# Wholesale Local Access Market Review: NGA Cost Modelling

Network & Cost Module Documentation

V1

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Prepared for:

Ofcom

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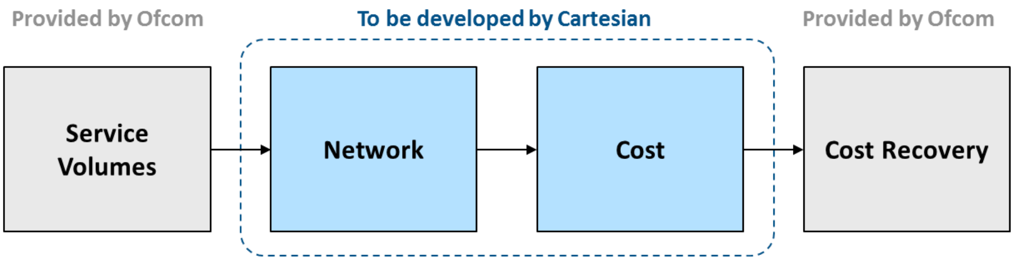
# 1 Introduction

1.1 Ofcom is undertaking a series of market reviews to examine the competitive conditions in fixed access markets over the period from April 2017 to March 2020, including those for wholesale local access (WLA) and wholesale fixed analogue exchange lines (WFAEL).

1.2 As part of the current review Ofcom is considering its regulatory approach for access to next generation access (NGA) services. In order to ensure a fit-for-purpose NGA model is available should it be required, Ofcom has engaged Cartesian to assist with the construction of a new bottom-up cost model for NGA services ('the 2016 NGA model'). Specifically, Ofcom has commissioned Cartesian to develop two (of the four) modules; the Network and Cost modules.

1.3 The Network module takes the FTTC capacity and coverage demand forecasts (Ofcom provides the Service Volume module) to dimension the access network. The Cost module calculates the capital and operating expenditure required to build and operate the dimensioned access network. The outputs from this module are used by the Cost Recovery module to calculate how costs are recovered over time and across services. Figure 1 below shows the relationship between the modules.

Figure 1. ***Overall NGA model architecture***




Source: Cartesian

1.4 This document provides an overview of the Network and Cost modules:

- Section 2 defines the scope of the 2016 NGA model;
- Section 3 describes the architecture of the hypothetical network on which the cost model is based;
- Section 4 describes the architecture and logic of the Network and Cost modules. The section describes how the network is dimensioned from the traffic inputs and how this network dimensioning drives costs. The section also describes the outputs that are then used to calculate the unit cost of NGA services.

1.5 This 2016 NGA Model documentation v1 accompanies Version 1 of the 2016 NGA model. Note that many of the network dimensioning parameters and cost inputs contained in this version of the model are holding assumptions. We will update these parameters as we collect data from CPs during the next phase of the 2016 NGA modelling exercise.

# 2 Scope

2.1 The scope of the 2016 NGA model comprises the portion of the NGA network up to the point of handover i.e. the point where access is made available to other CPs.[1]

## Technology

2.2 The technology considered in the 2016 NGA model is Cabinet-based VDSL2, also referred to as FTTC.

## Services

2.3 The number of NGA services supported by the 2016 NGA model is flexible; the current model version (v1) has space for up to six, which is likely to be sufficient. In this version of the 2016 NGA model, we consider one of the NGA services which BT currently offers, including both external and internal supply.[2]

2.4 Additionally, ancillary services are considered in the 2016 NGA model, including customer site installations and service provision.

## Geographic coverage

2.5 The geographical scope of the 2016 NGA model is based on the coverage area of BT's current and likely future FTTC Cabinet footprint in the United Kingdom. This includes locations in England (excluding the Hull area served by KCOM), Wales, Scotland and Northern Ireland.

2.6 The 2016 NGA model covers commercially viable areas only, i.e. excludes coverage areas that were partly funded by BDUK. We have used a data set for network coverage from BT which segments the BDUK-funded areas; allowing them to be easily excluded from the network dimensioning calculations.

## Timeframe

2.7 Time periods in the 2016 NGA model are financial years (FY), i.e. April to March. The 2016 NGA model considers a 40-year period, from 2007/08 to 2047/48 with an explicit modelling period until 2027/28 and values held constant thereafter.

2.8 The 2016 NGA model considers that in FY 2007/08 (which we call year 0), while there were no FTTC subscribers, there were likely some costs incurred, relating to pre-launch design and testing activities. In FY 2008/09, The 2016 NGA model considers that the FTTC network build started, in line with BT's actual rollout.[3]

## Model approach

2.9 An *FTTC Overlay* approach has been followed in the 2016 NGA model, with only those components that are specific to NGA services modelled on a bottom-up basis. The component costs for the

---

[1] In the instance of NGA, the point of handover is the Layer 2 Switch at the Exchange.

