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Model documentation for the Norwegian Communications Authority

Nkom's cost model of fixed core networks version 2.3F (Final)

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Contents

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1 Introduction

The Norwegian Communications Authority (Nkom) has determined prices for fixed termination in Norway by means of the long-run incremental cost (LRIC) method since 1 January 2012.

In 2009–11, with the assistance of Analysys Mason, Nkom developed a cost model of fixed network infrastructure in Norway, including core networks, access networks and the costs of co-location services. The model of fixed core networks included both a public and Telenor-confidential calculation of a national incumbent operator, as well as calculations of the costs of a pure VoIP player, an access owner and an unbundler. The model could also consider both legacy (TDM) and next-generation network (NGN) architectures.

The final model of fixed core networks (the "v1.6 model") was released in May 2011 and was used to inform the price regulation of wholesale fixed origination and wholesale fixed termination in Norway (at the time referred to as Markets 2 and 3, respectively). This price regulation used:

- for wholesale fixed voice termination, the long-run average incremental cost excluding administrative overheads, which we refer to as "LRAIC"
- for wholesale fixed voice origination, the long-run average incremental cost including both administrative overheads and an additional mark-up for the unrecovered costs of wholesale fixed termination for carrier-preselect (CPS) subscribers (with and without wholesale line rental), which we refer to as "adjusted LRAIC+".

Since the model of fixed core networks was first developed in 2009, the European Commission (EC) has released a new Recommendation on relevant markets (in October 2014) where regulation is still needed to safeguard competition.[1] These markets have also been defined by the European Free Trade Association Surveillance Authority (EFTA Surveillance Authority, or ESA).[2] According to the ESA definition, the market for wholesale fixed origination was removed as a relevant market, and the market for wholesale fixed termination became Market 1.

The regulation in place for Telenor for wholesale fixed origination was removed in Nkom's final pricing decision of January 2016. Ten operators were price-regulated symmetrically for the wholesale fixed voice termination service.

The cost model comprises three modules:

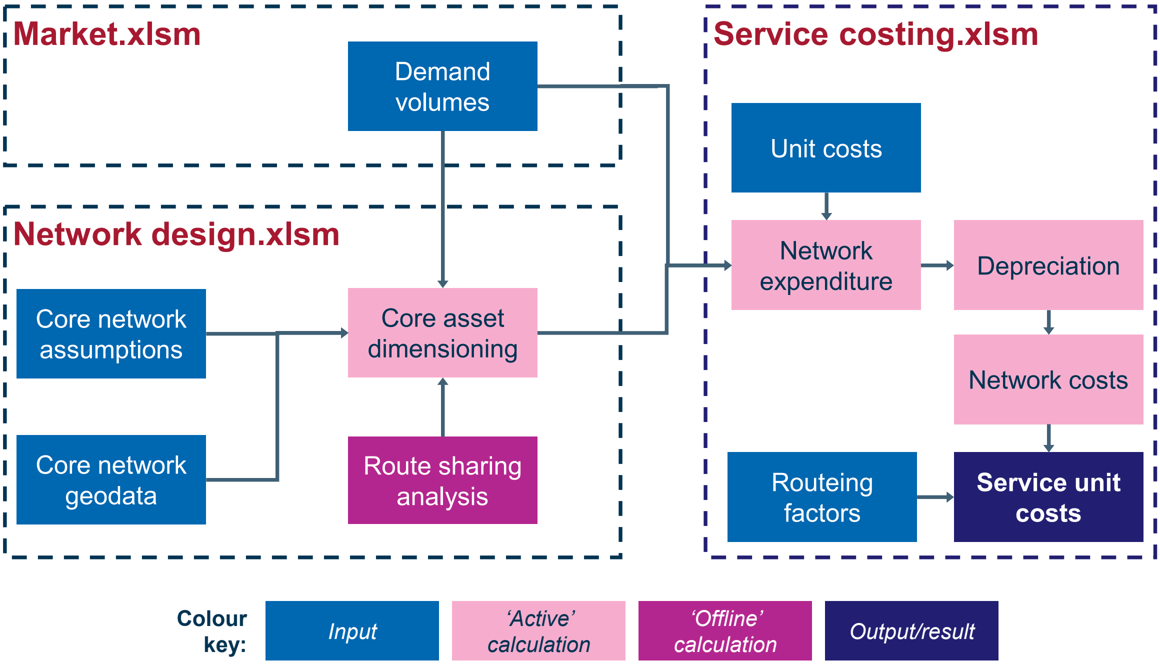
1 For the EC definition, see COMMISSION RECOMMENDATION C(2014) 7174 of 09.10.2014 on relevant markets within the electronic communications sector susceptible to ex ante regulation in accordance with Directive 2002/21/EC. Available at http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?action=display&doc_id=7045

2 See http://www.eftasurv.int/media/decisions/College-decision---Revision-of-ESA-Recommendation-on-Relevant-Markets-susceptible-to-ex-a.pdf

- A Market module that calculates traffic and subscriber volumes for the modelled operator over the modelling period.
- A Network Design module that calculates the network assets required to serve the assumed volumes of traffic and subscribers, and its associated capital and operational expenditures.
- A Service Costing module that calculates the unit costs of each service according to the various costing methodologies.

These modules are summarised in Figure 1.1 below.

Figure 1.1: Modular structure of the cost model [Source: Analysys Mason, 2014]



The model uses the demand inputs in the Market module and the network design inputs in the Network Design module to dimension a fixed core network and its associated expenditure. In the Service Costing module, the expenditure is then depreciated and allocated using routeing factors to give the unit costs by service.

Since the v1.6 model was finalised and the pricing decision implemented, the Norwegian fixed market evolved. In particular:

- Telenor announced plans to modernise its core network, by gradually phasing out traditional fixed telephony (PSTN/ISDN) technologies and replacing them with new technologies. This had implications for the v1.6 model, which assumed migration to a fixed NGN architecture using MSANs.
- Voice subscriptions and voice traffic on fixed networks continued to fall, although total broadband subscriptions (across all the technologies available in Norway) increased.

- The EFTA Surveillance Authority released its own Recommendation on the costing of fixed and mobile termination rates in April 2011.

In order to further develop the v1.6 model in the context of these developments, a draft model (v2.0D) was released for consultation in December 2013. Following feedback from industry, a number of changes were made, resulting in the final updated model (the "v2.0F model"). This was published in April 2014.[3]

In January 2018, a revised version of this model (the "vAcc2.2 model") was released as part of the consultation on the decisions for Markets 3a and 3b, according to the 2014 EC Recommendation on relevant markets.[4] This included a refined version of the v2.0F model. As well as an update of the demand assumptions, a calculation for the core-related costs of bitstream services in Norway was implemented. This version of the model forms the starting point for the development of the v2.3F model, undertaken during 2018.

The focus of this most recent update of the LRIC model of fixed core networks has been in relation to updating the demand inputs in the Market module with the most recent information, as described in Section 3. In addition, the impact of a migration to a new voice interconnection protocol has been considered, which is described in Section 4.5.

This document sets out the revisions that have been undertaken as part of this update, and is laid out as follows:

- Section 2 describes the conceptual approach from the Nkom v1.6 model and any revisions we believe are required for updating the model.
- Section 3 describes the changes made to the demand forecasting.
- Section 4 describes the changes made to the fixed core network design.
- Section 5 describes the calculations in the model that reflect the EC/ESA Recommendations.

The report includes a number of annexes containing supplementary material:

- Annex A provides reference material adapted from the v1.6 model documentation that describe aspects of the fixed core network design that have since been revised.
- Annex B summarises the locations of the sources used to update the Market module.
- Annex C provides the expansion of acronyms used in this document.

3 See https://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-kjerne

4 See https://www.nkom.no/marked/markedsregulering-smp/anbefaling-2016/marked-3a

2 Conceptual approach for the Nkom v2.3F model

The document *Conceptual approach for the LRIC model for fixed networks*[5] ("the 2010 concept paper") was developed as part of the original LRIC modelling process and contained the principles on which the Nkom v1.6 model was based. This included both the bottom-up calculations and the subsequent top-down reconciliation. This section summarises the relevant concepts and describes whether we believe any revisions are required. The conceptual issues previously considered can be classified in terms of four modelling dimensions. These are: operator, technology, service and implementation.

The remainder of this section is set out as follows:

- Section 2.1 reaffirms the conceptual issues associated with the Nkom v1.6 model of fixed core networks.
- Section 2.2 deals with conceptual issues related to the definition of the operator to be modelled.
- Section 2.3 discusses conceptual issues related to the technologies employed.
- Section 2.4 examines conceptual issues related to the service definitions.
- Section 2.5 explores conceptual issues related to the implementation of the model.

The concepts set out in this section has not been revisited as part of the 2018 update of the LRIC model of fixed core networks.

2.1 Summary of recommendations from the Nkom v1.6 model

The 2010 concept paper established the principles for the Nkom v1.2/v1.4/v1.6 models[6] of fixed core networks in Norway. The paper contains 49 principles covering the models of fixed core, fixed access and co-location services that were developed. Figure 2.1 below summarises the 22 principles that are relevant to the Nkom v2.3F model of fixed core networks. Principles [43] and [44] are related to the co-location model. The remaining 25 principles are related to the access model and are therefore not considered here.

Figure 2.1: Conceptual decisions from the original fixed LRIC model development that are relevant to the Nkom v2.3F model [Source: Analysys Mason, 2014]

Principle	Summary from the final concept paper	Chapter
[1] Definition of increments	Separate increments are defined for a pure LRIC approach and a LRAIC approach	Section 2.5.1
[3] Treatment of common costs	Use equi-proportionate mark-up (EPMU)	Section 2.5.2
[4] WACC	The WACC will be defined by an external consultant	Section 2.5.3

5 See http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess/_attachment/1805?_download=true&_ts=139100f7b30.

6 The v1.2 draft model was released in February 2010. The v1.4 model was released in January 2011 alongside Nkom's draft decision. The v1.6 model was released in May 2011 alongside Nkom's final pricing decision.

Principle	Summary from the final concept paper	Chapter
[9] ISDN traffic	ISDN voice traffic is not modelled separately	Section 2.4
[10] Leased lines and transmission services	Reasonably identified services are captured	Section 2.4
[11] Next generation-specific core services definitions	The same definitions are used as with the current network	Section 2.4
[12] Voice termination fee structure	The same fee structure will be used	Section 2.4
[13] NGN-interconnect products definition	Based on connections of 10Mbit/s, 100Mbit/s and 1Gbit/s Ethernet	Section 2.4
[17] Network configurations modelled	Network configurations are modelled using separate sets of parameters (for national incumbent, pure access leaser, pure access owner, pure VoIP player)	Section 2.2
[34] PoI in the NGN	The number is assumed to remain the same as current levels	Section 2.4
[36] Node scorching	All switching and routeing elements are assumed to be deployed in efficient locations, i.e. we use the scorched-node principle	Section 2.3.1
[37] Modelling switches and routers in the data network	Traditional ports rather than optical adapters are assumed	Section 2.3.1
[38] Next-generation core model	The NG core model will be an IP/Ethernet core with no legacy TDM/SDH	Section 2.3.1
[39] Switchers and routers in the NGN	Optical adapters rather than electrical ports are assumed	Section 2.3.1
[40] Evolution to NGA/NGN	The impact of migration on an efficient core network node architecture was investigated	Section 2.3.2
[41] Migration from the current network model to the NGN model	An exogenous approach with consistent parameters migrating services is used	Section 2.3.2
[42] Level of trench sharing	Trench sharing is considered using a parameter-based approach, for the testing of a range of inputs	Section 2.3.3
[45] Definition of unit asset costs	Unit equipment costs, installation cost, cost of spares held and cost of decommissioning are all defined	Section 2.3.4
[46] Definition of cost trends	Cost trends are defined for capital and operational expenditures	Section 2.3.4
[47] Asset lifetimes	An economic lifetime is defined for each asset	Section 2.3.4
[48] Depreciation calculation	Economic depreciation is used	Section 2.5.4
[49] Modelling period	The period from 1991 to 2050 is modelled	Section 2.5.5

For the purposes of the update in 2013–14, we found that only one of the 22 principles in Figure 2.1 above (Principle [34]) needed to be revised. No principles have been revisited since that update i.e. there have been no revisions to the principles for the purposes of deriving the v2.3F model.

2.2 Operator-related conceptual issues

The conceptual issue considered in this section is shown in Figure 2.2.

Figure 2.2: Principles of operator-related conceptual issues [Source: Analysys Mason, 2010]

Principle	Summary from the final concept paper
[17] Network configurations modelled	Network configurations are modelled using separate sets of parameters (for national incumbent, pure access leaser, pure access owner, pure VoIP player)

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

The model is required to provide an understanding of the cost of fixed wholesale voice termination for operators designated as having SMP. Currently, ten operators are designated as having SMP in this market, following the last pricing decision in 2016.[7]

Any modelling of the operators was 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. Four types of operators, based on the list of business models listed by Nkom in its 2006 market review, are described in Figure 2.3 below and were considered in the v1.6 model.

Figure 2.3: Generic operator types [Source: Analysys Mason, 2010]

Operator type	Description	How the model will be adapted
Telenor (incumbent scale)	Telenor uses its access network to offer: • PSTN • both broadband and VoB to the same end users • broadband	This is the base model.
Access leasers	These operators lease access circuits from Telenor and use them to offer: • PSTN • both broadband and VoB to the same end users • broadband based on LLU	The model has a small core similar to Telenor's NGN. It also includes a backhaul network to aggregate services from the access/ distribution nodes to the core nodes. Geographical expansion of the modelled network is based on actual deployment achieved by a typical operator.
Access owners	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 • broadband based on own access	The model has a small core similar to Telenor's NGN. It also includes a backhaul network to aggregate services from access nodes to the core nodes. Geographical expansion of the modelled network is based on actual deployment achieved by a typical operator.

[7] See https://eng.nkom.no/market/market-regulation-smp/markets/market-2-and-3

Operator type	Description	How the model will be adapted
Access independent	These operators neither own nor lease infrastructure. They rely on service-based access to offer: • PSTN • VoB to the end users	The model has a small core similar to Telenor's NGN. It does not include any backhaul network. Geographical expansion of the modelled network is limited to the core network and driven by the requirement for different points of interconnect.

The hypothetical configurations were designed to use only one type of access on a defined network footprint (e.g. an unbundler, an access owner and a reseller).

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

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

The 2011 and 2016 pricing decisions use the outputs from the incumbent scale modelling. Although the alternative operator calculations are retained in the Nkom v2.3F model, the incumbent scale calculation is the focus of the update. This is because there is little difference between the final results of each of the alterative operator parameterisations and the incumbent scale parameterisation. This is also in line with Nkom's 2011 pricing decision (paragraph 253 of this decision describes why separate values would not be required).[8]

The principle itself is not revised, since the capability to model alternative network configurations was retained.

2.3 Technology-related conceptual issues

In this section, we describe the technological aspects of the model. This includes underlying technologies, migration between technology generations, transmission topology and equipment unit costs. The issues considered in this section are shown in Figure 2.4.

