be calculated for each asset class.

Routeing factors determine the amount of each element's output required to provide each service. In order to calculate incremental service costs, incremental unit output costs will be multiplied by the routeing factors according to the following equation:

$$Cost(Service_k) = \sum_{assets} \mathrm{cos}t\_per\_unit\_output(asset_i) \times RouteingFactor(asset_i, service_k)$$

As discussed in Section 2.2, EPMU will be employed to mark up common costs if required.

5.6 Year(s) of results

Due to the implementation of an ED calculation in the core network model, the period modelled will be from 1991 to 2050. The start year of 1991 reflects the (average) digitisation of the current voice platform. The final year of 2050 ensures full cost recovery of all assets, including those with the longest lifetime (60 years).

For the access model, the period modelled will be dependent on the depreciation choice, the lifetime of the assets and our understanding of when relevant assets were deployed. At a minimum, the period will be 2008 to 2015. This will allow reconciliation of 2008 results as part of the top-down calibration leading to a hybrid model. It also provides a forward-looking view that should inform the next round of analysis of relevant markets.

The forward looking period will require forecasts of service demand to be developed. In addition, price trends will need to be projected for the period of examination.

Principle 49. For the purposes of an ED calculation for the core network model, the model will cover the period 1991 to 2050.

For the access network model, the model will cover, at minimum, the period 2008 to 2015.

5.7 Documentation

The aim of the model documentation will be to put any model user with a reasonable knowledge of the issues in a position to understand both the main features of the model and its technicalities. The model documentation will explain, where possible, the reasons for the choices adopted in the model, consistent with the conceptual approach and specifications set out in this paper, agreed by NPT and informed by industry consultation.

The model documentation will explain:

- the conceptual principles underpinning the model
- the algorithms and calculations used to calculate demand, network and cost components of the model
- the key results of the model
- how the model has been calibrated against actual operator data (if appropriate or non-confidential)
- how to use the model to test relevant scenarios and input parameters.

We will also separately document the geographical analysis that we undertake on the MapInfo datasets, including the sampling methodology and testing processes employed.

6 Summary of principles

This section summarises the principles of the LRIC model for fixed networks identified in this paper.

Principle 1. Two cost increment approaches for the core network will be modelled:

Defining separate increments for wholesale termination and other services using the voice platform (including wholesale origination) – a “pure LRIC” approach.

Defining one increment as all traffic throughput on network – a LRAIC approach.

Principle 2. The increment in the access network will be defined as the total volume of all services using the access network - a LRAIC approach.

Principle 3. Where required, an EPMU approach will be employed for marking-up common costs.

Principle 4. A WACC will be used in the model in order to provide a return on investments. The approach to defining the WACC will be determined by an advisor.

Principle 5. In the bottom-up model, active access line volumes will be aggregated by copper and by fibre. These volumes will then be compared to top-down data.

Principle 6. A variety of access-related services will be modelled. However, the size of most assets in the access network over time will not be varied on the basis of demand, but rather a forecast driven by locations passed. However, the costs of access will be recovered over the forecast demand.

Principle 7. Services covering access to both ducts and fibre in the access network can be included in the Market 4 service set.

Principle 8. Consistent with the approach for the current network, the costs of NGA connections will be determined through the recovery of the total cost of a NGA architectural deployment over the active access connections in that architecture.

Principle 9. Traffic generated by ISDN lines will be included in the above voice services i.e. there will not be specific ISDN voice services.

Principle 10. Leased lines and other transmission services reasonably identified will be captured within the core network model.

Principle 11. NG-specific core services will not be separately defined and modelled: the same service definitions will be used as with the current network.

Principle 12. The same fee structure (namely a port set-up fee, a monthly port fee, a per-call set-up fee and a per-minute conveyance fee) will be used where clear reasons exist for disaggregation. The 2Mbit/s port interface will be modelled as a minimum.

Principle 13. Three NGN-interconnect products will be defined corresponding to connections based on 10Mbit/s, 100Mbit/s and 1Gbit/s Ethernet.

Principle 14. The costs of both full and shared access to both copper loops and sub-loops will be calculated for the current network.