[2] Internal services refer to the ones provided by Openreach to BT's downstream divisions, and external services are provided by Openreach to 3rd party CPs

[3] On July 2008, BT announced plans to deploy higher speed broadband using FTTC. See the following link for more details: http://stakeholders.ofcom.org.uk/binaries/consultations/nga_future_broadband/summary/main.pdf

current generation access (CGA) network that are also shared with the NGA services will be considered further in the WLA market review and are not currently included in the 2016 NGA model.

2.10 The network module employs a scorched node approach.[4] In this context, *node* refers to the Exchange, PCP and FTTC Cabinets: The 2016 NGA model uses route lengths that are derived from the distances between the actual locations of BT's assets.

2.11 Those network components which are shared between NGA services and CGA services (e.g. segments of duct and copper) are outside of the scope of Cartesian's Network and Cost modules and will be considered further in the WLA market review.

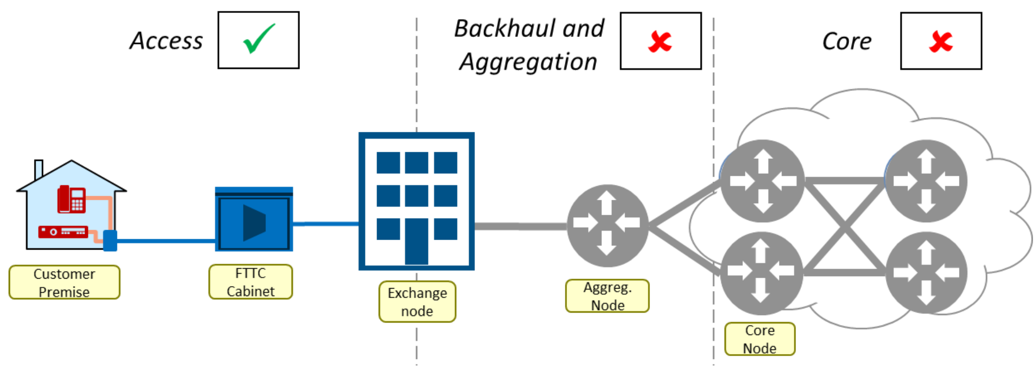
[4] In a scorched node approach, the existing network nodes are considered to be fixed. All other network elements can be optimised.

# 3 Network Architecture

## Overview

3.1 The 2016 NGA model comprises the access network segment, covering the NTE at the customer premise up to the Exchange node. Figure 2 provides a high level overview of the network architecture, identifying the segments in scope for the model.

Figure 2. ***High level Network architecture: segments in scope***

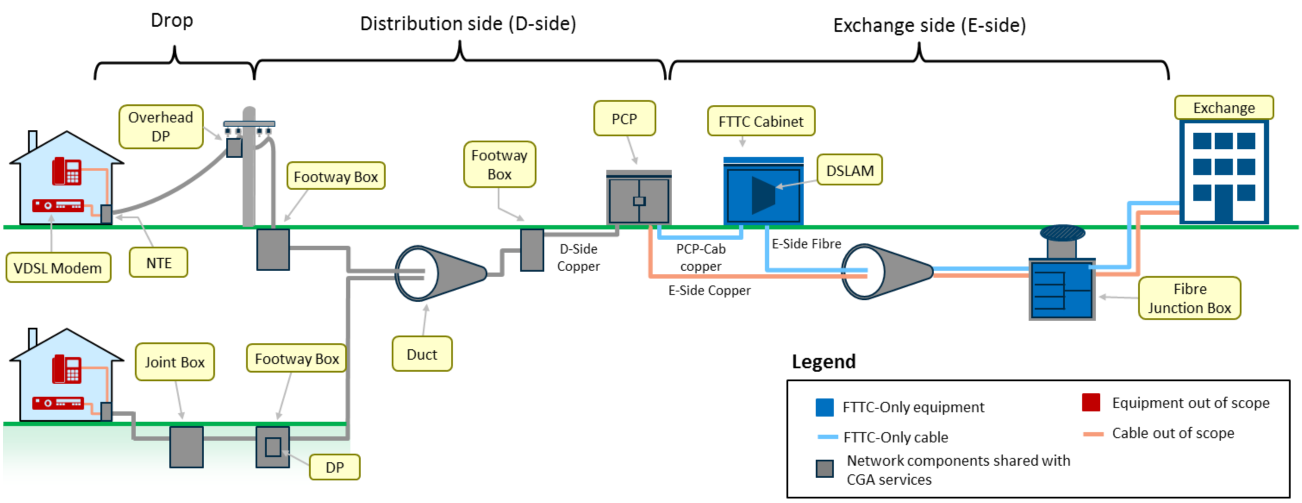



Source: Cartesian

3.1 Figure 3 below shows a more detailed physical architecture diagram of the access network considered in the 2016 NGA model. As explained in paragraph 2.9, only those elements specific to FTTC are considered in the Network module, modelled on a bottom-up basis (blue in the diagram), these network elements are explained in detail in the following subsections.