Figure 2.4: Principles of technology-related conceptual issues [Source: Analysys Mason, 2010]

Principle	Summary from the final concept paper
[36] Node scorching	All switching and routeing elements are assumed to be deployed in efficient locations, i.e. we use the scorched-node principle
[37] Modelling switchers and routers in the data network	Traditional ports rather than optical adapters are assumed
[38] Next-generation core model	The next-generation core model will be an all-IP/Ethernet core with no legacy TDM or SDH

8 http://www.nkom.no/marked/markedsregulering-smp/marked/marked-2-og-3/_attachment/1086?_ts=13847b2c937

Principle	Summary from the final concept paper
[39] Switchers and routers in the NGN	Optical adapters rather than electrical ports are assumed
[40] Evolution to NGA/NGN	The impact of migration on an efficient core network nodes architecture was investigated
[41] Migration from the current network model to the NGN model	An exogenous approach with consistent parameters migrating services is used
[42] Level of trench sharing	Use a parameter-based approach, allowing testing of a range of inputs
[45] Definition of unit asset costs	Unit equipment costs, installation cost, cost of spares held and cost of decommissioning are all defined
[46] Definition of cost trends	Cost trends are defined for capital and operational expenditures
[47] Asset lifetimes	An economic lifetime is defined for each asset

2.3.1 Technology standard

This section describes the modelled technologies. We describe the TDM and NGN designs separately below.

TDM ('current') network design

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).

Component parts of the various network elements (e.g. port cards, chassis) were modelled explicitly in the v1.6 model, and are dimensioned according to known parameters and drivers such as voice minutes and call attempts.

In the rest of this section, we describe the modelled network nodes, voice platforms, data platforms and control platforms for the TDM network.

► *Network nodes*

Nodes in the TDM network exhibit a hierarchical structure as shown in Figure 2.5.

Figure 2.5: Core network nodes [Source: Analysys Mason, 2011]

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.

Network asset	Asset description
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.

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.

The greater the level of granularity/detail that was used directly in the calculation, the lower the extent of network 'scorching' that was being used.

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.

The locations from the v1.6 model continue to be used in the model and are assumed to still be efficient.

► *Voice platform*

The structure of the modelled core network TDM voice platform is outlined below.

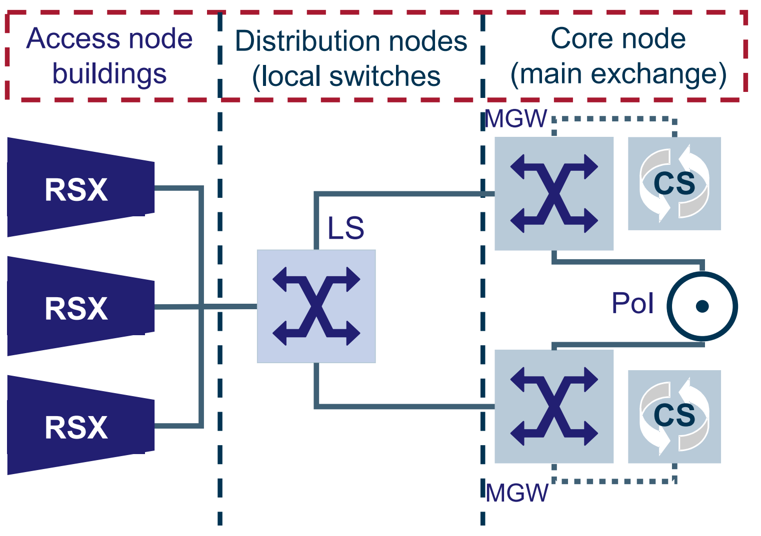


Figure 2.6: Modelled TDM voice core network deployment in Norway [Source: Analysys Mason, 2011]

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 in Figure 2.7 below.

Figure 2.7: Voice platform assets [Source: Analysys Mason, 2011]

Network asset	Asset description
Remote switching stage or remote switching unit (RSX)	The digital remote concentrators (RSX) are located in the access node. Multiplexes voice circuits back to the distribution node.
Local Switch (LS)	Active switching occurs for the first time at the LS. All calls go to an 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 another 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. The MGW handles the user traffic and the CS handles the call control. The MGWs are under the control of a CS.
PoI	Domestic PoIs are provided via MGWs that interconnect directly with other operators' networks.
IGW	IGWs are used to interconnect with foreign operators.

► *Data platform*

The structure of the modelled core network data platform is outlined below.

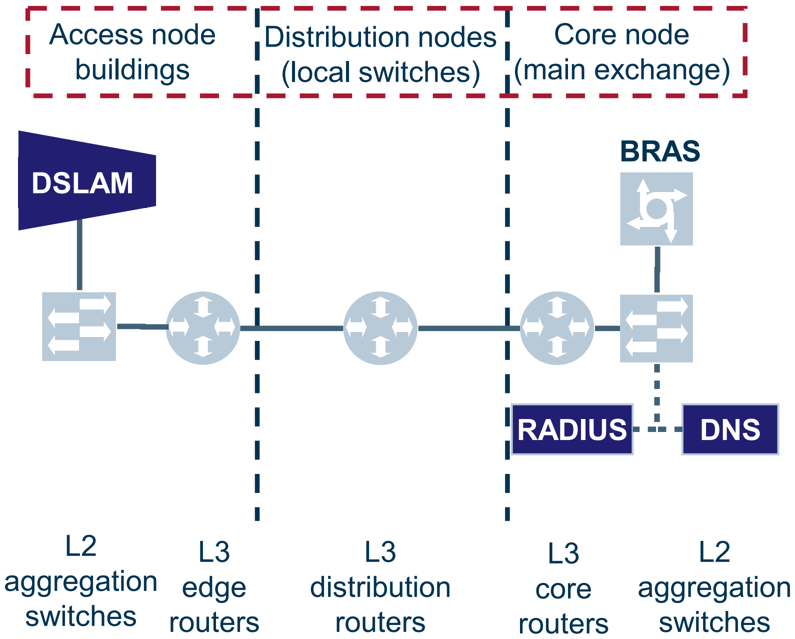


Figure 2.8: Modelled core network data platform [Source: Analysys Mason, 2011]

In the v1.6 model, edge routers were assumed to be linked to two distribution routers for resilience purposes. Distribution routers were assumed to be deployed in pairs and linked to a pair of core routers for resilience also. The core routeing layer was assumed to be fully meshed. The major data platform assets are described in the Figure 2.9 below.

Figure 2.9: Data platform assets [Source: Analysys Mason, 2011]

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.
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. It is also the interface to like 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.
DNS	The domain name server (DNS) translates human-readable computer hostnames.
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.

Modern switches and routers can be fitted with optical adapters or with traditional electrical ports. We assumed traditional ports were used.

Revisions to the design of the data platform in the Nkom v2.0F model are described in Section 4.2. No revisions have been made for the v2.3F model.

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

► *Control platforms*

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, were modelled in a logical fashion. Specifically, at least one unit of each of these systems was assumed to be required, with software/licence upgrades purchased in line with increasing use of capacity (e.g. calls per second on the IN).

The major network control assets are discussed in detail below in Figure 2.10.

Figure 2.10: Control platform assets [Source: Analysys Mason, 2011]

Network asset	Asset description
Network synchronisation equipment	Many services running on current digital telecommunications networks require accurate synchronisation for their correct operation.
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.
Network management system	This equipment is a combination of hardware, software, and accommodation facilities to monitor and administer a network.
Intelligent network (IN)	Allows operators to provide value-added telephony services.

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

NGN design

This section outlines the reference design of the next-generation core asset deployment in the v1.6 model. We describe the modelled network design and network nodes in turn.

The structure of the next-generation network platform in the v1.6 model is outlined below. Changes made for the v2.0F model (and retained in the v2.3F model) are described in Section 4.2 and 4.3.

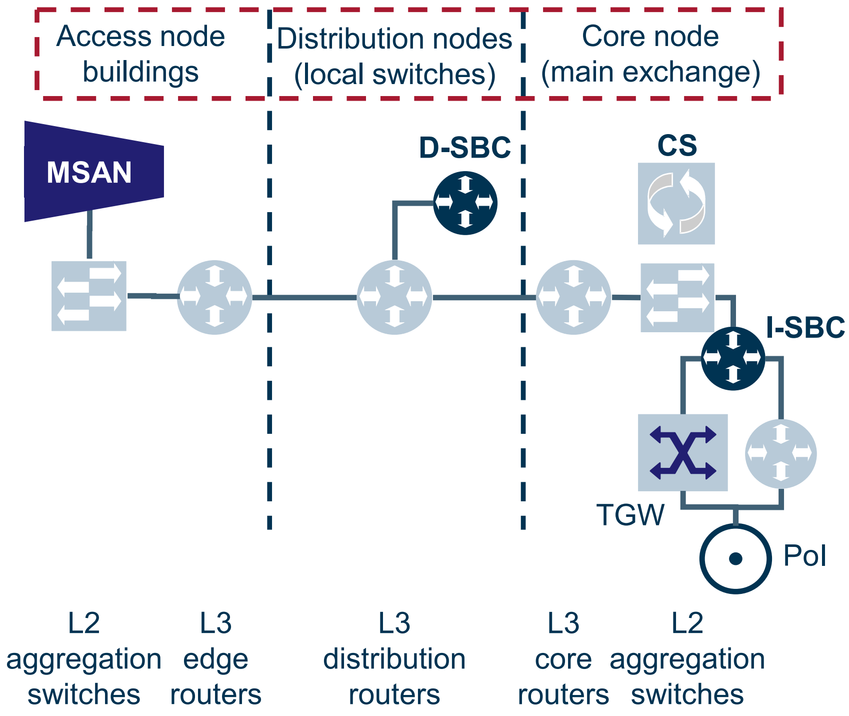


Figure 2.11: Modelled NGN platform [Source: Analysys Mason, 2011]

The long-term evolution of the next-generation core architecture was assumed to be a converged IP-based platform, which aggregates a variety of different access nodes. In the short-to-medium term, this network was assumed to be used in conjunction with exchange-based MSANs providing PSTN services through use of a VoIP server gateway. The transport layer from the MSAN towards the core was based on Ethernet and IP/MPLS switches and routers.

The list of assets modelled in the next-generation core are summarised in Figure 2.12.

Figure 2.12: Assets required for a next-generation core [Source: Analysys Mason, 2011]

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 networks to IP for transit over the next-generation 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 voice network controlled by the call server. It provides security between the different network 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.
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.

An all-IP/Ethernet next-generation core was modelled with no legacy TDM or SDH in the v1.6 model and has been retained thereafter. We revisited the design of the next-generation core for the v2.0F model, as described in Section 4.2, but have not revised the design for the v2.3F model.

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.

Switches and routers could be fitted with optical adapters or with traditional, electrical ports. They were assumed to use the former in the v1.6 model and we have retained this approach thereafter.

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

► *Network nodes*

At the distribution node level, an assessment was made to understand if all distribution nodes would become distribution aggregation nodes, or whether they would be downgraded to access node functionality. For the v1.6 model, it was concluded to be less likely that the core nodes would be rationalised.

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

The functionality of the nodes was largely retained in the v2.0F model, and therefore also the v2.3F model. Sections 4.2 and 4.3 describes how the equipment deployed to fulfil this functionality is currently represented.

2.3.2 Migration between the platforms

This section outlines the treatment of core network technology generations. Nkom sought not only to capture a modern IP-based next-generation core deployment, but also to consider the transition from the TDM network deployment. Two possible approaches were identified to address this in the model: exogenous and endogenous.

Exogenous approach

The exogenous approach consists in applying a glide path to derive the termination rate through logical steps:

- construct a model that could be run in two modes – one for the TDM network and one for a full next-generation core
- the current fixed termination rate (FTR) cost would be based on the forward-looking deployment of the TDM network
- the FTR model for the NGN would be based on a future forward-looking deployment, including phase-in of the next-generation 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 TDM to next-generation platforms.

Figure 2.13 illustrates how the unit cost/demand profiles for both technologies may look.

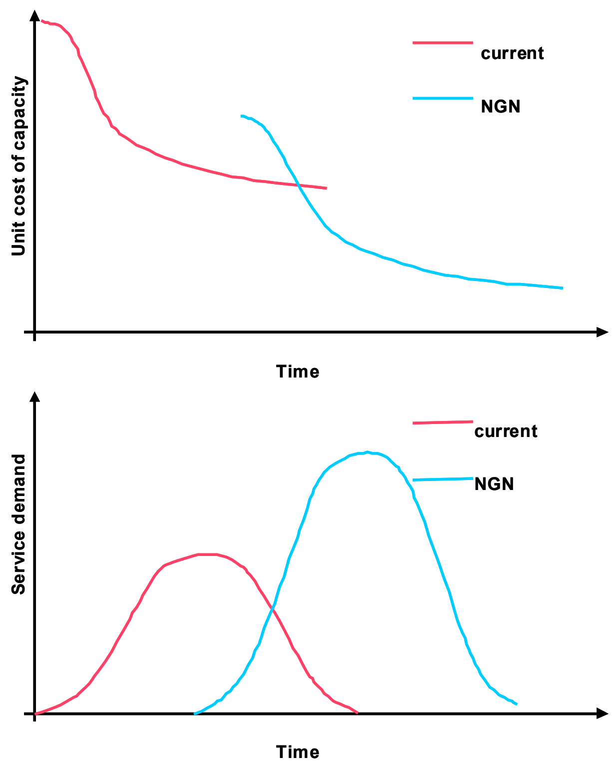


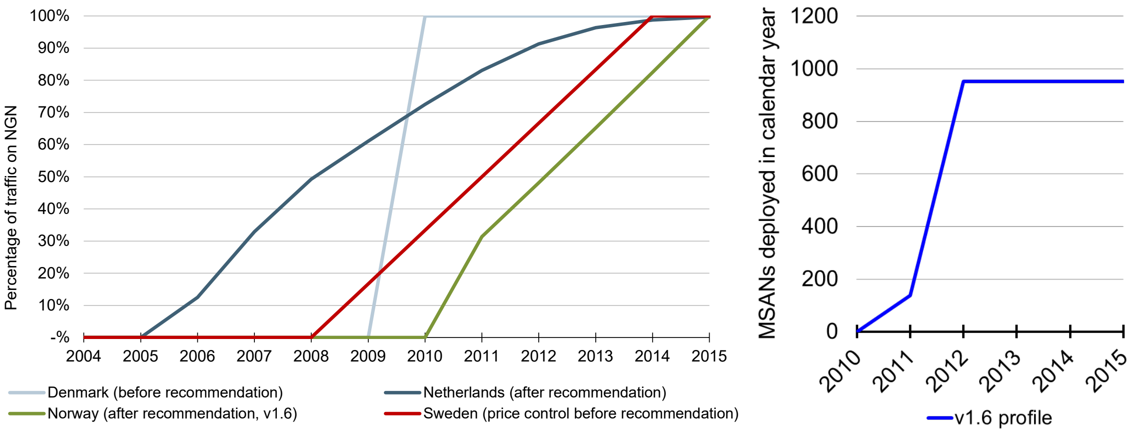
Figure 2.13: Demand and cost proxies for multiple generations [Source: Analysys Mason, 2010]

Endogenous approach

For the endogenous approach, the next-generation core can be phased in directly. In a fixed deployment, migration of the core network on its own can be a much faster process, with only around 100 core and distribution nodes in which to conduct upgrades. It also benefits from end-user services being independent from the transport mechanism.