Principle 15. The costs will be calculated for copper SLU for a FTTN/VDSL deployment, and fibre unbundling for a FTTH/PTP deployment.

Principle 16. A separate co-location module will be constructed, which will calculate the costs associated with co-location in various types of locations in the Telenor network. Consideration will be made of the scope for co-location services in a current network compared with a next-generation architecture.

Principle 17. The model will be capable of reflecting a number of network configurations, which are modelled using separate sets of parameters.

Principle 18. A commercially available database of Norwegian building locations will be used for the access network modelling.

Principle 19. Telenor's service area boundaries will be used as a partition for Norway.

Principle 20. Geotypes will be defined on its selected geographical areas using average road per location. This geotyping may be refined, where appropriate, using additional geographical data related to these areas.

Principle 21. As part of the offline calculation, a stratified sample of areas from each geotype will be used to calculate representative access deployments using the network design algorithms. The outputs of this sample will be used to derive the input parameters for the active calculation phase.

Principle 22. For the current architecture, a copper deployment will be used (with some fibre) that uses EF and HF to connect all buildings requiring connectivity back to the switch.

Principle 23. The access network model will include the capability to consider the deployment of FTTN/VDSL, FTTH/PTP and FTTH/GPON for a given set of areas, as described at the beginning of Section 5.2. Issues related to capturing migration to an NGA network are discussed in Section 5.2.5.

Principle 24. A modified scorched-node principle will be used, in which the level of scorching is clearly defined as an a priori assumption at the building locations of the MDF in the network. Consequently, in the current network deployment, all of the concentrators and switching elements in such accommodation are assumed to be deployed in efficient locations.

Principle 25. The scope of the access network model will be limited to exclude Jan Mayen, the dependencies, Antarctica and Svalbard.

Principle 26. A clustering algorithm will be employed to determine the locations served by network nodes. The algorithm will be flexible and able to determine clusters according to a range of capacity and distance constraints. It will use straight-line distance for simplicity, although means to increase the geographical awareness of the algorithm will be investigated, so that the occurrence of unreasonable clusters can be minimised.

Principle 27. Modified Prim and Dijkstra spanning tree algorithms will be used to determine the layout of cabling in the access network. The intention is to use the algorithm to determine a spanning tree for each cluster of locations in the service area. Although not Steiner tree methodologies, these algorithms have several improvements on a simple minimum spanning tree algorithm; in particular they can account for cable tapering.

Principle 28. For the trench and cable calculations for the access network, lengths will be calculated on the basis of p–functions, where the coefficients will be calibrated using geographic analysis of streets and households in Norway. The use of street-distances will take into account topological constraints on the network deployment. Equivalent calculations for the core network will be based on road/rail distances and will inherently take account of topological constraints. Elevation effects will be incorporated into the mode as a mark-up on the calculated distances.

Principle 29. Functionality will be included within the active calculations to assume some aerial deployment in the Norwegian access network.

Principle 30. Assuming sufficiently detailed costs and geographical data related to trenching is available, the data will be used to inform the costs of digging trench in an efficiently deployed network according to terrain.

Principle 31. We will model one size of duct used in the access network.

Principle 32. When modelling current and next-generation networks, the default assumption will be that the boundary between the access and core network will not be moved. Changes in the position of the boundary can be tested through simple scenarios.

Principle 33. We will retain the same geotypes used in the current access network in the NGA model. This will support the cost of deployment of a specific NGA architecture across a geotype.

Principle 34. The number of PoI in a NGN will be assumed to remain the same as current levels. Alternative values may be considered as sensitivities to the model.

Principle 35. We will model the NGA architectures deployed (which may vary across geotypes) as standalone, with a reasonable utilisation profile over time, rather than modelling an explicit migration between the legacy and NGA architectures. Any potential savings in trench/duct would be calculated exogenously. The design algorithms will not be capable of either identifying or using duct from a legacy network.

Principle 36. A modified scorched-node principle will be used, in which the level of scorching is clearly defined as an a priori assumption at the location of the core nodes in the network. Consequently, in the current network deployment, all of the switching and routeing elements are assumed to be deployed in efficient locations.

Principle 37. Switches and routers in current data networks will be assumed to have traditional ports and not optical adapters.