3.2 As per paragraph 2.11, those network elements which are shared between NGA services and CGA services are not included in the bottom-up modelled network (grey in the diagram).

Figure 3. ***Access network FTTC physical architecture***




Source: Cartesian

## D-side Duct and Copper

3.3 FTTC services use the existing copper infrastructure from the subscriber premise up to the PCP, including NTEs, poles and distribution points, as well as D-side duct and copper. The costs of these shared components will be considered further in the WLA market review and are not included in the 2016 NGA model.

## PCP Cabinets

3.4 PCP cabinets are used for both NGA and CGA services. The cost estimate for this network component is therefore not included in the 2016 NGA model.

3.5 The size of PCP cabinets varies in real-world networks depending on the number of premises served. In the 2016 NGA model we assume that FTTC cabinets attached to *large PCPs* serve a larger number of FTTC customers compared to those attached to small PCPs. Given that we are modelling a hypothetical *efficient* network, and that DSLAM deployment costs are material, we model different sizes of DSLAM being used for the various sizes of PCPs that they serve.

3.6 An underlying assumption behind the consideration above is that the FTTC service uptake is independent of the size of the PCP. Therefore, we assume that the utilisation of a large FTTC cabinet, in percentage terms, is the same as the utilisation of a small FTTC cabinet.

3.7 The number of premises served by the PCP Cabinets will be used to estimate the number of FTTC Cabinets of each size, as explained in paragraph 3.18.

## PCP-to-FTTC Cabinet

3.8 The PCP is connected to the FTTC Cabinet via copper tie cables passed through an underground duct. Both the duct and the PCP-FTTC Cabinet Tie Cables need to be built specifically for NGA services, therefore these costs are modelled on a bottom-up basis.[5]

3.9 The distance between the two cabinets will ideally be as short as possible, however in reality it depends on planning constraints. Openreach states that the tie cable lengths must not exceed 100m.[6] Figure 4 below illustrates the physical layout of the PCP-FTTC Cabinet connection.

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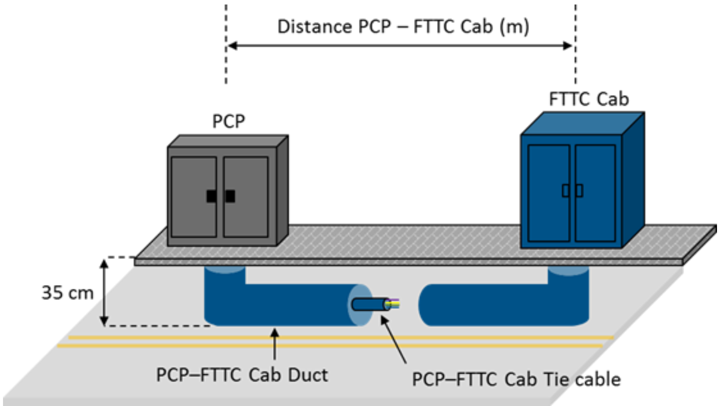
[5] In reality, if the FTTC Cabinets are relatively far apart, in addition to new duct there may be some re-use of existing duct. However, only new duct is included in the 2016 NGA model.

[6] SLU – Openreach Internal Reference Offer. Note that the rules on FTTC cabinet and tie cables are common between SLU and GEA FTTC.

Figure 4. ***High level diagram of PCP - FTTC Cabinet connection***




Source: Cartesian

3.10 The primary constraint to determine the location of the fibre cabinet – and hence the separation between a PCP and a FTTC Cabinet – is space on the pavement, given the presence of other street furniture and driveways. We do not expect a material difference between these parameters for the various PCP sizes and geotypes. Therefore, the 2016 NGA model uses an average value for the distance PCP - FTTC Cabinet.