An exogenous approach was used in the v1.6 model, as determined in the 2010 concept paper. This was based on the fact that an exogenous approach allows users to easily test the cost implications of the rate of migration and allows easier testing of a wide range of scenarios. The v1.6 migration profile is shown in Figure 2.14 below for both traffic (left) and the access nodes upgraded with next-generation core equipment (right).

Figure 2.14: Migration profile for nodes and traffic [Source: Analysys Mason, 2011]



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).

This principle remains unchanged in the v2.3F model, although the migration profile was updated in the v2.0F model. The migration profile to NGN was assumed to be complete by 2017, meaning that the modelled core network from that time forward is a pure NGN. This has not been changed in the v2.3F model.

2.3.3 Transmission network

In addition to assessing an efficient number of core network nodes and the assets within each location, an important part of the network to understand is the trench/cable network linking these locations together. The core transmission assets are described in Figure 2.15 below.

Figure 2.15: Core transmission assets [Source: Analysys Mason, 2010]

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.

Network asset	Asset description
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.

Three methods for defining the core network transmission routes considered were investigated, as shown in Figure 2.16.

Figure 2.16: Comparison of options for understanding core network links and the processing required [Source: Analysys Mason, 2010]

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.

Option 3 was used in the v1.6 model and has been retained thereafter.

Furthermore, in fixed networks, where trenching represents 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 were made on the basis of information from industry parties, Nkom and geographical analysis with MapInfo. This was then fed into the model in order to calculate the length of duct within each of these types.

A parameterised approach was used to accomplish this in a LRIC model, informed by:

- mapping links within each level in the modelled core onto a street network

- approximating access network trench using 'buffer' areas around each access node.

This approach is illustrated below in Figure 2.17. 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.

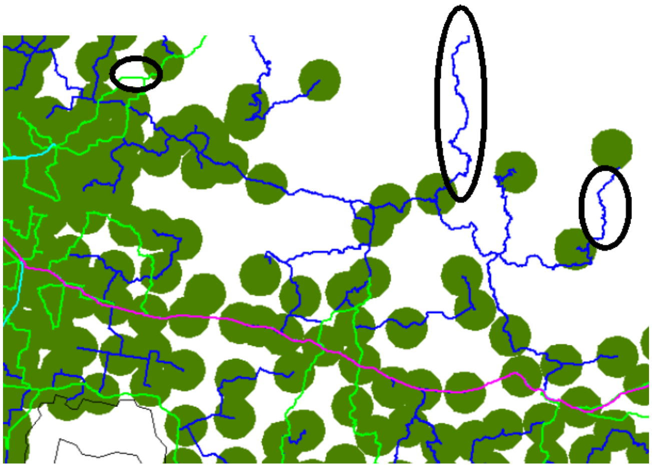


Figure 2.17: Identifying the sharing of routes between the access network and the core network [Source: Analysys Mason, 2010]

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.

The parameters were all derived for the v1.6 model, meaning that it could calculate assuming several different levels of trench sharing. However, the final model assumed no trench sharing i.e. the parameters were not used. This was because the inclusion or exclusion of trench sharing was found to have a very small impact on the LRAIC of termination. The trench-sharing approach has not been revised since.

2.3.4 Input costs

For each of the principles in this section below (related to unit costs, cost trends and asset lifetimes respectively), we have not revised the approach used since.

The operation of a fixed network is characterised by expenditure over time, which can be accounted for as either:

- *Capital expenditure (capex)* is 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 expenditure prevailing at each point in time. We would expect that the capital investment cost of an asset should include the capitalisation of operational expenditure 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.

- *Operational expenditure (opex)* is expensed in the profit and loss account in the year it is incurred, thus not tying up any capital (other than monthly ongoing working capital). Operational expenditure 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, operational expenditure will be defined relating to the operation and maintenance of that asset.

In addition, the modern equivalent asset (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 reflects the MEA trend of capital and operational expenditures, assessed in real terms to remove the underlying effects of inflation.

Principle [46]: Cost trends will be defined for capital and operational expenditures. Consideration of the cost-trends with and without inflation will be made.

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 were 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.

2.4 Service-related conceptual issues

The conceptual issues considered in this section are shown in Figure 2.18.

Figure 2.18: Principles of service-related conceptual issues [Source: Analysys Mason, 2010]

Principle	Summary from the final concept paper
[9] ISDN traffic	ISDN voice traffic is not modelled separately.
[10] Leased lines and transmission services	Reasonably identified services are captured.
[11] Next generation-specific core services definitions	Same definitions are used as with the current network.
[12] Voice termination fee structure	Same fee structure will be used.
[13] NGN-interconnect products definition	Based on connections of 10Mbit/s, 100Mbit/s and 1Gbit/s Ethernet.

Principle	Summary from the final concept paper
[34] PoI in the NGN	The number is assumed to remain the same as current levels.

The principal requirement of the model is to understand the costs of services related to the fixed voice markets.

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, result in a lower unit cost for voice and data services. This is particularly true for networks built on NGN architecture, where voice and data services are delivered via a single platform. As a result, a full list of services was included within the v1.6 model, since a proportion of network costs needed to be allocated to these services.

Current core services

The modelled voice services are listed in Figure 2.19 below.

Figure 2.19: Voice services [Source: Analysys Mason, 2010]

Service	Description
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.

Service	Description
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.

The consultation of the 2010[9] concept paper concluded to model PSTN and ISDN voice traffic together, rather than as separate voice services. This approach has been retained thereafter.

Principle [9]: Traffic generated by ISDN lines is included in the above voice services i.e. there are no specific ISDN voice services.

The services relating to Internet access included in the model are listed in Figure 2.20. These services are included to capture backhaul requirements from the local exchange towards the core network. In the development of the vAcc2.2 model in 2018, a generic bitstream service was added in order to determine the associated costs of such a service.

Figure 2.20: Internet access services [Source: Analysys Mason, 2010]

Service	Description
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.

In addition, a number of 'other' services, shown in Figure 2.21 below, have been identified as relevant for the core model.

Figure 2.21: Other services [Source: Analysys Mason, 2010]

Service	Description
Leased lines	Includes leased-line services provisioned for either retail customers, other operators, or internal use. These were modelled as analogue leased lines, low-capacity digital leased lines (<=8Mbit/s), high-capacity digital leased lines (>8Mbit/s) and fibre (dark or wavelength).
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 and mobile networks, etc.). This excludes the leased-line services defined above. These were modelled as analogue leased lines, low-capacity digital leased lines (<=8Mbit/s), high-capacity digital leased lines (>8Mbit/s) and fibre (dark or wavelength).

9 See https://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess/_attachment/1805?_download=true%26_ts=139100f7b30

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

This principle has been retained thereafter.

NG core services

The core services in the v1.6 model NGN were based on existing services. The services described above would still be available within a next-generation 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 subscriber) may change
- 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.

This principle has been retained thereafter.

Wholesale products

It is assumed that wholesale voice interconnection products can be charged using 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. This approach has been retained in the v2.3F model.

The move to NGN will lead to 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. Charging mechanisms were structured as in the current network. This approach has been retained thereafter.

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

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. A next-generation core would likely move towards fewer, large core switching nodes. Fewer nodes does not necessarily mean fewer PoIs, 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.

At the time of the original model development, there were 14 PoIs in 13 locations in Norway. It was understood in 2010 that this number was unlikely to change in Norway, particularly as these locations have already undergone a phase of rationalisation in recent years.

However, the actual number of PoI locations in Norway was consolidated to 2 in 2012, which we reflected in the NGN in the v2.0F model. The principle was revised during the development of the v2.0F model to its current form below and has been retained thereafter.

Principle [34]: The number of PoI locations assumed in the modelled NGN will be 2. Alternative values may be considered as sensitivities to the model.

2.5 Implementation-related conceptual issues

The conceptual issues revisited in this section are shown in Figure 2.22.

Figure 2.22: Principles of implementation-related related conceptual issues [Source: Analysys Mason, 2010]

Principles	Summary from the final concept paper
[1] Definition of increments	Separate increments are defined for a pure LRIC approach and a LRAIC approach.
[3] Treatment of common costs	Use equi-proportionate mark-up (EPMU) where required
[4] WACC	The WACC will be defined by an external consultant.
[48] Economic depreciation calculation	Economic depreciation is used.
[49] Modelling period	The period from 1991 to 2050 is modelled.

2.5.1 Increments

We defined separate increments for the core network, to cost the relevant wholesale fixed voice services. In assessing an incumbent operator's cost base, separate increments led to the identification of costs common to both increments, as illustrated in Figure 2.23.

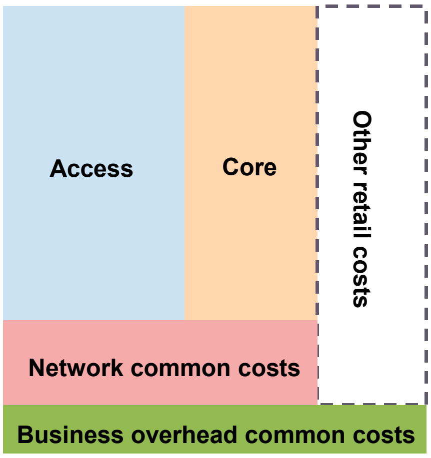


Figure 2.23: Access and core increments and common costs [Source: Analysys Mason, 2010]

In the TDM network, the definition of the border between access and core networks is between the equipment side of the main distribution frame and the PSTN concentrator. 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 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 wholesale fixed voice markets

The European Commission Recommendation of 2009[10] ("EC Recommendation") states that the relevant increment 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 this market 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 excluded non-traffic-related costs, which may correspond with any identified fixed costs attributable to the increment, as illustrated below. Supporting these two increments was 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 wholesale fixed voice termination could mean that common costs need to be recovered over a subset of services. For this subset of services, including wholesale fixed voice origination, this could lead to results that are above long-run average incremental costs (LRAIC). The model was able to accommodate this eventuality, by using LRAIC^+ and adjusted LRAIC+ methodologies. These are described in Section 5.

An alternative approach is to define the increment as all traffic conveyed across 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 below. Such an approach would allow for reconciliation of the costs produced by the top-down model and is consistent with previous LRAIC approaches.

10 European Commission C(2009) 3359 final COMMISSION RECOMMENDATION of 7.5.2009 on the Regulatory Treatment of Fixed and Mobile Termination Rates in the EU.
See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:124:0067:0074:EN:PDF.

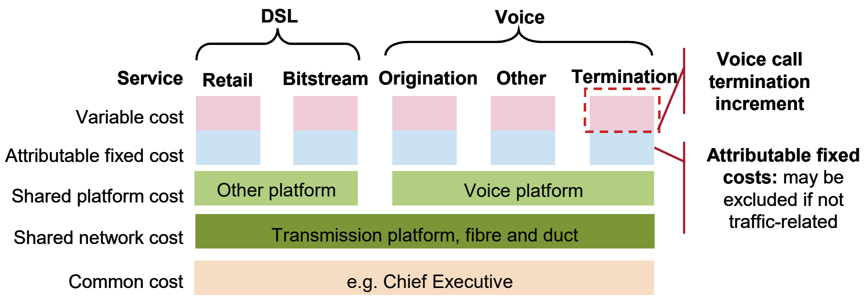


Figure 2.24: Illustration of voice call termination increment [Source: Analysys Mason, 2010]

Therefore, two increments were modelled.

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 wholesale fixed voice termination service, as implied in the EC Recommendation. The LRAIC approach is applicable to all fixed voice services.

No changes have been required to this principle since its original drafting, since it remains consistent with both the EC Recommendation and the ESA Recommendation.

2.5.2 Mark-up

As highlighted previously, the calculation of incremental costs for a fixed operator identified 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 Nkom) common costs may be allocated to the increments. Where rational allocations cannot be made on cost-causality principles, then mark-ups are required.

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 and results in uniform treatment of all service costs in the business.

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

This approach has been retained thereafter.

2.5.3 WACC

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.

The model included WACC as a parameter. The value of the WACC to use for the fixed access and fixed core networks was determined by the external adviser appointed by Nkom.

Principle [4]: A WACC was used in the model in order to provide a return on investment. The approach to defining the WACC was determined by an adviser.

This approach has been retained thereafter.

2.5.4 Depreciation

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
- gross book value (GBV): the total of all capital investments made in the business, less the investments made in assets which have been replaced or retired
- gross replacement cost (GRC): the total capital expenditure which would be required to replace the entire network asset base today
- net book value (NBV): the GBV less accumulated depreciation on assets.

The efficiently incurred expenditure in a fixed business must be recovered over time and any tied-up capital (i.e. expenditure not recovered in the year it is incurred) must earn a normal return on investment. The method by which the expenditure is 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 operational expenditures and uses different calculation methods to produce the annualised cost in current and future years. Economic depreciation is the recommended approach for regulatory costing. The table below shows that only economic depreciation properly considers all potentially relevant depreciation factors.[11]

Figure 2.25: Factors considered by each depreciation method [Source: Analysys Mason, 2010]

	HCA	CCA	Tilted annuity	Economic
Modern-equivalent asset (MEA) cost today		✓	✓	✓
Forecast MEA cost			✓	✓
Output of network over time				✓
Financial asset lifetime	✓	✓	✓	✓[12]
Economic asset lifetime			✓	✓

Economic depreciation was the default method used in the v1.6 model and has not been revised thereafter. This remains consistent with both the EC Recommendation and the ESA Recommendation.

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

2.5.5 Years of results

Due to the implementation of an economic depreciation calculation in the v1.6 model of core networks, the period modelled was 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).

The forward-looking period required forecasts of service demand to be developed. In addition, price trends were projected for the period of examination.

Principle [49]: For the purposes of an economic depreciation calculation for the core network model, the model will cover the period 1991 to 2050.

We have retained this approach thereafter.

11 As shown, tilted annuities cannot capture changes in network output over time. An adjustment term can be included in the tilted annuity formula that can approximate the impact of small changes in network output over time, but only economic depreciation can capture the impacts of significant changes in network output over time on cost recovery.

12 Economic depreciation can use financial asset lifetimes, although strictly it should use economic lifetimes (which may be shorter, longer or equal to financial lifetimes).

3 Demand forecasting

Since the development of the Nkom v2.0F model, certain new trends and technologies have emerged in the fixed market, which have required a reassessment of the modelling of the demand forecasts. Although the calculations have remained more or less unchanged, several of the demand parameters have been revised.

Data received from Nkom, operators and from publicly available data sets have been used to update demand parameters in the Nkom v2.3F model:

- Section 3.1 details the updates made to historical demand parameters
- Section 3.2 discusses the changes made to forecast demand parameters.

3.1 Updates of historical demand parameters

Historical demand updates for the years 2013–17 were provided both in the Nkom market data and by Telenor in response to data requests. These have been used in the update of historical demand parameters undertaken for the Nkom v2.0F model and retained in the Nkom v2.3F model.