Principle 38. The NG core model will be an all-IP/Ethernet core with no legacy TDM or SDH. This will be the long-term deployment and would be consistent with the deployment of a new entrant.

Principle 39. The switches and routers in the NGN networks will be assumed to have optical adapters and not electrical ports.

Principle 40. The impact of an evolution to NGA/NGN on an efficient core network nodes architecture will be investigated.

Principle 41. We will use an exogenous approach, with consistent parameters migrating services from the current network model to the NGN model. A set of migration rate scenarios will be used to show the sensitivity of service costs. The model will be capable of generating unit cost outputs for single networks (i.e. current and NGN).

Principle 42. A parameter-based approach will be taken to quantify the level of trench sharing between the access and core network layers (and hence quantify the zero-cost trench), allowing testing of a range of inputs.

Principle 43. Costs of co-location services will be constructed by building up from individual cost components. Detailed cost information will be requested from Telenor for each of these components.

Principle 44. Certain costs will be allowed to vary by geography in the co-location module. The split of geography will depend on the granularity of data received during the data collection phase and will be only used on those components where there is material variation.

Principle 45. Costs for each asset will be defined in terms of unit equipment costs, installation cost, cost of spares held and cost of decommissioning. The decommissioning cost will be set to zero by default unless a value can be substantiated. For each asset an operating expenditure will be defined relating to the operation and maintenance of that asset.

Principle 46. Cost trends will be defined for capital and operational expenses. Consideration of the cost-trends with and without inflation shall be made.

Principle 47. Economic lifetimes will be defined for each asset.

Principle 48 For the core network model, we will make explicit use of an economic depreciation calculation.

For the access model, we will investigate appropriate adjustments in the access network model to accommodate changing demand profiles. This will take the form of either a tilted annuity or an economic depreciation calculation.

Principle 49. For the purposes of an ED calculation for the core network model, the model will cover the period 1991 to 2050.

For the access network model, the model will cover, at minimum, the period 2008 to 2015.

Annex A: Conceptual approach for algorithms

This annex describes the principles underlying the algorithms that we will use in both the dimensioning of both the access network and the core network. The classes of algorithms are:

- clustering algorithms, as described in Section 5.2.3
- spanning tree algorithms, as described in Section 5.2.3
- travelling salesman problem (TSP) algorithms, as described in Section 5.3.4.

A.1 Clustering algorithms

The clustering algorithm is expected to be a top-down clustering algorithm, as used in the FCC's hybrid cost proxy model (HCPM). These algorithms take a set of locations, as well as their associated demand (in terms of access line requirements), and group them subject to a capacity and a distance criterion. These algorithms would be used to aggregate:

- locations into small groups that can be served by a single end distribution point (EF)
- these groups into larger groups that can be served by a single distribution box (DB).

The algorithm uses two phases: a creation phase and a refinement phase.

A.1.1 Creation phase

This phase groups the points into a set of clusters, beginning with the full set of points, and proceeds as follows:

- the demand-weighted centre is calculated for this "parent" cluster of all points
- "Child" clusters are grown by adding points from the parent cluster incrementally
- the point that is furthest from the parent cluster's centre is used as the seed for a new child cluster
- points that would not exceed the child's cluster capacity and would not break the distance criterion are then added incrementally until no more addition is possible
- each time a point is added to the child cluster, the demand-weighted centres of both the current child and parent clusters are re-calculated
- this continues until the parent cluster itself satisfies both the capacity and distance criteria.

This process of clustering fixes the number of clusters.

A.1.2 Refinement phase

The creation phase does not necessarily create an optimal set of clusters. We have designed several refinement algorithms to improve the clusters, some examples of which are described below.

Simple re-assignment

For each point *P* in turn, the cluster identifies the cluster (after itself) whose demand-weighted centre is closest to its own. *P* is then moved to this cluster if the following conditions are satisfied:

- *P* is closer to this demand-weighted centre than its own
- the new cluster has sufficient spare capacity
- all points in the new cluster obey the distance constraint with respect to the re-calculated cluster centre.

This process continues cycling through all points, multiple times if necessary, until no more re-assignment is possible.