3.11 The average PCP – FTTC Cabinet distance is used to derive the length of the duct. The formula used is as follows:

$$Avg\ Duct\ PCP\_\mathrm{FTTC}\ Cab(m) = Avg\ Dist\ PCP\_\mathrm{FTTC}\ Cab(m) + 2 \cdot DepthDuct\ (m)$$

Given that the recommended duct depth for telecoms is 0.35 m (source: Openreach Developers' Guide, v7.0 April 2013. '*Recommended value in footways'*), the formula results in:

$$Avg\ Duct\ PCP\_\mathrm{FTTC}\ Cab(m) = Avg\ Dist\ PCP\_\mathrm{FTTC}\ Cab(m) + 0.7\ (m)$$

3.12 The PCP – FTTC Cabinet Tie Cable length is also derived from the PCP – FTTC Cabinet distance. The number of copper cable pairs is dependent on the PCP size, therefore the 2016 NGA model includes a different cable type for each PCP size.

3.13 The Tie Cable length is modelled on a similar basis to the duct, in terms of distance between the PCP and the FTTC Cabinet. However, the copper cable needs to be connected to patch panels within the cabinets, which are installed above the ground level. Therefore the formula to calculate the cable length is as follows:

$$Avg\ Tie\ Cable\ PCP\_FTTC\ Cab(m) = Avg\ Duct\ PCP\_FTTC\ Cab(m) + 2 \cdot Avg\ PatchPanelHeight\ (m)$$

3.14 We assume that the Patch Panel Height is approximately 1 metre above ground level,[7] based on typical FTTC Cabinet and PCP Cabinet sizes. Therefore the total Tie Cable length formula is as follows:

$$Avg\ Tie\ Cable\ PCP\_FTTC\ Cab(m) = Avg\ Dist\ PCP\_FTTC\ Cab(m) + 2.7(m)$$

3.15 We calculate the total distance using geospatial analysis of BT's actual PCP and FTTC Cabinet location data. The average distance between PCP and FTTC Cabinets is 12.3m (a total distance of [✂] over

[7] *Avg PatchPanelHeight* is the sum of the patch panel height above ground and the duct depth.

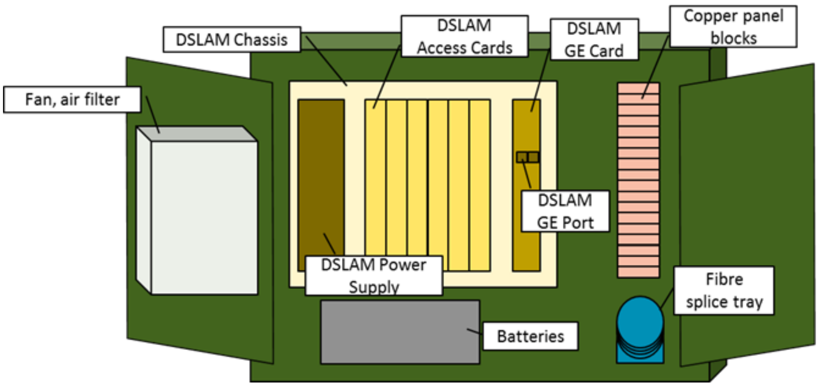
 

[✂] FTTC Cabinets) therefore the average length of the Tie Cable PCP-FTTC Cab is [✂]. These values are used as inputs in Version 1 of the 2016 NGA Model.

## FTTC Cabinet

3.16 Inside each FTTC Cabinet is a DSLAM, which multiplexes the VDSL2 connections from a number of subscribers into an Ethernet link connected to an Exchange. Figure 5 below shows the DSLAM with its subcomponents, as well as other equipment required in the FTTC Cabinet.

Figure 5. ***Diagram with key network components inside an FTTC Cabinet***




Source: Cartesian

3.17 Some subcomponents of larger super-components have been grouped in the 2016 NGA model, with their cost aggregated. This allows a reduction in the number of elements considered in the 2016 NGA model without compromising its accuracy. The list of elements inside a FTTC Cabinet used in the 2016 NGA model is shown in the table below.

Figure 6. ***FTTC Cabinet elements used in the 2016 NGA model***

| Network elements in the 2016 NGA model | Subcomponents included |
|---|---|
| FTTC Cabinet | - FTTC Cabinet<br>- Copper panel blocks<br>- Fibre splice tray<br>- Fan, air filter system<br>- Battery back-up<br>- Security system |
| DSLAM Chassis | - Frame<br>- Control Board<br>- Power Supply<br>- Software Licence |
| DSLAM Access Card | - Access Card |
| DSLAM Gigabit Ethernet (GE) Card | - GE Card |
| DSLAM GE Port | - GE Port, Small Form-factor Pluggable (SFP) |