As in the v2.0F model, the demand volumes for the incumbent scale operator in the v2.3F model are assumed to be based on either Telenor's own data (stored on the *CONF_TN* worksheet, which is internal to Nkom) or using data available from public sources (stored on the *PUBLIC_TN* worksheet, which is published in the v2.3F model). The default selection for consultation is to use the data on the *PUBLIC_TN* worksheet.

The model worksheets that contain all the relevant market data (*A2_Market demand*, *CONF_TN* and *PUBLIC_TN*) have been updated for the Nkom v2.3F model in order to align demand inputs with the Nkom market data.

The sources used to update the Nkom v2.0F model are shown below. URLs for online sources are provided in Annex B.

Figure 3.1: Overview of sources used to update the Market module [Source: Analysys Mason, 2019]

Source	Input updated
Confidential Telenor data	Telenor traffic and subscribers for 2013–17 on the *CONF_TN* worksheet (these values are not included in the public release of the v2.3F model).
Statistisk sentralbyrå (http://www.ssb.no)	Population in 2013–17, population forecast for 2018–50, households in 2013–17, establishments in 2009–17.
Nkom's public Ekomstatistikken database	Fixed telephony subscriptions, fixed broadband subscriptions, fixed telephony and dial-up traffic, VoIP telephony traffic, traffic from fixed and mobile networks.
Telenor's analytical tool	Telenor voice subscribers, Telenor broadband subscribers

Source	Input updated
Nkom's v8F LRIC model of mobile networks	Mobile penetration rate, mobile-terminated minutes.
Market data provided by Nkom[13]	Leased lines, data transmission services.

3.2 Updates of forecast demand parameters

The population year-end historical data and forecasts have been updated for the years 2018–50 using data from Statistisk Sentralbyrå (SSB).[14]

The changes made to the 2013–17 parameters in the Nkom v2.3F model discussed in Section 3.1 have resulted in revisions being made to some of the long-term demand forecasts.

The most significant of the updated forecasts in the Nkom v2.3F model are described in more detail below (using the PUBLIC_TN information), namely:

- macroeconomic indicators in Section 3.2.1
- fixed voice connections in Section 3.2.2
- fixed broadband connections in Section 3.2.3
- originated and terminated voice in Section 3.2.4
- business connectivity services in Section 3.2.5
- business connectivity throughput in Section 3.2.6.

3.2.1 Macroeconomic indicators

The population year-end historical data for 2013–17 was updated as well as the forecasts with low-, medium- and high-growth levels for the period 2018–50. However, we have also kept the population forecast used in the vAcc2.2 model (this was released as part of Nkom's access modelling work) for reference. The medium-growth forecast is used in the v2.3F model. A comparison of this forecast with that used in the v2.0F model is shown in Figure 3.2.

13 This is the data that Nkom collates from operators and aggregates to write its regular reports on the Norwegian market for electronic communications services.

14 See http://www.ssb.no/befolkning/.

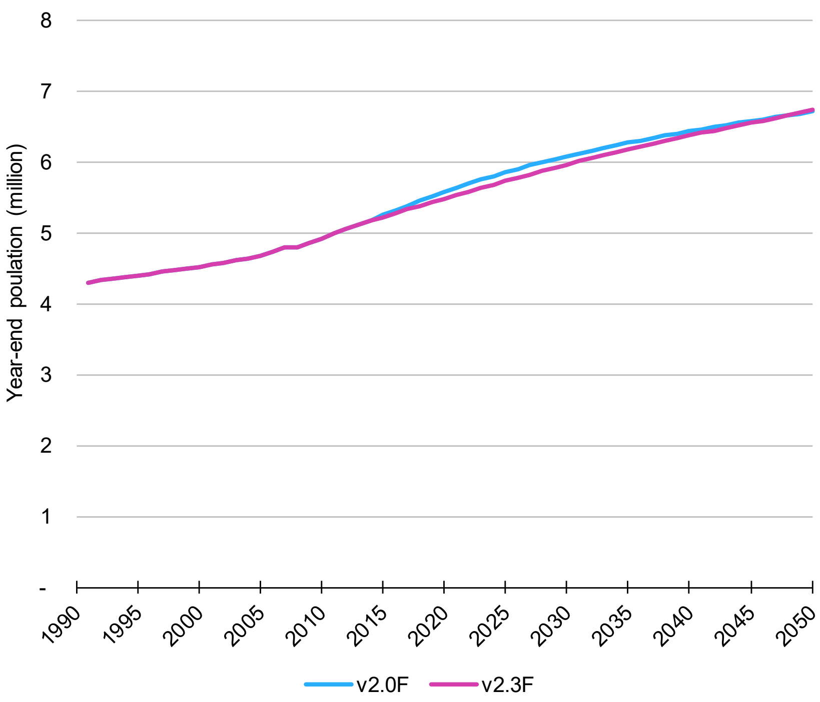


Figure 3.2: Population, historical and forecast, in the Nkom v2.0F and v2.3F models [Source: Analysys Mason, 2019]

The historical values for households were updated for the period 2013–16. The time series assumed in the v2.0F and v2.3F models are represented in Figure 3.3 below.

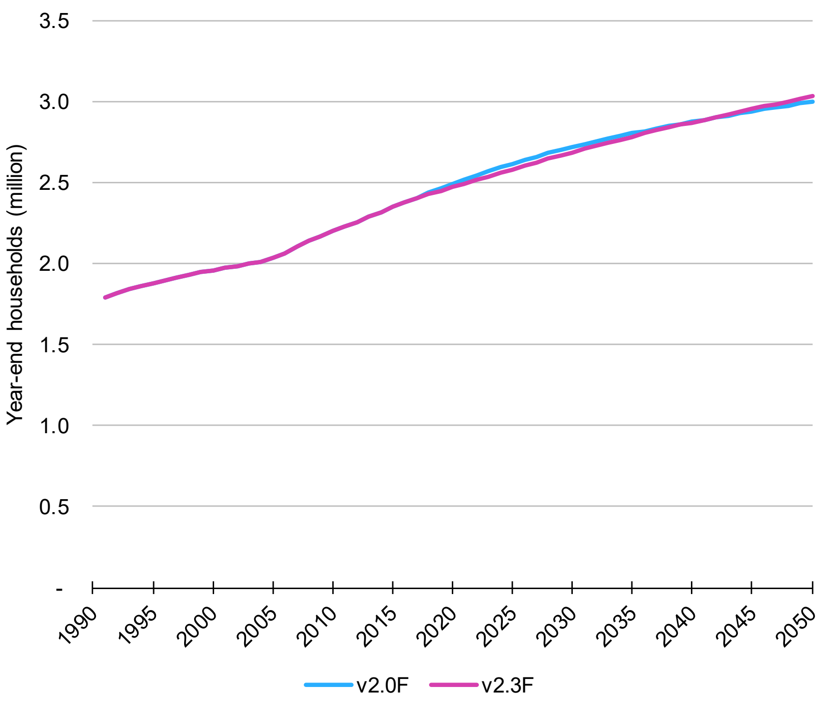


Figure 3.3: Households, historical and forecast, in the Nkom v2.0F and v2.3F models [Source: Analysys Mason, 2019]

Historical values for establishments (i.e. business sites) were updated for the period 2009–17. Figure 3.4 below shows the forecasts used in the v2.0F and v2.3F models.

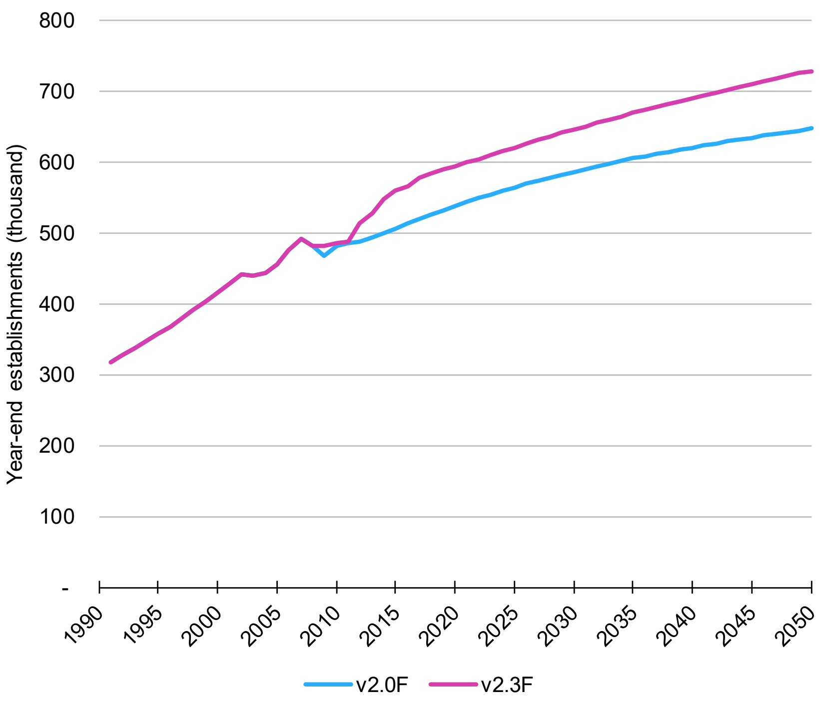


Figure 3.4: Establishments, historical and forecast, in the Nkom v2.0F and v2.3F models [Source: Analysys Mason, 2019]

3.2.2 Fixed voice connections

Business and residential voice connections have decreased more than was forecast in the v2.0F model (see Figure 3.5 below). Therefore, in the v2.3F model we reduced the number of fixed voice connections accordingly, but still assumed a stable level of connections in the long term, as was the case in the v2.0F model. On the basis of operator forecasts of fixed voice subscribers sent to Nkom, we have now modified the v2.3F model so that voice connections continue to decline in the future, as shown in Figure 3.6 below. To do this, we have reduced the average number of fixed voice connections per household and per business site that are forecast in the long term

Figure 3.5: Market-level fixed voice connections [Source: v2.0F model, Analysys Mason, 2014]

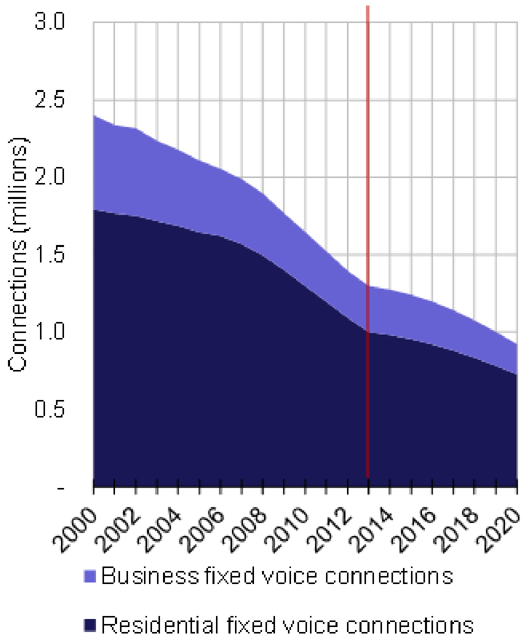
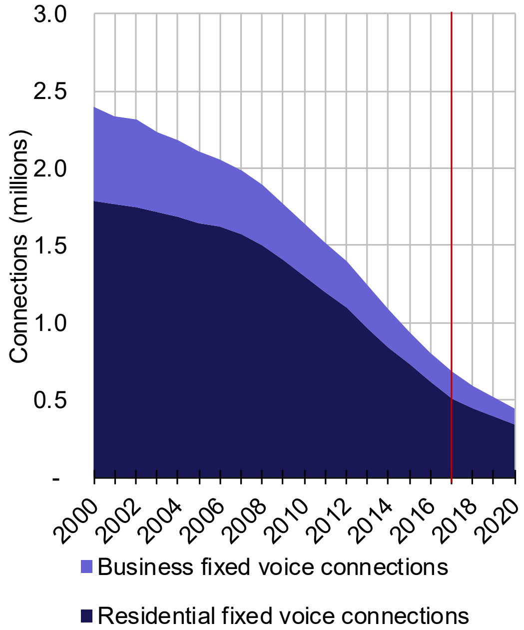


Figure 3.6: Market-level fixed voice connections [Source: v2.3F model, Analysys Mason, 2019]



Analysys Mason Research's own forecasts of fixed voice connections also assume a continued year-on-year decline after 2017.

In addition, we have separately modified the forecast fixed voice traffic, as described in Section 3.2.4 below.

3.2.3 Fixed broadband connections

We have slightly modified the forecast for fixed broadband connections by adjusting the saturation of fibre connections.

Figure 3.7: Fixed broadband connections [Source: v2.0F model, Analysys Mason, 2014]

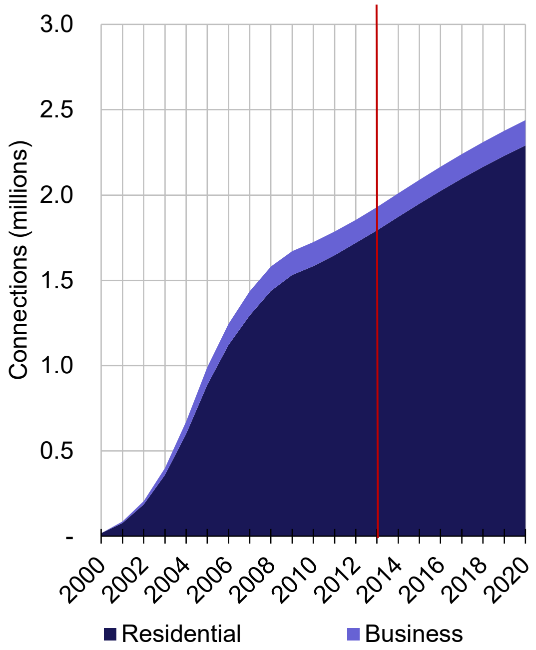
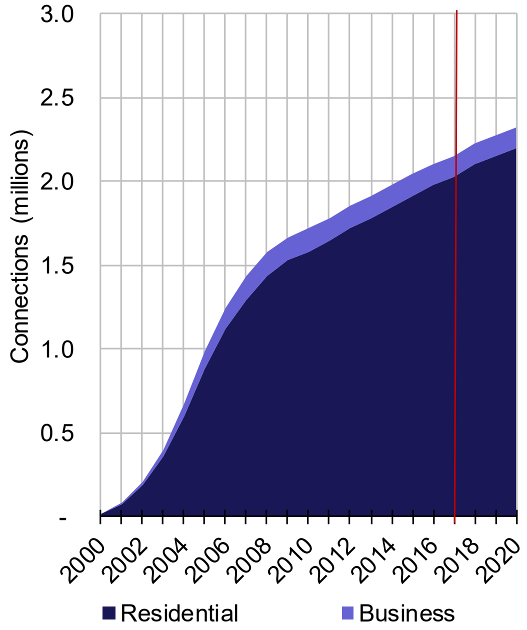


Figure 3.8: Fixed broadband connections [Source: v2.3F model, Analysys Mason, 2019]



3.2.4 Originated and terminated voice

In the v2.3F model, we have revised the forecast parameters for voice traffic, in order to reflect a future decline in fixed voice traffic that is consistent with a fall in voice connections. Comparisons of the forecasts for both types of voice traffic in the v2.0F and v2.3F models are shown overleaf. In the v2.3F model, we have increased the proportion of originated voice that is assumed to be originated on mobile networks (thereby reducing fixed voice origination), and also reduced the proportion of mobile-originated traffic that is assumed to be terminated on fixed networks (thereby reducing fixed voice termination).