Full optimisation

For each cluster, the total distance between all the points and the cluster centre is derived. Then, it cycles through all points *P* in turn, multiple times if necessary, until no points have been moved in a whole cycle. The loop:

- identifies the cluster of *P* and the total distance (*d1*) between all points in this cluster and its cluster centre
- temporarily removes *P* from its cluster and re-calculates the demand-weighted cluster centre and the total distance (*d2*) between the cluster points and the new cluster centre
- restores *P* to its cluster and the demand-weighted centre
- for each cluster with spare capacity, stores the total distance (*d3*) between all points in this cluster and its current cluster centre
- adds *P* separately into each cluster with spare capacity and re-calculates the demand-weighted cluster centre and the total distance (*d4*) between the cluster points and the new cluster centre
- finds the cluster with spare capacity which gives the largest reduction in total distance (i.e. which maximises ([*d1*-*d2*]-[*d4*-*d3*])
- the point is moved to this cluster with spare capacity if it maximises ([*d1*-*d2*]-[*d4*-*d3*]) and would also satisfy the normal distance constraint using its new demand-weighted centre.

Swap

For each point *P* in turn, this algorithm:

- identifies the cluster whose demand-weighted centre is closest

- if the cluster is not its current cluster and, if moving *P* to the new cluster violates the capacity criterion, then tries to find a point in the new cluster which can be swapped with *P* so that:
  - both new clusters satisfy the cluster capacity constraint
  - the sum of the two distances between the points and the old cluster centres is improved compared with before
  - if the first two are true, then it is also checked if the sum of the two distances between the points in their original clusters and their original cluster centres is less than the sum of the two distances between the points in their new clusters and their new cluster centres
  - both obey the distance constraint with respect to the new demand-weighted centre of their new clusters
- if such a point is found, then it revises the two clusters and re-calculates their demand-weighted centres
- if several such points are found in the new cluster, then it uses the point which reduces the sum of the distances by the most.

A.2 Spanning tree algorithms

These algorithms take a set of locations and their demand and derive a set of edges that form a spanning tree between the locations. They derive an efficient trench/cable network to link:

- locations back to their parent EF
- EFs back to their parent HF, using existing trench where possible
- HFs back to the RSX, using existing trench where possible.

The algorithms that we have designed minimise a proxy cost function, which takes the form $k_1*d + k_2*c + k_3*d*c$ for copper or fibre deployment. *d* is the distance between two points and *c* is the number of pairs required between the two points (the capacity). The terms of this function are intended to estimate the costs of trench, jointing and cable respectively.

We have designed two flavours of minimum spanning tree algorithms:

- a modified version of Prim's algorithm
- a version of Dijkstra's algorithm.

A.2.1 Modified Prim

This algorithm begins with the individual points and their respective demands. It starts at the central node. For the purposes of this description, we will describe the case of joining end distribution points (EFs) back to their parent distribution box (DB):

- the algorithm adds vertices to the tree incrementally, by joining an unattached vertex to a vertex in the existing tree using an edge
- at each stage, the algorithm stores the identities of all attached EFs and all unattached EFs
- all possible pairs of EFs containing an attached EF and an unattached EF are considered
- for each such pair, the unattached EF is temporarily attached to the tree at the attached EF and the average cost per unit capacity of the new candidate tree is calculated. The cable size required to serve the unattached EF is calculated for the link:
  - if the average cost per unit capacity is lower than the previous best value, then the tree is temporarily updated with the required cabling all the way back to the DB.
  - if the average cost per unit capacity is still lower than the previous best value when the cabling requirements have been fully updated all the way back to the DB, then the pair of EFs is stored as the best pair
- for the pair of EFs that generates the lowest average cost per unit capacity overall, the unattached EF in the pair is joined to the attached EF in the pair
- the edge is added to the spanning tree and the lists of (un)attached EFs are updated
- the throughput capacity and cabling at the DB is also calculated
- the total network proxy cost of the updated tree is calculated for future comparisons
- this process iterates until there are no remaining unattached Efs.

A.2.2 Dijkstra

This algorithm begins with a set of cluster centres and a set of points contained within the clusters.