Source: Cartesian

3.18 The Version 1 of the 2016 NGA model includes two types of FTTC Cabinets, with the following port and card capacity:

Figure 7. ***DSLAM Capacity for each Cabinet type***

| Cabinet Type | Network components in the 2016 NGA model | Capacity | Total Capacity |
|---|---|---|---|
| Type 1 | FTTC Cabinet | 1 DSLAM Chassis | 128 subscribers |
| | DSLAM Chassis | 4 DSLAM Access Cards | |
| | DSLAM Access Card | 32 FTTC subscribers | |
| Type 2 | FTTC Cabinet | 1 DSLAM Chassis | 288 subscribers |
| | DSLAM Chassis | 6 DSLAM Access Cards | |
| | DSLAM Access Card | 48 FTTC subscribers | |

Source: Cartesian

3.19 BT has stated, all FTTC Cabinets deployed by BT in the UK except for two, out of a total of ca. 70,000 cabinets[8], have a single 1 GE link connecting them to the Exchange), and considering that DSLAMs can typically support 4 - 8 GE ports (depending on the size of the DSLAM), we conclude that 1 GE

[8] This figure reflects BT's full FTTC coverage in the UK, including BDUK areas.

interface cards are sufficient at the FTTC Cabinet, and that as such there is no need to model 10 GE interface cards.

*FTTC Cabinet Rollout*

3.20 As discussed in paragraphs 2.5 and 2.6, Version 1 of the 2016 NGA Model aims to reflect the number of cabinets in BT's actual FTTC Cabinet commercial (i.e., non-BDUK) rollout up to FY 2015/16.

3.21 From FY15/16 onwards, we assume that the number of FTTC Cabinets remains flat, which implies that BT's FTTC commercial has reached completion.[9] This assumption will be verified, following input from CPs. The table below shows the FTTC Cabinet rollout and premises covered in Version 1 of the 2016 NGA Model:

Figure 8. ***FTTC Cabinet rollout used in the 2016 NGA Model [Placeholder values]***

| Actual / Estimate | FY | New FTTC Cabinets | Total FTTC Cabinets | % Premises covered |
|---|---|---|---|---|
| Actual | FY09/10 | 1,000 | 1,000 | 0-10% |
| Actual | FY10/11 | 10,000 | 11,000 | 10-20% |
| Actual | FY11/12 | 12,000 | 23,000 | 30-40% |
| Actual | FY12/13 | 15,000 | 38,000 | 50-60% |
| Actual | FY13/14 | 10,000 | 48,000 | 60-70% |
| Actual | FY14/15 | 2,000 | 50,000 | 70-80% |
| Actual | FY15/16 | 1,000 | 51,000 | 70-80% |
| Estimate | FY16/17 | 0 | 51,000 | 70-80% |
| Estimate | FY17/18 | 0 | 51,000 | 70-80% |
| Estimate | FY18/19 | 0 | 51,000 | 70-80% |
| Estimate | FY47/48 | 0 | 51,000 | 70-80% |

Source: Cartesian. The number of FTTC Cabinets are placeholder values and thus do not represent BT's actuals.

3.22 Following input from BT, Version 1 of the 2016 NGA Model dimensions the FTTC Cabinets to support up to 30% service adoption.[10] Specifically, we use this assumption to identify the type of each FTTC Cabinet in the network. Given that the two types of DSLAM used by BT support 128 and 288 subscribers respectively, the following dimensioning rule is used to identify the type of FTTC Cabinet:

3.23 <u>Type 1 FTTC Cabinet (128 subs capacity):</u> if the respective PCP Cabinet covers less than 128 / 0.30 = 427 premises

3.24 <u>Type 2 FTTC Cabinet (288 subs capacity):</u> if the respective PCP Cabinet covers more than 128 / 0.30 = 427 premises

3.25 Using BT data of premises covered by each PCP Cabinet, we calculate the number of FTTC Cabinets of each type from FY09/10 up to FY15/16. The percentage of Type 2 FTTC Cabinets in this period ranges from 34% to 41%.

[9] This excludes BT's FTTC rollout partly funded by BDUK.
[10] This corresponds to BT's most recent take-up assumption used for dimensioning FTTC rollouts, mainly in BDUK areas.

Figure 9. ***Split of new FTTC Cabinets by Type used in the 2016 NGA Model***

| Actual / Estimate | FY | Type 1 FTTC Cabinets | Type 2 FTTC Cabinets | Percentage Type 2 FTTC Cabinets |
|---|---|---|---|---|
| Actual | FY09/10 | 620 | 380 | 38% |
| Actual | FY10/11 | 6,000 | 4,000 | 40% |
| Actual | FY11/12 | 7,680 | 4,320 | 36% |
| Actual | FY12/13 | 8,850 | 6,150 | 41% |
| Actual | FY13/14 | 6,400 | 3,600 | 36% |
| Actual | FY14/15 | 1,320 | 680 | 34% |
| Actual | FY15/16 | 590 | 410 | 41% |
| Estimate | FY16/17 | 0 | 0 | N/A |
| Estimate | FY17/18 | 0 | 0 | N/A |
| Estimate | FY18/19 | 0 | 0 | N/A |
| Estimate | FY47/48 | 0 | 0 | N/A |

Source: BT, Cartesian. The number of FTTC Cabinets by type are placeholder values and thus do not represent BT's actuals.