We expect the absolute level of mobile voice traffic observed to continue to rise as a result of continued population growth that is forecast in the v8F mobile LRIC model.

Figure 3.9: Originated voice traffic [Source: v2.0F model, Analysys Mason, 2014]

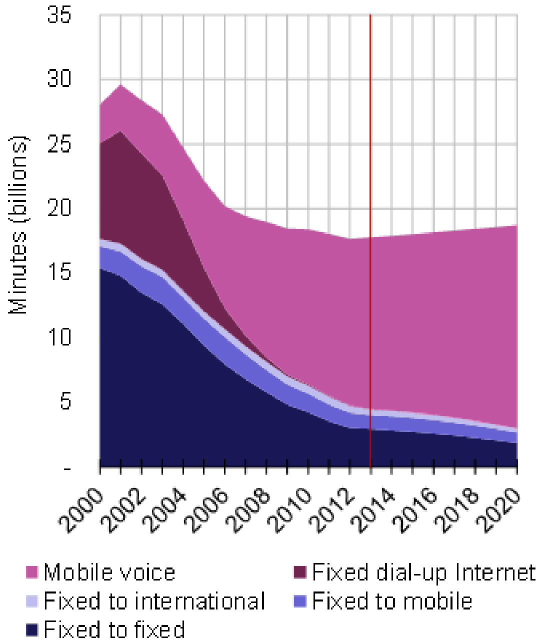


Figure 3.10: Originated voice traffic [Source: v2.3F model, Analysys Mason, 2019]

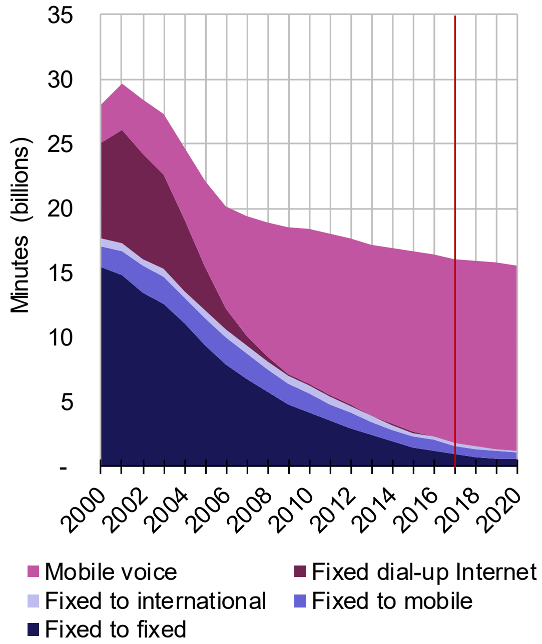


Figure 3.11: Terminated voice traffic [Source: v2.0F model, Analysys Mason, 2014]

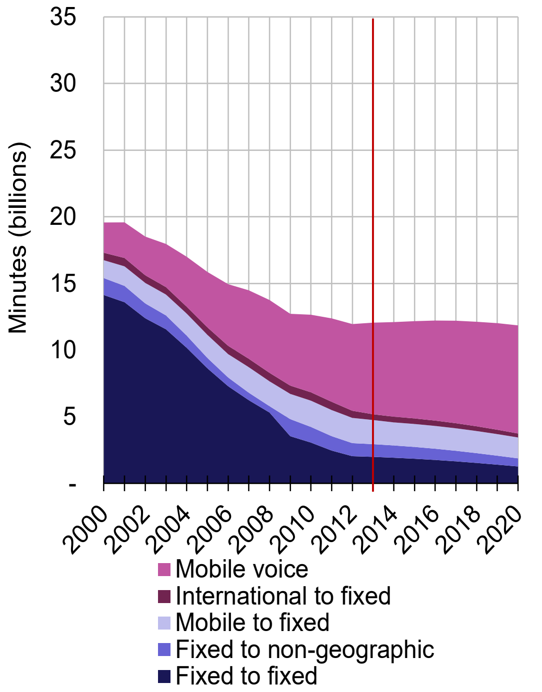
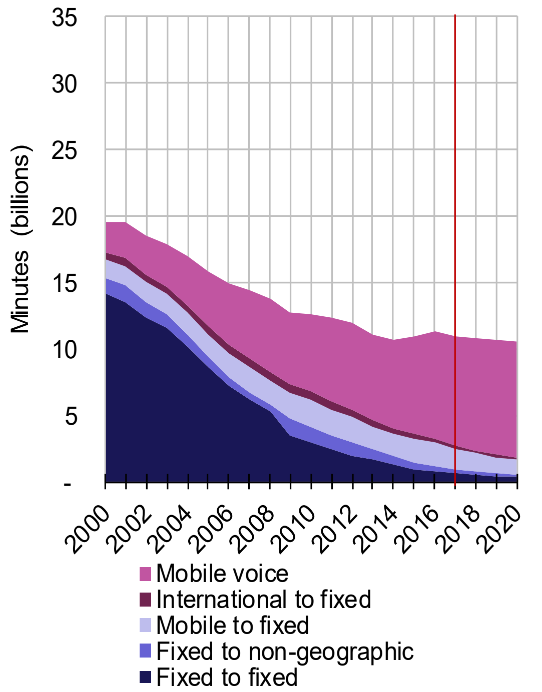


Figure 3.12: Terminated voice traffic [Source: v2.3F model, Analysys Mason, 2019]



3.2.5 Business connectivity services

We have not revised the forecast parameters of business connectivity services. The difference between the forecasts in the v2.0F and v2.3F models is a result of updating the historical data points for 2009–17. Business broadband connections are now assumed to remain flat in the long term.

Figure 3.13: Business connectivity [Source: v2.0F model, Analysys Mason, 2014]

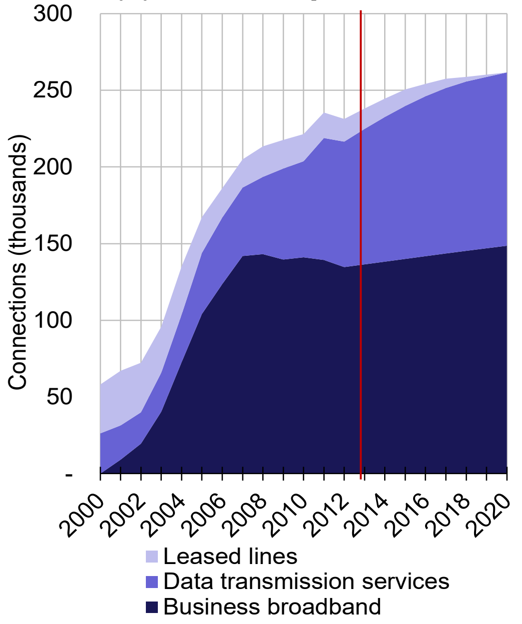
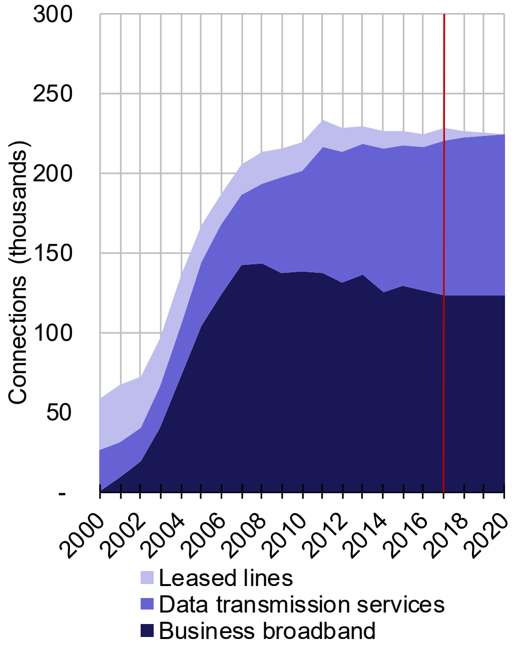


Figure 3.14: Business connectivity [Source: v2.3F model, Analysys Mason, 2019]



3.2.6 Business connectivity throughput

We have increased the assumed saturation points for the average required IP throughput of the "IP-VPNs based on fixed assets or closed networks" category, as well as those for the "Ethernet VPN and others" category.

Figure 3.15: Business connectivity throughput [Source: v2.0F model, Analysys Mason, 2014]

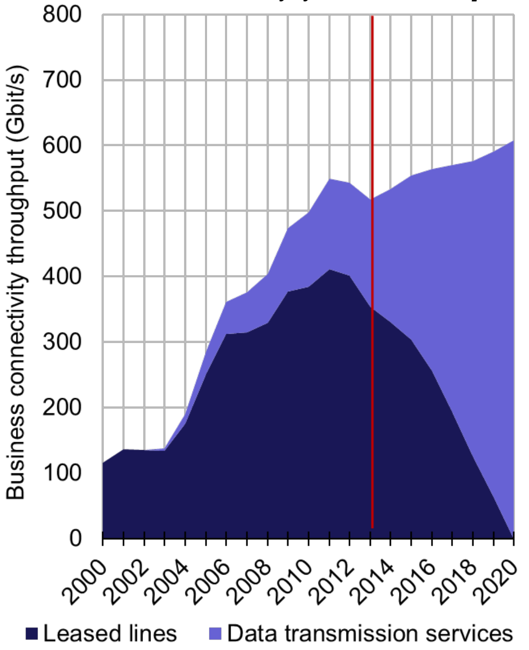
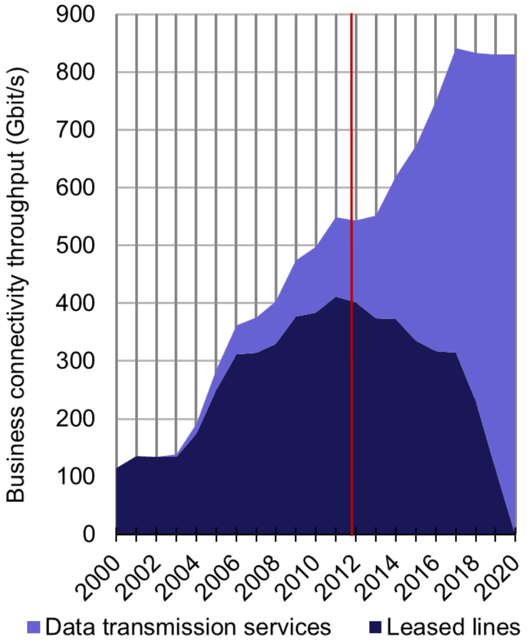


Figure 3.16: Business connectivity throughput [Source: v2.3F model, Analysys Mason, 2019]



4 Fixed core network design

In this section, we discuss the revisions to the network design in Nkom's fixed core LRIC model when developing the v2.0D and v2.0F models, based on the data received from industry parties in 2013. The TDM network design was unchanged, i.e. only the NGN design was restructured.

No aspects of the network design calculation have been revised when developing the v2.3F model; only demand-related forecasts have been changed. This section is set out as follows:

- Section 4.1 outlines the existing NGN design in the v1.6 model
- Section 4.2 provides the NGN design in the current version of the model
- Section 4.3 describes the new NGN calculations
- Section 4.4 describes the approaches applied to provisioning spare capacity in the network
- Section 4.5 describes the implementation of a migration profile for voice traffic from SS7 to SIP interconnect.

4.1 Outline of original NGN design

Figure 4.1 below outlines the NGN design in the v1.6 model, as published on Nkom's website[15] (originally constructed in 2009–11).

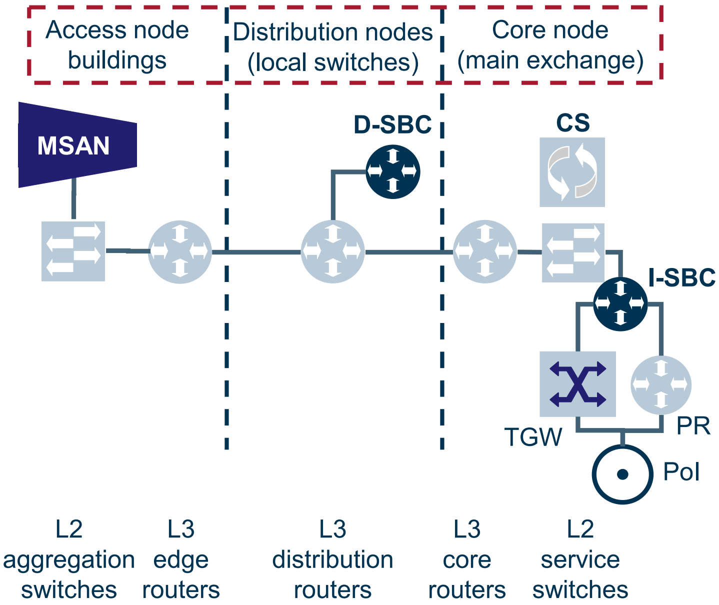


Figure 4.1: Overview of next-generation network design in the v1.6 LRIC model [Source: Analysys Mason, 2011]

The key features of this network design were as follows:

- in the 4000 access nodes, the RSXs (and installed DSLAMs) were replaced by MSAN units (there is also a mini-MSAN option) according to a single migration profile ending in 2015

15 See http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-kjerne/_attachment/1810?_download=true&_ts=13910119007.

- MSAN line cards are assumed to be allocated to subscriber increments, not voice services
- session border controllers (SBCs) were deployed at two levels of the network
  - 80 distribution SBCs (D-SBC) that face the access network
  - 13 interconnection SBCs (I-SBC) that face the networks of the interconnecting operators
- trunk gateways (TGWs) were deployed for SS7 interconnection
- peering routers (PRs) were deployed for SIP interconnection
- next-generation call servers (CSs) were also deployed.

All of these assets above have the chassis and port card components modelled separately. There are other assets that were common to both the TDM network and the NGN. These included:

- wireless transmission links
- access (CWDM) transmission equipment
- distribution (CWDM) transmission equipment
- core (DWDM) transmission equipment.

Separate assets were also defined for the components of "site rentals", "air conditioning unit" and "UPS and Generator" that were ascribed to the NGN. They were suffixed with "– Other".

4.2 Our updated NGN design

We separate this chapter into discussions related specifically to the VoIP platform and the remaining core network infrastructure.

The new NGN design was implemented in the v2.0F model and has not been updated for the purposes of the v2.3F model.

VoIP platform

We deploy a single NGN voice platform for both residential and business customers. The diversity of the different types of offered services for the two platforms can be recognised through the MTAS, with the MTAS communicating with a single IMS core, as shown below.

We have refined the Call Server (CS) asset already encoded within the model to better reflect the various components (DNS, ENUM, HSS, CSCF and MGC). In particular, these separate out fixed costs, per-subscriber costs and per-traffic-minute cost components as appropriate. We have also deployed a Provider Edge (PE) router at each core node location to route voice traffic.