As a starting point, for each pair of clusters, the cheapest pair of points with which to join a pair of clusters through their centres is calculated using the proxy cost function. The points that a cluster centre passes through on the way to linking to the other cluster centres are also stored, so that the total distance traversed along trench between the two points can be calculated.

The subsequent calculation is strictly the Dijkstra algorithm and starts at the central node. For the purposes of this description, we again describe joining the end distribution points (EFs) back to their parent distribution box (DB). The algorithm then proceeds as follows:

- it is assumed that initially all EFs are joined directly to the DB (in a star formation)

- beginning at the DB, for every other EF the requirements to link it to the DB are recalled, in terms of:

  – extra trench
  – cost of linking the two points in their respective EF clusters (using the proxy cost function)
  – cabling cost of linking the two EFs (i.e. excluding trench cost)
  – total sheath length between them.

Then, until all EFs in the DB cluster have been connected to the DB, the algorithm proceeds as follows:

- for the given connected EF (the first stage uses the DB itself), look through the remaining unconnected EFs and decide which of these can be linked directly to this connected EF with the least proxy cost

- having identified the unconnected EF that can be joined to the selected connected EF, test whether it is a cheaper proxy cost to go from this unconnected EF to the DB by going through the selected connected EF, or going via the direct connecting path calculated from the unconnected EF to the DB (i.e. Is the EF connected directly to the DB, or via existing links?)

- next, determine, for each unconnected EF in turn, whether it is more cost effective to get to the DB via the newly connected EF or remain with its current path. Again, all unconnected EFs are initially assumed to go directly back to the DB, but this can evolve with each loop of the algorithm. If it arises that it is more cost-effective, the path for the disconnected EF should be changed to be via this newly connected EF

- check if it is cheaper for any other EF to be connected to the DB via this newly connected EF. If it is cheaper, then change the routeing of these EFs

- set the selected connected EF to be the newly connected EF and recommence the loop.

This can lead to EFs being ‘daisy-chained’ back to their respective DB. These algorithms can also be refined to ensure that cables do not double-back on themselves en route to the parent node.

A.3 Travelling salesman problem

In the core network, ring structure will be deployed at most layers of the network. The purpose is to ensure resilience of traffic flows, so that if the ring fails on any one link, then the traffic will still be able to be automatically routed. An algorithm has been designed that seeks to minimise the distance-based cost associated with the deployment of trench and fibre. It further seeks to minimise cost through the implementation of multi-rings, in which a child ring is linked to the parent ring by means of two bridging nodes for resilience purposes, as shown below.

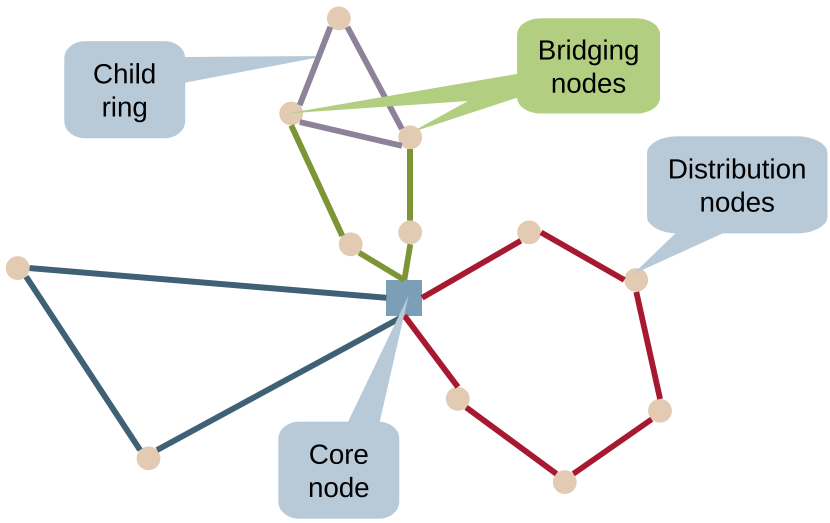

Figure A.1: Ring structures in the core network, joining distribution nodes to a core node in a set of resilient rings [Source: Analysys Mason]