## E-side Duct

3.26 Fibre cables deployed in underground ducts connect the FTTC Cabinets to the Exchanges. From previous studies we understand that civil work is the largest cost item when deploying new buried networks.[11] Taking this into account, we would expect an efficient operator deploying FTTC would maximise the re-use of existing duct infrastructure. Therefore, the 2016 NGA model assumes that the E-side fibre from the FTTC Cabinet to the Exchange is installed, where possible, in the existing E-side ducts carrying copper cables for CGA services, e.g. WLR, LLU.

3.27 As with D-side ducts, shared E-side Duct cost are not included in the 2016 NGA model. Our approach to calculating the cost of additional E-side Duct is outlined in paragraph 3.36.

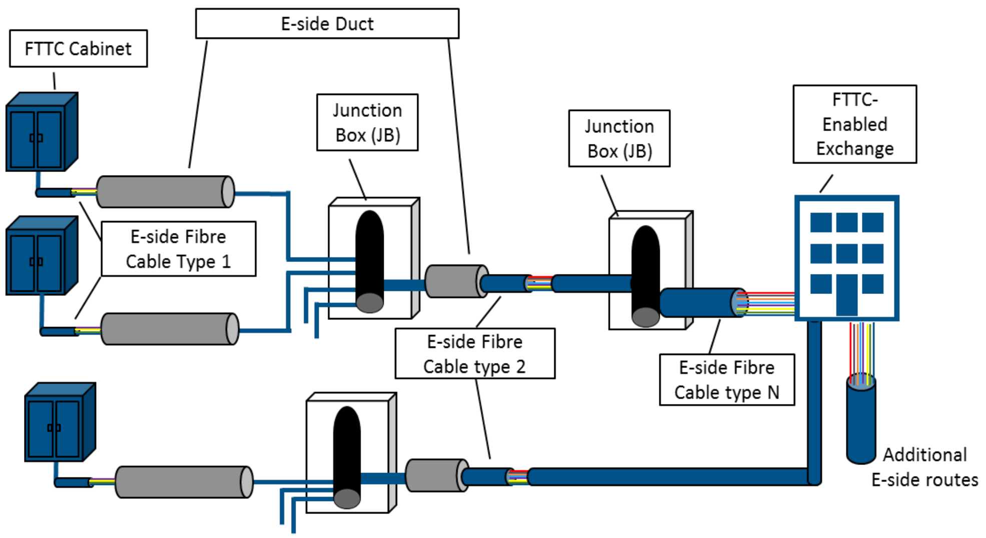
## E-Side Fibre

3.28 Fibre cable in the E-side segment of the 2016 NGA modelled network is used exclusively by NGA services. Therefore, E-side fibre costs are modelled using a bottom-up approach.

3.29 The E-side network topology considered in the cost model consists of a number of fibre cables types, with different fibre-pair counts. The thinnest cables are used at the egress of the FTTC Cabinet. The cables of various routes are aggregated into larger cables at Junction Boxes (JB). There may be a number of JBs between an FTTC Cabinet at the Exchange. Figure 10 below shows the E-side network topology considered in the 2016 NGA model.

[11] In Cartesian's report *Economics of Shared Infrastructure Access* for Ofcom (2010), we estimated the costs for a CP to provide FTTP services using different infrastructure access options. For New Build, we calculated that 52% and 61% of the total annualized cost would correspond to civil works in urban and suburban geotypes, respectively (for 31% market penetration).

Figure 10. ***Typical network topology at the E-side segment***




Source: Cartesian

3.30 Version 1 of the 2016 NGA model (accompanying this report) uses six types of fibre cables, ranging from 12 fibres (i.e. 6 pairs) to 256 fibres (128 fibre pairs). These cable sizes are in line with BT Cables' fibre cable product catalogue.[12] The fibre cables will be over-dimensioned (i.e. a number of fibres will be left unused at the time of installation). Spare fibres can be used for maintenance purposes and may also be used to meet future demand without the need to deploy new cables.

3.31 The number of fibre cable types, the fibre count of each type and the fibre dimensioning rules will be updated, following input from CPs. Figure 11 below shows the placeholder values included in Version 1 of the 2016 NGA model.