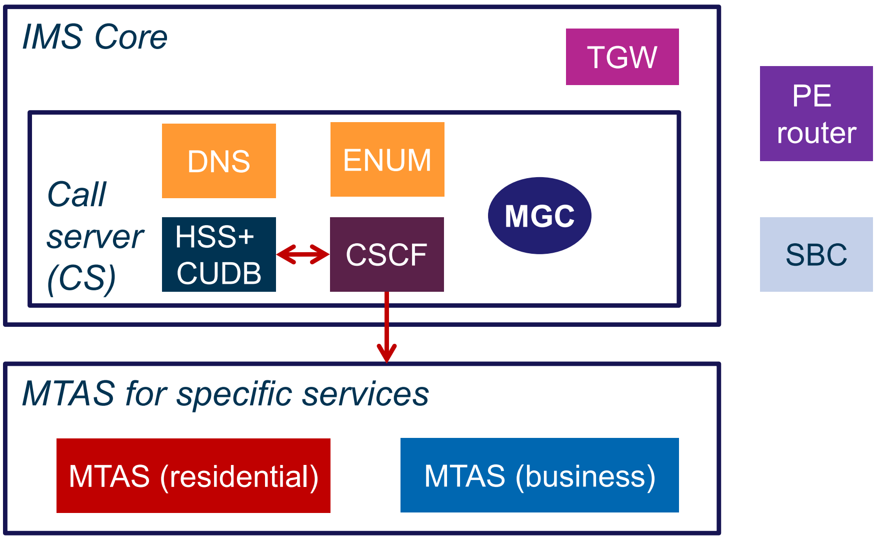


Figure 4.2: Consolidated VoIP platform [Source: Analysys Mason, 2014]

With regard to the SBCs, we now assume that there are only six D-SBC locations in the network (this is the "SBCs where DR co-located with CR" option that was included as an option in the v1.6 model). We have reviewed new data received during the update, in line with a suggestion from the Ministry regarding the previous decision to review this aspect of the network design when new data became available[16]. Furthermore, we now assume that there are only two I-SBC locations deployed in the NGN (from 2013 onwards), rather than thirteen as assumed in the v1.6 model. This is because, since mid-2012, Telenor has primarily used a single interconnect area arrangement with two PoI locations.

Finally, we have included voice-dedicated "PE routers" at each core node to handle voice traffic.

Remaining core network infrastructure

An overview of our revised NGN design is shown below in Figure 4.3. This is similar to the v1.6 model, except that:

- We assume that the existing RSXs are ultimately removed, with POTS being provided by either (a) replacing existing DSLAMs with new units (NGN DSLAMs) that are capable of handling POTS line cards, or (b) where no DSLAM is deployed alongside the RSX, in most cases[17] we replace the RSX with a mini-NGN DSLAM capable of handling POTS line cards.

- We have redefined the core routers to be IP/MPLS routers.

16 See section 3.4 of the Ministry's response to the "Appeal of Post and Telecommunications Authority's decision August 2011 in markets 2 and 3", available at http://www.nkom.no/marked/markedsregulering-smp/marked/marked-2-og-3/_attachment/1083?_ts=13847ad1120.

17 In the v2.3F model, for 10% of locations where there is an RSX and no DSLAM, no NGN DSLAM is deployed. Instead, we assume these areas will be served by other architectures (e.g. hybrid-fibre coax) in the long term.

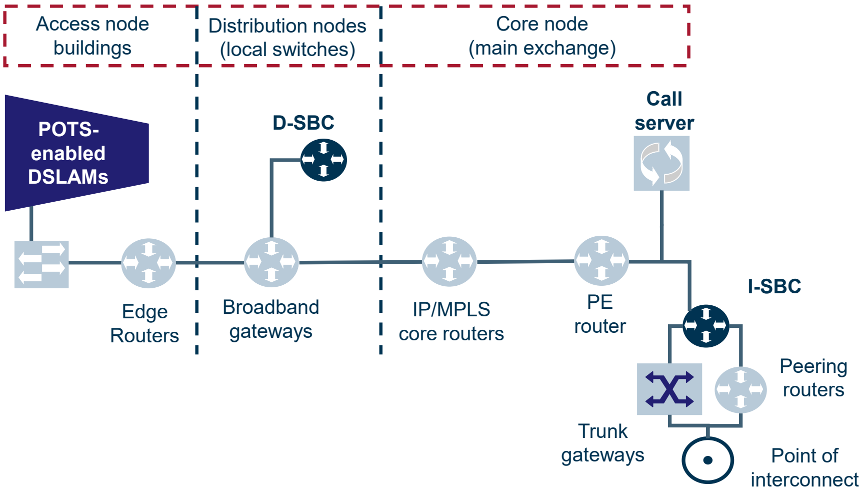


Figure 4.3: Overview of updated NGN design [Source: Analysys Mason, 2014]

Faster options for transmission speeds were implemented in the model where appropriate. For example, the core network transmission uses 40Gbit/s rather than 10Gbit/s as was the case in the v1.6 model. In addition, distribution transmission now uses DWDM technology, rather than CWDM as was the case in the v1.6 model.

The migration profile for the replacement of RSXs and DSLAMs with NGN DSLAMs was revised during the finalisation of the v2.0F model and has not been revisited for the v2.3F model. The migration was assumed to be complete as of 2017.

4.3 Current NGN design calculations

This section describes the network asset calculations currently implemented in the model. In particular, the key assets that we dimension are NGN DSLAMs and voice-dedicated PE routers, as set out below. In addition, we have dimensioned software upgrades for SBCs and call servers. This is also set out below.

NGN DSLAMs

NGN DSLAMs are dimensioned in the Network Design module on the *A6_NwDes* worksheet. The calculations are similar in structure to those dimensioning MSANs with the added inclusion of an input based on the proportion of access nodes migrated to the NGN DSLAM architecture and dimensioning including the number of fibre ports.[18] This can be seen in Figure 4.4 below.

[18] Telephony-related line cards in the NGN DSLAMs are allocated to the subscriber increment rather than voice traffic.

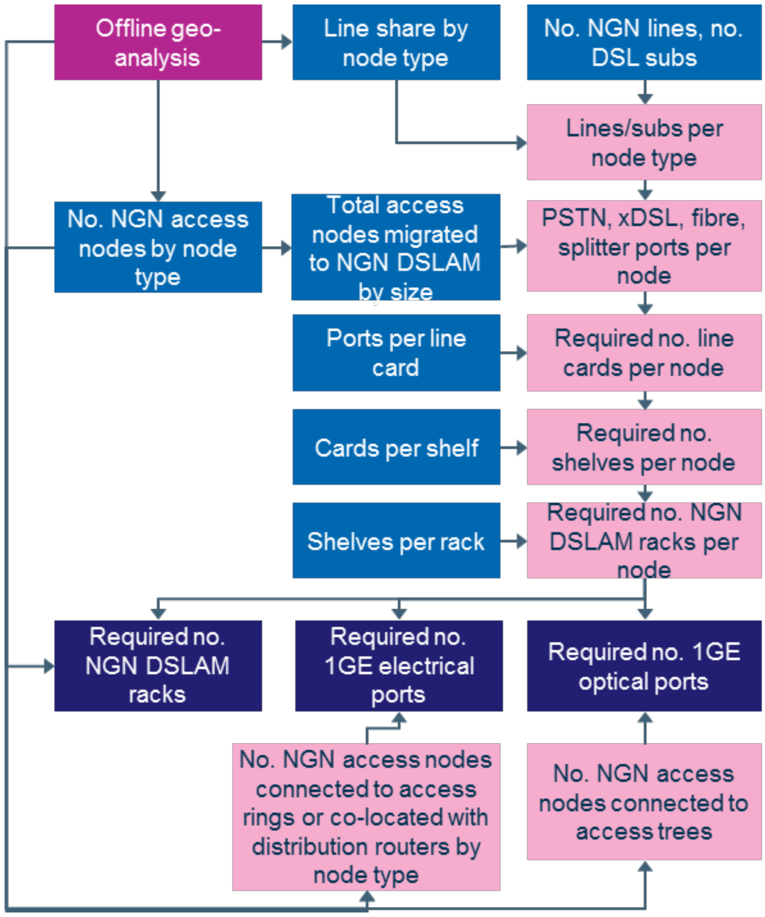


Figure 4.4: NGN DSLAM calculation flow [Source: Analysys Mason, 2014]

Provider Edge (PE) routers for voice traffic

The voice-dedicated PE routers are dimensioned in the Network Design module on the *A6_NwDes* worksheet. The calculations are similar in structure to those dimensioning other router assets as seen in Figure 4.5 below.

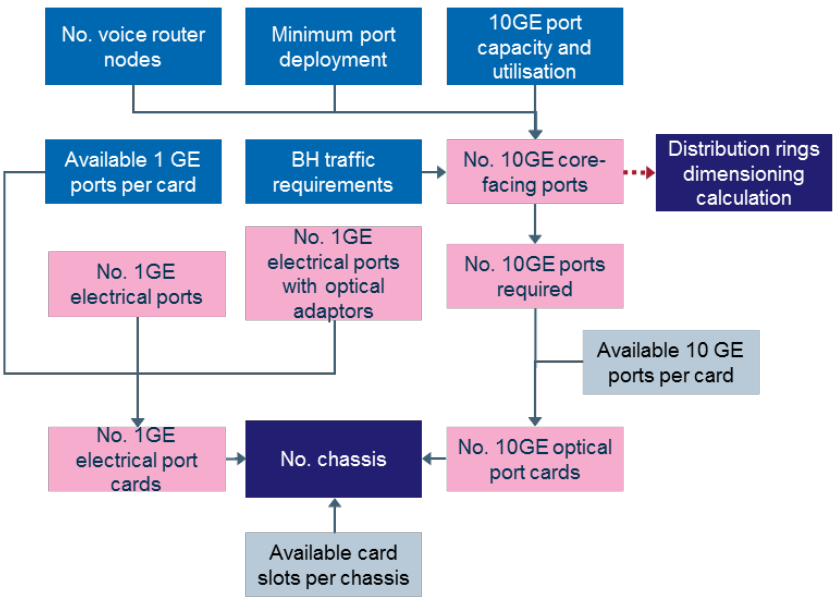


Figure 4.5: Voice-dedicated PE router calculation flow [Source: Analysys Mason, 2014]

Software upgrades

We have refined the dimensioning of the software components for session border controllers (SBCs) and the call server (CS).

The structure of the dimensioning of hardware remains the same as it was in the v1.6 model. Software is however separately dimensioned based on the number of subscribers or volume of traffic in appropriately sized quantities. For example, another SBC software licence is purchased for every 25 000 additional subscribers, or part thereof. The CS software is dimensioned similarly, except that two separate software licence assets are dimensioned, one driven by subscribers and the other driven by traffic volumes.

4.4 Provisioning of spare capacity

The network design deploys minimum levels of equipment (e.g. at least one line card per RSX shelf, at least one shelf per RSX rack, etc.) by using the ROUNDUP() function. Some assets (e.g. the call server) have an input specified on the *A2b_NwDesIn* worksheet that requires a certain minimum deployment of that asset for resilience purposes.

Several utilisation factors are defined on the *A2b_NwDesIn* worksheet of the Network Design module, which lead to spare capacity being deployed (i.e. assets are assumed to operate at a certain level of utilisation).

In particular, there is also a "Monte Carlo" distribution factor with value 0.5 on this worksheet that is used in the line card and shelf dimensioning calculations on the *A6_NwDes* worksheet. For example, when we calculate the xDSL line card requirements per RSX by calculating the ratio of xDSL ports divided by the number of ports per line card, we add 0.5 to this ratio to dimension slightly more line cards than would otherwise be needed.

When demand throughput for an asset falls, it could be interpreted as triggering an eventual decrease in the number of capacity-driven assets in the modelled network (coverage-driven assets should not be affected by reductions in demand). The model allows a period of delay to be included between the point at which the demand reduction occurs, and the point at which the asset is retired. This delay can take the values of 0, 1, 2 or 100 years, whereby:

- 0 implies that assets are retired directly in the year that demand reduction occurs
- 1 implies that retirement lags behind demand reduction by 1 year
- 2 implies that retirement lags behind demand reduction by 2 years
- 100 implies that assets not reduced until the shutdown of the network occurs.

This "Retirement delay" functionality is defined by asset on the *A7_AssetIn* worksheet of the Network Design module.

4.5 Migration from SS7 to SIP interconnect

Since the model of fixed core networks was first developed in 2009, the option to assume some/all voice is carried via Session Initiation Protocol (SIP), rather than SS7 protocol has been included. In all previous versions of the model, use of SS7 was assumed in the long-term (no voice is carried as SIP).

However, the model could assume a migration profile for voice to be carried as SIP rather than SS7: this is determined by inputs on the *A2a_NwDesScen* worksheet of the Network Costing module. Whilst voice is carried as a mix of the two protocols, both the SS7 and SIP assets are operated in parallel. As soon as some voice is carried as SIP in the model, SIP-related assets (like the peering routers) are deployed. As soon as zero traffic is carried as SS7 in a given year, all remaining SS7 assets (like the trunk gateway, TGW) are shut down.

For the v2.3F model, migration to SIP is assumed to commence in 2017. This reflects the evolution of the Norwegian market. The migration is assumed to be complete in 2020, meaning that from 2021 onwards, interconnect is assumed to be all SIP-based. Therefore, by the end of the next anticipated regulation period, the model will be SIP-only.

5 Calculations related to the EC/ESA Recommendations

Both the EC[19] and ESA[20] released recommendations regarding the costing calculations for fixed termination rates. A number of adjustments were made to the Nkom v1.6 model to consider these recommendations when developing subsequent versions of the model:

- Section 5.1 describes the pure LRIC calculation included in Nkom's model
- Section 5.2 summarises the LRAIC and LRAIC+ calculations in Nkom's model
- Section 5.3 sets out the adjusted LRAIC+ and LRAIC^+ calculations in Nkom's model for the purposes of costing fixed voice origination services.

5.1 The Pure LRIC calculation

The Nkom v1.6 model was developed in 2009. The pure LRIC calculation implemented at the time is set out in the final "Service costing module" section of the Nkom v1.6 model documentation.[21] In April 2011, ESA subsequently released its own Recommendation.

Both recommendations specify that only the costs "avoided when not offering voice termination" are allocated to the voice termination service, with wholesale termination to be treated as the last service in the network. In addition, it is specified that non traffic-related costs (such as subscriber costs), network common costs and business overhead costs are not to be allocated to the end result.