Figure A.1 above shows the output of the algorithm for joining a set of distribution nodes together in a set of resilient rings back to a core node. This is calculated using a multi-ring travelling salesman algorithm, which adheres to the following principles:

- distribution nodes may be connected to the parent core node using optimised multiple SDH rings
- each ring may only contain a limited number of distribution nodes
- each distribution node must be linked back to its core node within a maximum number of links
- in the case of multiple rings, the capacity of a child ring (a ring which does not contain the core node) must also be carried on the parent ring (the ring which contains the core node)
- for resilience, child rings must be connected to the parent ring by two bridging nodes
  - where they connect to the parent ring at the core node, only one bridging node is required
- an add-drop multiplexer unit (ADM) is required at each distribution node on a ring, with its capacity dimensioned according to the total traffic carried on the ring.

Annex B: Glossary

AAA	Authentication, authorisation and accounting
ADM	Add-drop multiplexer
ADSL	Asymmetric digital subscriber line
AGW	Access gateway
ATA	Analogue telephone adapter
ATM	Asynchronous transfer mode
BAP	Broadband access platforms
BRAS	Broadband remote access server
BU	Bottom-up
CAPM	Capital asset pricing model
CCA	Current cost accounting
CEO	Chief Executive Officer
CPE	Customer premise equipment
CPI	Consumer price index
CPSO	Carrier pre-selection operator
CS	Call server
D/E	Debt/equity
DB	Distribution box
DLC	Digital loop carrier
DNS	Domain name system
DSL	Digital subscriber line
DSLAM	Digital subscriber line access multiplexer
DWDM	Dense wave division multiplexing
EC	European Commission
EF	Endefordeler
EPMU	Equi-proportionate mark-up
ERG	European Regulatory Group
ETRS	European Terrestrial Reference System
EU	European Commission
FAC	Fully-allocated cost
FAR	Fixed asset register
FR	Frame relay
FTR	Fixed termination rate
FTTH	Fibre-to-the-home
FTTN	Fibre-to-the-node
GBV	Gross book value
GigE	Gigabit Ethernet
GPON	Gigabit passive optical network
GRC	Gross replacement cost
HCA	Historical cost accounting

HCPM	Hybrid cost proxy model
HF	Hovedfordeler
HFC	Hybrid-fibre coax
IGW	International gateway
IN	Intelligent network
IP	Internet protocol
ISDN	Integrated services digital network
LLU	Local loop unbundling
LRAIC	Long-run average incremental cost
LRIC	Long-run incremental cost
LS	Local switch
MDF	Main distribution frame
MEA	Modern equivalent asset
MF	Mellomfordeler
MGW	Media gateway
MPLS	Multi protocol label switching
MSAN	Multi-service access node
MSPP	Multiservice provisioning platforms
NBV	Net book value
NG	Next-generation
NGA	Next-generation access
NGN	Next-generation network
NOK	Norwegian krone
NPT	Norwegian Post and Telecommunication Authority
NRC	Net replacement cost
NTP	Network termination point
O&M	Operation and maintenance
ODF	Optical distribution frame
OLT	Optical line terminator
PDH	Plesiochronous digital hierarchy
PoI	Point of interconnect
PON	Passive optical network
PSTN	Public switched telephone network
PTP	Point-to-point
RADIUS	Remote authentication dial-in user service
RAS	Remote access server
RSS	Remote switching stage
RSU	Remote switching unit
RSX	Remote switching stage or remote switching unit
SAC	Subscriber acquisition cost
SBC	Session border controller
SDH	Synchronous digital hierarchy
SDSL	Symmetric digital subscriber line

SEP	Signalling end-points
SLU	Sub-loop unbundling
SMP	Significant market power
SS7	Signalling System 7
SSU	Synchronisation supply units
STP	Signalling transfer point
TD	Top-down
TDM	Time-division multiplex
TGW	Trunk gateway
TSP	Travelling salesman problem
USO	Universal service obligation
VDSL	Very high-rate digital subscriber line
VoB	Voice-over-broadband
VoIP	Voice over internet protocol
VPN	Virtual private network
WACC	Weighted average cost of capital
WiMAX	Worldwide interoperability for microwave access
WLR	Wholesale line rental
xDSL	Generic term for DSL