Figure 11. ***E-side fibre cable types and over-dimensioning rules [placeholder values]***

| No fibre routes (min - max) | Fibre cable type | Spare fibres (min - max, in %) |
|---|---|---|
| 1 - 2 | 6-pair | 67% - 83% |
| 3 - 4 | 12-pair | 67% - 75% |
| 5 - 8 | 24-pair | 67% - 79% |
| 9 - 16 | 48-pair | 67% - 81% |
| 17 - 30 | 72-pair | 58% - 76% |
| 31 - 64 | 128-pair | 50% - 76% |
| > 65 | 2 x 128-pair | 53% - 75% |

Source: Cartesian

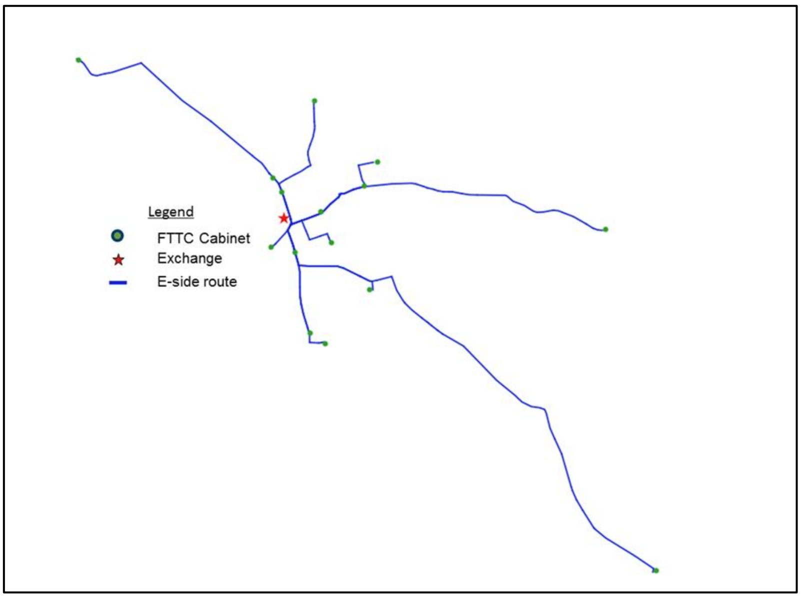
3.32 We estimate the routes and lengths of the E-side fibre cables and number of cable joints using geospatial analysis of BT's actual FTTC Cabinet and Exchange location data up to FY 2015/16. Cartesian uses a combination of open-source software (e.g. R and PostgreSQL), commercial software

[12] http://www.btcables.com/products/voice/optical-fibre-cables

and Cartesian's proprietary analytics platform, Ascertain, for the geospatial analysis. As per paragraph 3.21, we assume the NGA deployment to be complete from 2015/16. Therefore the E-side cable lengths and number of cable joints stay constant for the remainder of the model. This assumption will be validated following input from CPs.

3.33 Figure 12 below shows an example of the geospatial analysis, displaying the cable routes from a sample Exchange to its FTTC Cabinets, using a *shortest route* algorithm which follows existing roads. We assume that a new Cable Joint is required whenever two or more routes meet. This version of the model includes the results of the geospatial analysis for the E-side cable and Cable joints.