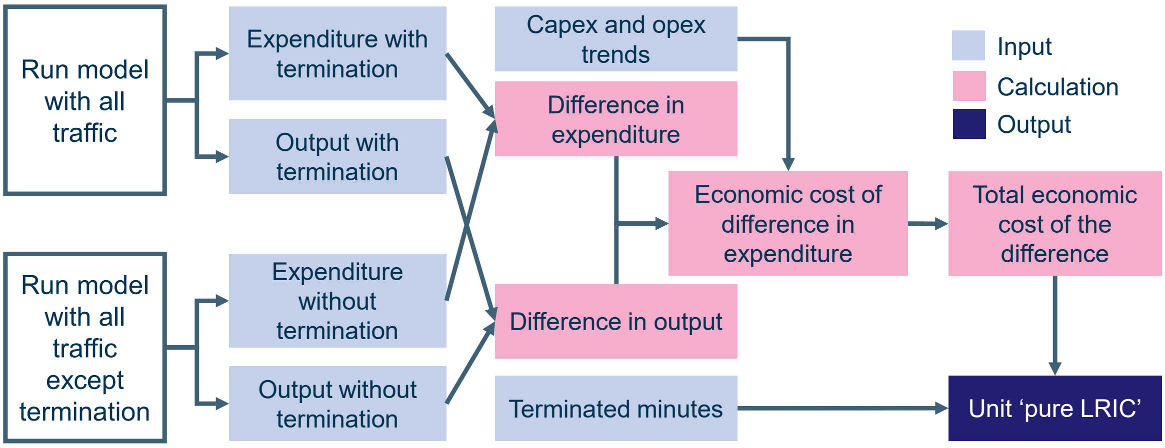
To calculate the pure LRIC in the Nkom v2.3F model requires that the model is run twice: once with wholesale mobile terminated voice and once without. This can be done by clicking on the "Run costing calculations" macro button on the *A1_Control* worksheet in the Market module. This results in the model performing the calculation twice, with the necessary information from both runs stored as values on the *A6_pureLRIC* worksheet in the Service Costing module. The pure LRIC of termination is then calculated as shown in Figure 5.1.

19 See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:124:0067:0074:EN:PDF.

20 See http://www.eftasurv.int/media/internal-market/ESAs-Recommendation-on-termination-rates.pdf.

21 See http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-kjerne/_attachment/1807?_download=true&_ts=13910105a49.

Figure 5.1: Calculation of pure LRIC [Source: Analysys Mason, 2014]



The difference in both capex and opex (the *avoidable* expenditures) is determined from the two model calculations, and economic depreciation is then applied to this difference. This is run separately for capex and opex, in order to apply their respective cost trends. The pure LRIC of termination in each year is then calculated as the ratio of total economic cost in that year divided by total (avoided) terminated minutes.

In calculating the pure LRIC, the modelled network design assumptions reflect some of the consequences of the modelled network carrying a lower traffic loading over its lifetime when termination is excluded. The pure LRIC calculation has been further refined in the modelling in terms of two technical adjustments detailed below. This is because a pure LRIC calculation is based on the technicalities of the cost model at the margin (in response to a small increment of traffic).

5.1.1 Technical adjustments to the network design to increase traffic sensitivity

The calculation includes specific traffic sensitivity in parts of the network design where assets are not avoided (i.e. not avoided in the network model calculations), but where it can be expected that assets would be avoided in the case of a real network dimensioned for no termination traffic.

These adjustments in the network calculation alter how asset counts are calculated when excluding voice termination, and as such increase the modelled avoidable cost and thus the pure LRIC.

There are currently no such adjustments active in the Nkom v2.3F model.

5.1.2 Technical adjustments to the costing calculation to include non traffic-sensitive costs

The pure LRIC calculation was also adjusted to include costs from certain assets that are not dimensioned to be traffic-sensitive, but where it can be expected that costs would be avoided in the case of a network dimensioned for no termination traffic. In the v1.6 model, this was used to include wholesale-related costs from the call server. In the v2.3F model, we now model the call server in more detail and have removed it from the adjustment. However, for consistency with the v9 mobile

LRIC model, we include the network billing system, intelligent network (IN) platform[22] and the voice-related network management systems (NMS) with this adjustment.

The Nkom v2.3F model has the functionality to include part or all of the calculated LRAIC per unit of output (i.e. excluding all mark-ups) for these selected assets as an additional contribution to the pure LRIC. The calculation can be found on the *A6_pureLRIC* worksheet of the Service Costing module and the corresponding methodology is shown below in Figure 5.2. The routeing factors by asset for the voice termination services are used to calculate the total LRAIC contribution across all terminating minutes in each year from these selected assets. For each year, a proportion of this contribution is then added to the total avoided cost and divided by the number of terminated minutes to derive the final pure LRIC per minute.

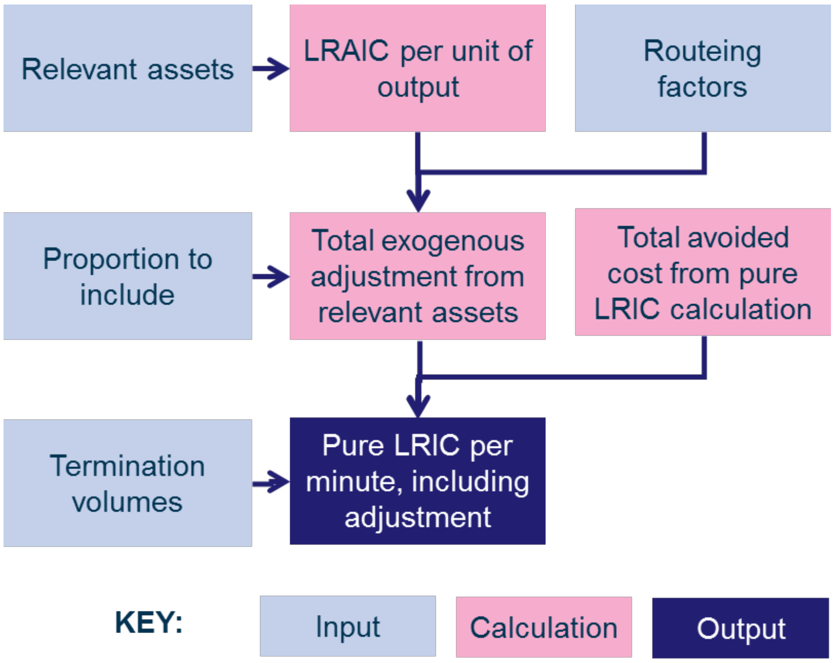


Figure 5.2: Calculation of an additional contribution to the pure LRIC to capture non traffic-sensitive costs [Source: Analysys Mason, 2014]

5.2 LRAIC and LRAIC+

The LRAIC and LRAIC+ (long-run average incremental cost, excluding and including common costs respectively) are calculated in the same way as for the previous versions of the model, consistent with the historical approach in Europe for fixed and mobile termination costing.

For the LRAIC, the average incremental costs of traffic are defined in aggregate and then allocated to various traffic services using routeing factors.

The LRAIC+ is then derived using an equi-proportionate cost-based mark-up for network common costs and administrative overheads.

22 The IN platform (modelled along with the value-added service platform) is allocated to the subscriber increment rather than the traffic increment in the fixed network. This was established in the earlier versions of the cost model. Therefore, the LRAIC contribution from this asset is zero. However, even if the asset was allocated across the traffic increment, the contribution would be almost zero.

5.3 Adjusted LRAIC+ and LRAIC^+

One effect of not using LRAIC+ to price-regulate fixed termination is that it has implications for the cost recovery of various assets by other services (whether price-regulated or not). In particular, fixed voice origination is price-regulated for Telenor. The model can consider both the cases where the termination price-regulation is LRAIC and pure LRIC, as described below.

Possible pricing voice termination approach using LRAIC

In this case, a proportion of the administrative costs unrecovered by termination would in principle be recovered by other services, including origination. The v2.3F model includes the capability to attribute the unrecovered administrative overheads from voice terminated to carrier pre-select (CPS) subscribers to wholesale originated voice. This calculation is undertaken on the *A9_LRAIC^* worksheet of the Service Costing module.

Possible pricing voice termination using pure LRIC

In this case, it is possible for other services, including both originated voice and on-net voice, to carry more of the common costs (in particular, of the voice platform).

We call the approach used to determine this cost recovery LRAIC^+. It seeks to treat the cost allocation between on-net and originated voice consistently. On-net calls can be compared (for modelling purposes) to a combination of two legs: call origination and call termination.

Accordingly, we calculate the LRAIC^ values by setting the cost recovery on the on-net second leg (termination-like) to be equal to the termination (pure LRIC) cost, and then recovering all remaining costs using a modified routeing table (and a subsequent modified economic output table). The net effect is that the costs no longer picked up by termination are recovered over other services in accordance with these new routeing factors. Accordingly, there are material unit cost increases for origination and the first (origination-like) leg of on-net traffic in the LRAIC^.

However, the net effects on the costs of on-net minutes end-to-end are small, since they are the sum of a higher cost origination-like leg and a lower cost termination-like leg. This is to be expected, since the same total costs are being recovered over the same total traffic.

The calculation of the economic costs using LRAIC^+ are undertaken on the *A8_ED^* worksheet of the Service Costing module, whilst the *A9_LRAIC^* worksheet contains the final results of the calculation.

Annex A Reference material adapted from the v1.6 model documentation

For full details of the network design in the Nkom v1.6 model, please refer to the Nkom v1.6 model documentation.[23] For reference, the sections of the Nkom v1.6 model documentation regarding the calculations in the model that have been modified in the v2.3F model are provided below. We also include the description of how to run the model.

A.1 High-level flow of the calculations in the network design module

Figure A.1 shows a high-level overview of the flow of the calculations dimensioning the deployed network in the Network Design module. It draws on the following inputs:

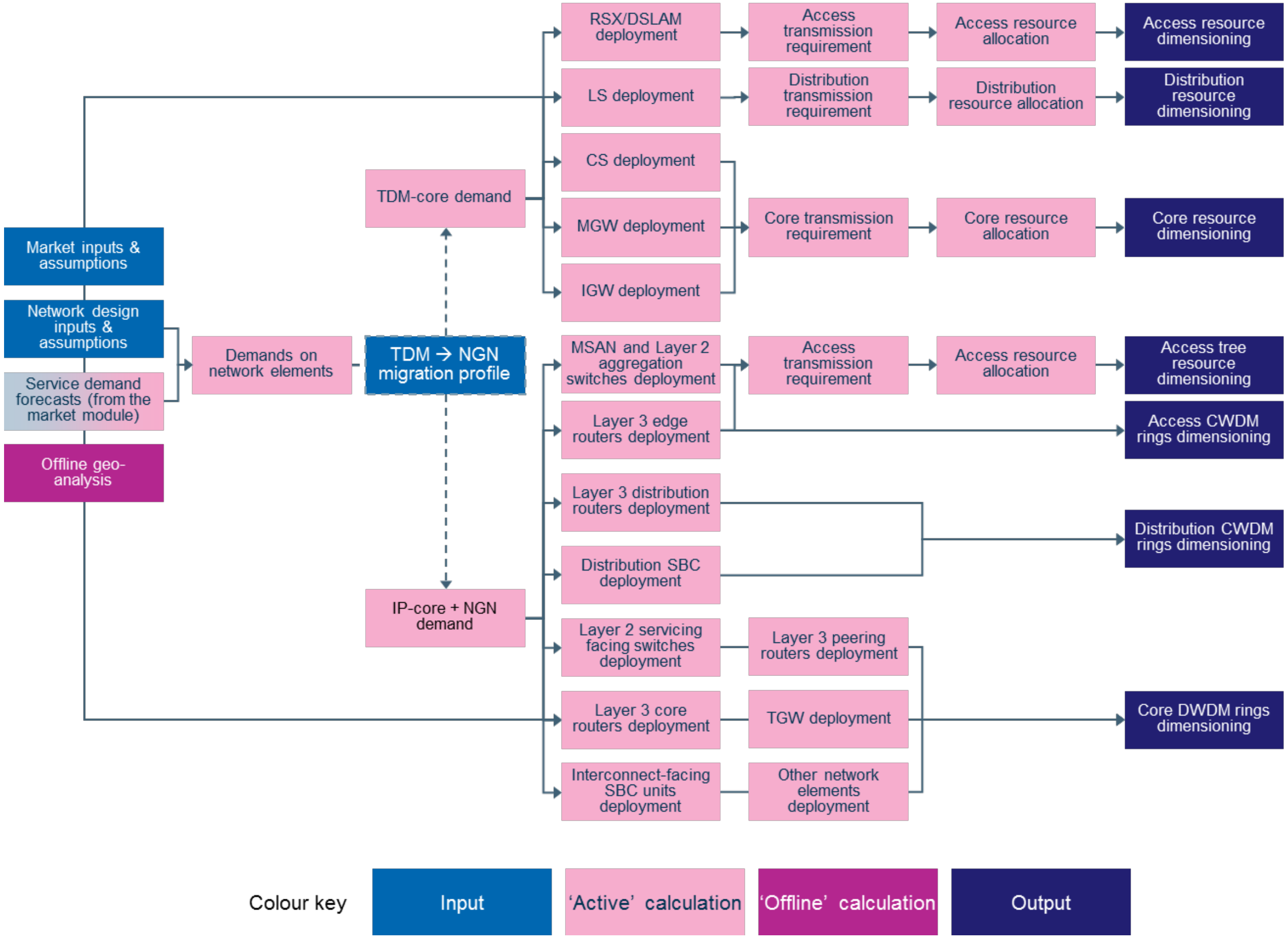
- market inputs and assumptions
- service demand forecasts (from the market module)
- network design inputs and assumptions
- offline geo-analysis, and
- the TDM–NGN migration profile.

These drive the requirements for individual assets throughout the network. These are described in more detail for the major asset groups below, namely:

- line cards and MSANs in Section A.2
- distribution session border controllers (SBCs) in Section A.3
- national switches in Section A.4
- interconnect-facing SBCs in Section A.5.

23 See http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-kjerne/_attachment/1807?_download=true&_ts=13910105a49.

Figure A.1: High-level flow of the calculations in the v1.6 Network Design module [Source: Analysys Mason/Nkom, 2011]

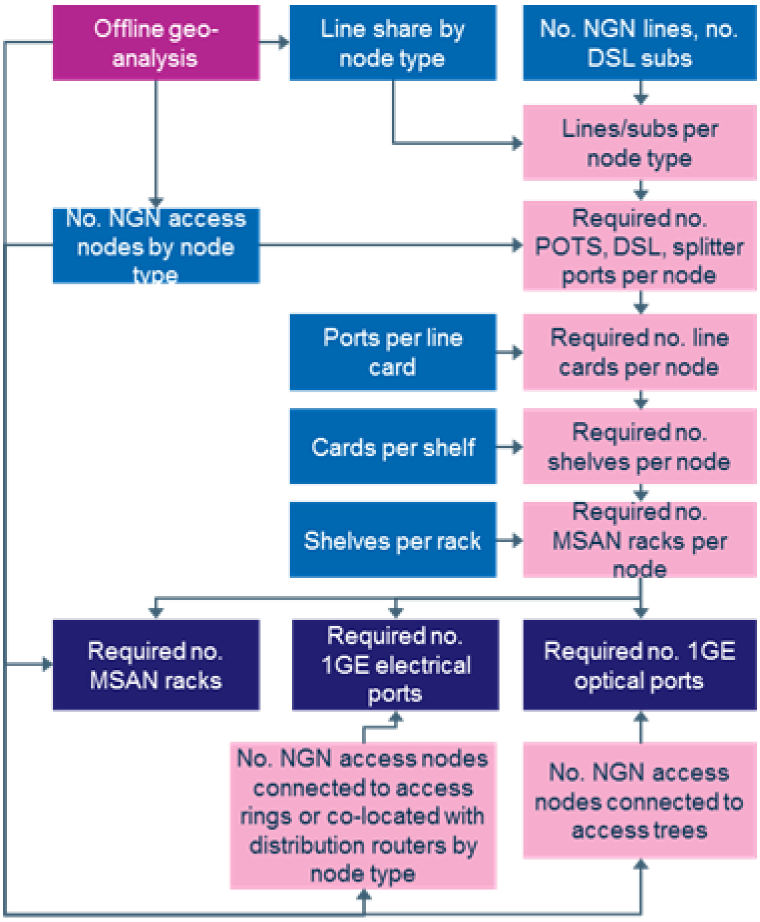


A.2 Line card and multi-service access node (MSAN) deployment

Figure A.2 below summarises the calculation of the required number of line cards and MSAN racks. Key features of the calculation are as follows:

- MSANs replace DSLAMs and provide TDM to VoIP conversion 'centralised' within the exchange
- the number of NGN lines and DSL subscribers drives the required number of POTS, DSL and splitter line ports, taking into account the line share of each node type
- a Monte Carlo input is used to take into account variability in exchange size
- the total number of line cards and MSAN racks per node is calculated based on line card size, shelf space and rack space
- multiplying this with the total MSAN-migrated access nodes gives the total number of line cards and MSAN racks required
- different ports are required for the MSANs:
  - — 1GE electrical ports are used for MSANs that are connected to access rings or co-located with the distribution nodes
  - — 1GE optical ports are used for MSANs that are connected to access trees.

Figure A.2: Calculation of number of line cards and MSAN racks in the v1.6 model [Source: Analysys Mason/Nkom, 2011]



A.3 Distribution session border controller (SBC) deployment

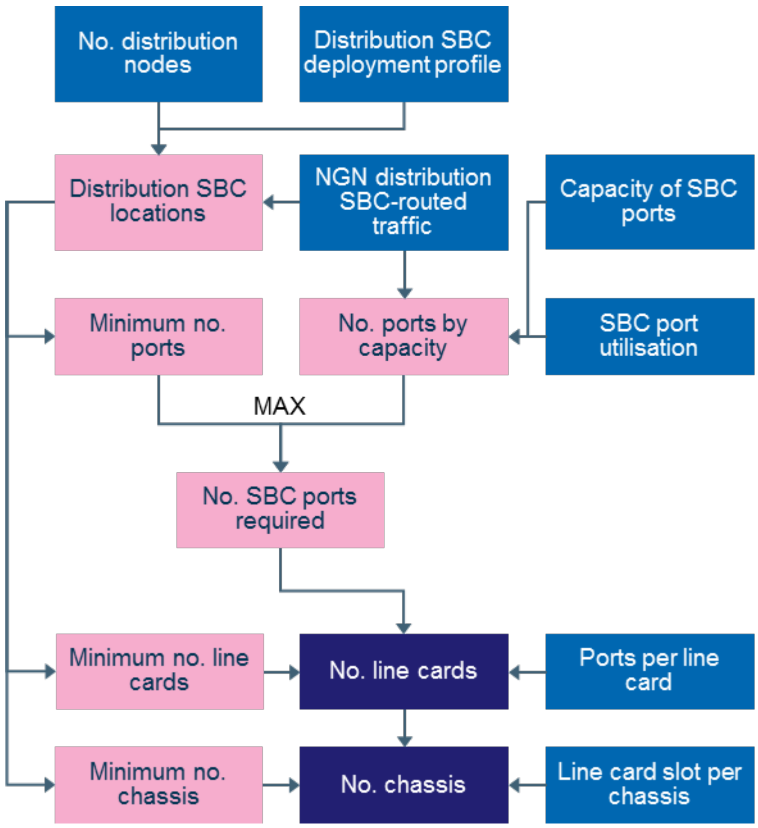
In the v1.6 model, two choices of distribution SBC deployment profiles influence the calculation shown in Figure A.3. These are:

- distribution SBCs are deployed to all distribution router nodes over time
- distribution SBCs are deployed to distribution router nodes co-located with core routers.

SBC capacities are driven by SBC-routed voice traffic (on-net, outgoing and incoming voice), assuming 1GE ports and a minimum deployment of 1 port per SBC location. After obtaining the number of ports, the numbers of line cards and chassis are obtained by assuming:

- 2 ports per card
- 2 line cards per chassis
- minimum deployment of 1 card/1 chassis per SBC location.

Figure A.3: Distribution SBC calculation in the v1.6 model [Source: Analysys Mason/Nkom, 2011]



A.4 National switching deployment

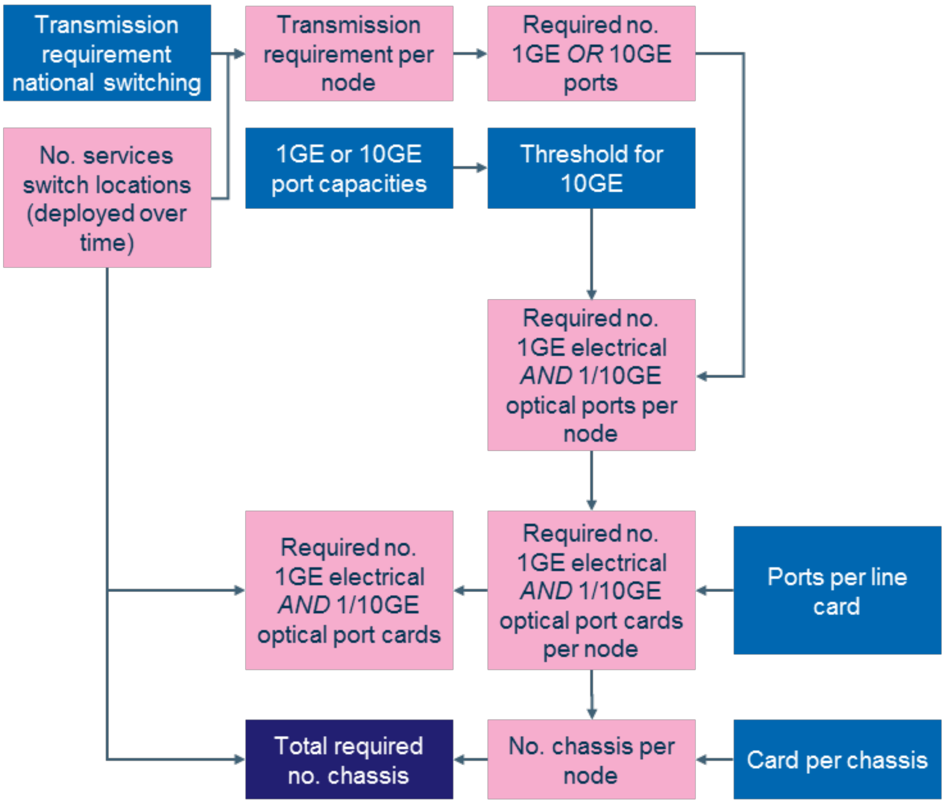
Figure A.4 describes the calculation of the required number of national switching ports and chassis. For Internet peering and to connect TV/VoD platforms, an additional switch per national location is deployed. Otherwise, national switching deployment is driven by:

- dial-up internet traffic
- xDSL traffic
- linear broadcast TV traffic
- VoD traffic.

If more than 2×1Gbit/s Ethernet ports are required, an upgrade to 10Gbit/s Ethernet ports is triggered. Capacity utilisation parameters are set to 40% to allow for redundancy in ports/cards/transmission. The following further technical parameters have been assumed:

- 48 ports per 1GE electrical port card
- 12 ports per 1/10GE optical port card
- 6 switch slots per chassis.

Figure A.4: Calculation of the required number of national switching ports and chassis in the v1.6 model [Source: Analysys Mason/Nkom, 2011]



A.5 Interconnect-facing SBC deployment

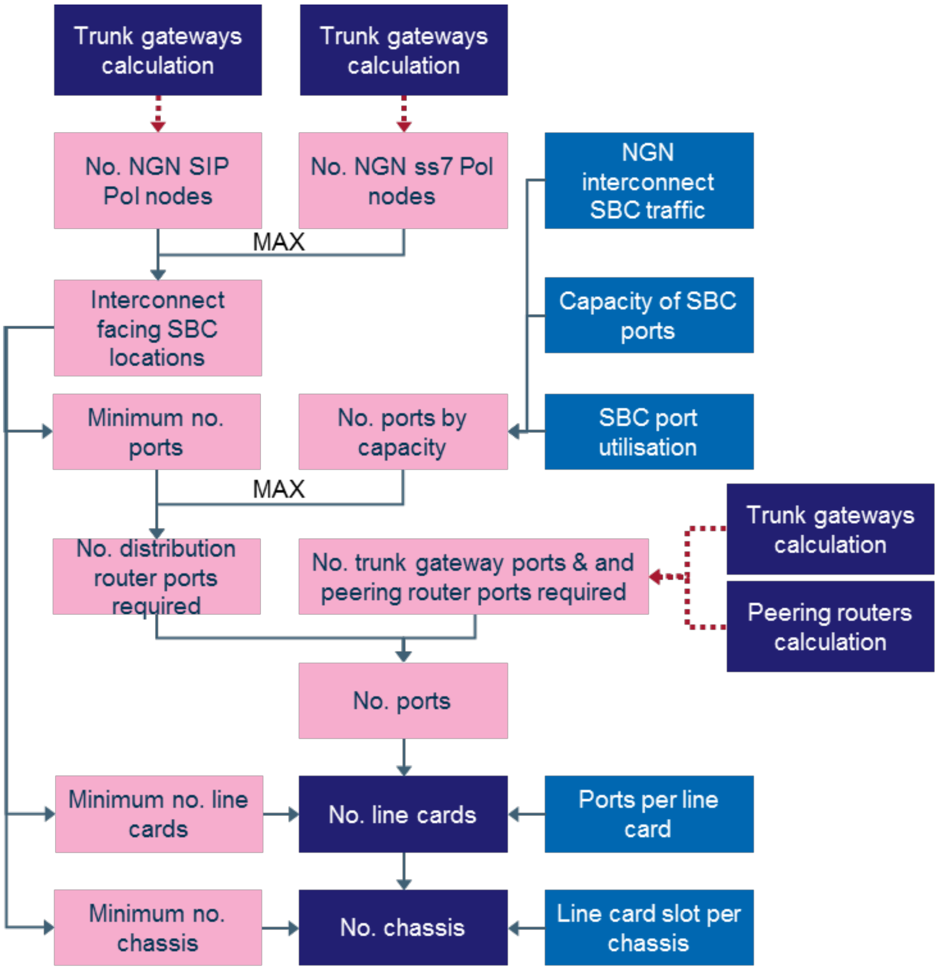
Interconnect-facing SBCs are present at all points of interconnection. The calculation of their required capacity and the number of ports can be seen in Figure A.5. SBC capacities are driven by SBC-routed interconnect voice traffic (outgoing, incoming and transit voice), assuming 1GE ports and a minimum deployment of 1 port per SBC location. The total number of ports required is the sum of:

- the number of distribution router ports required
- the number of trunk gateway ports required
- the number of peering router ports required.

After obtaining the number of ports, the number of line cards and chassis can be obtained by assuming:

- 2 ports per card
- 2 line cards per chassis
- minimum deployment of 1 card/1 chassis per SBC location.

Figure A.5: Interconnect-facing SBC calculation in the v1.6 model [Source: Analysys Mason/Nkom, 2011]



A.6 Running the model

Running the v2.3F model requires the following steps:

- Make sure all three Excel workbooks provided are saved in the same directory to preserve the inter-workbook links
- Open all three workbooks

  - When asked if you would like to update the linked information, click "No"
  - When asked whether or not to enable any macros, click "Enable Macros"
- Verify that the three workbooks are all linked together (using the Edit→Links command).

The model should be used with manual calculation enabled. To run the model correctly, in order to derive the results according to the various costing approaches implemented, a macro must be used. This macro can be run by clicking the "Run costing calculations" button on the *A1_Control* worksheet of the Market module.

The results can be viewed in the *A7_Results* worksheet of the Service Costing module. Charts showing the results according to the various costing approaches can also be found in this workbook.

Annex B Weblinks for sources

The table below lists the sources used to update the v2.3F model and their URLs.

Figure B.1: Summary of Market module data sources [Source: Analysys Mason, 2019]

Source	URL
Statistisk sentralbyrå	http://www.ssb.no Tables: 01222 (historic population), 09481 (population forecast), 09029 (number of establishments), 06076 (number of households)
Nkom’s public Ekomstatistikken database	https://ekomstatistikken.nkom.no Complete dataset for all services available from https://nkom.no/files/ekomportal/alle.csv
Telenor analytical tool	http://www.telenor.com/investors/reports/
Nkom mobile LRIC model	http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-mobilnett (version 9)
Pengepolitisk rapport	https://static.norges-bank.no/contentassets/4a558ba8828547af8b2620f144331250/ppr_1_18.pdf?v=03/22/2018091805&ft=.pdf

Annex C Expansion of acronyms

1GE	Gigabit Ethernet (1Gbit/s)
10GE	10 Gigabit Ethernet (10Gbit/s)
40GE	40 Gigabit Ethernet (40Gbit/s)
AAA	Authentication, authorisation and accounting
ADM	Add-drop multiplexer
ADSL	Asymmetric digital subscriber line
ATM	Asynchronous transfer mode
BH	Busy-hour
BRAS	Broadband remote access server
CCA	Current cost accounting
CEO	Chief Executive Officer
CPS	Carrier pre-select
CS	Call server
CSCF	Call Session Control Function
CWDM	Coarse wave division multiplexing
DNS	Domain name system
DSL	Digital subscriber line
DSLAM	Digital subscriber line access multiplexer
DWDM	Dense wave division multiplexing
EC	European Commission
ED	Economic depreciation
ENUM	E.164 Number Mapping
EPMU	Equi-proportionate mark-up
ESA	EFTA Surveillance Authority
FR	Frame relay
FTR	Fixed termination rate
GBV	Gross book value
GIS	Geographical information software
GRC	Gross replacement cost
HCA	Historical cost accounting
HSS	Home Subscriber Server
IGW	International gateway
IMS	IP multimedia subsystem
IN	Intelligent network
IP	Internet protocol
IPTV	Internet protocol television
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
MGC	Media Gateway Controller
MGW	Media gateway
MPLS	Multi protocol label switching
MSAN	Multi-service access node
MTAS	Multiservice Telephony Application Server
NBV	Net book value
NG	Next-generation
NGA	Next-generation access
NGN	Next-generation network

NMS	Network management system
PABX	Private Automatic Branch Exchange
PDH	Plesiochronous digital hierarchy
PE	Provider Edge
POTS	Plain old telephone service
PR	Peering routers
PSTN	Public switched telephone network
RADIUS	Remote authentication dial-in user service
RAS	Remote access server
RSX	Remote switching stage or remote switching unit
SBC	Session border controller
SDH	Synchronous digital hierarchy
SDSL	Symmetric digital subscriber line
SEP	Signalling end-points
SIP	Session Initiation Protocol
SMP	Significant market power
SS7	Signalling System 7
SSB	Statistisk Sentralbyrå
STP	Signalling transfer point
TDM	Time-division multiplex
TGW	Trunk gateway
UPS	Uninterruptible power supply
VPN	Virtual private network
WACC	Weighted average cost of capital
WLR	Wholesale line rental