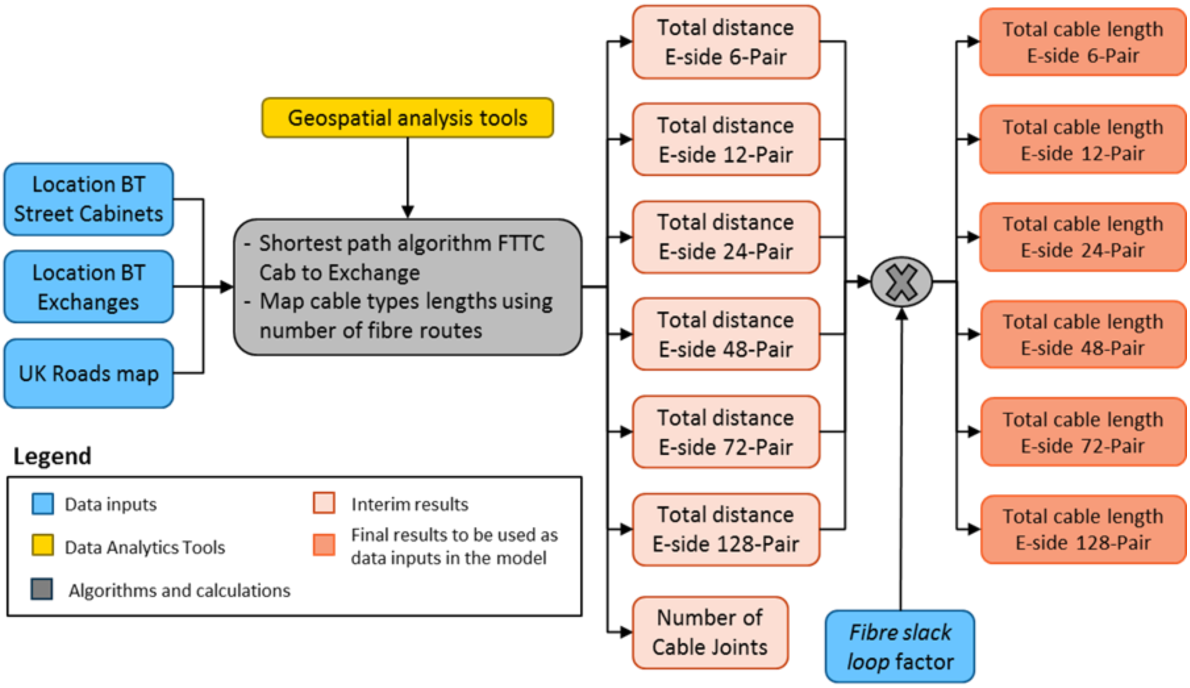
Figure 12. ***Initial output of the geospatial analysis, with the estimated E-side cable routes***




Source: Cartesian

3.34 Figure 13 below shows the analytical flow diagram to obtain the E-side cable length values. These values are used in the Network Module as inputs.

Figure 13. ***E-side fibre length geospatial analysis flow diagram***




Source: Cartesian

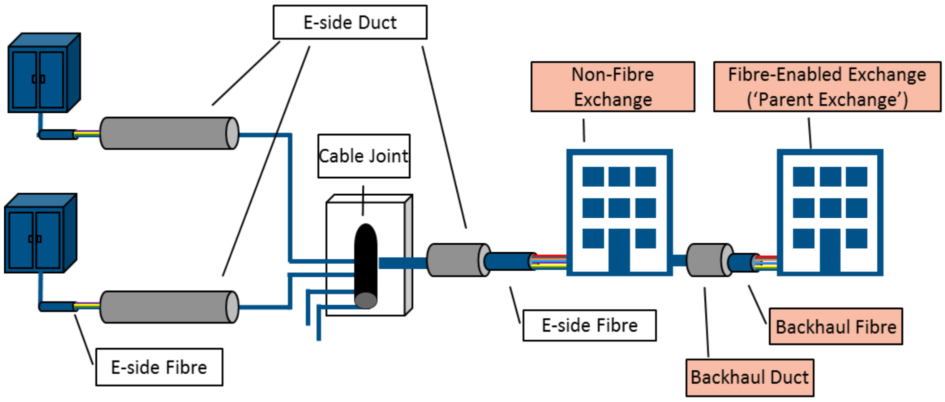
3.35 Note that the fibre slack loop factor, which is applied to the cable distance in order to calculate the total cable length, has not been included. These values will be updated in the final version following input from CPs.

## Backhaul Duct and Fibre

3.36 In the 2016 NGA modelled network there are two methods of connecting the FTTC Cabinet to the Parent Exchange. The first option consists of the E-side duct directly linking the FTTC cabinet with a fibre-enabled Exchange. We assume that these fibre installations do not require new duct. The second option consists of the E-side duct linking an FTTC Cabinet to the closest Exchange, which is not fibre-enabled (i.e. it is only used for CGA services). Under this second option, the fibre cable needs to be extended to its Parent Exchange, which is fibre-enabled. In the model we assume that the extension from the closest Exchange to the Parent Exchange uses existing duct. These two options are representative of the situation of the majority of cabinets in BT's network, and we consider to be an efficient way to use duct.

3.37 The connection between Exchanges is considered as part of the Backhaul network. Figure 14 below shows the E-side and Backhaul network topology in scope. These ducts and fibre may be used by services other than NGA (e.g. leased lines, Backhaul network for LLU). Version 1 of the 2016 NGA model makes the assumption that additional backhaul duct and fibre is not required for providing FTTC services, as they rely on existing infrastructure. This assumption will be confirmed with CPs.

Figure 14. ***Network topology with Backhaul Duct***




Source: Cartesian

3.38 We have calculated the distance between the non-fibre Exchanges and the Parent Exchanges, using location data from BT, in order to estimate the total length of the Backhaul duct and fibre up to FY15/16. As per paragraph 3.32, we assume that the Backhaul duct and fibre lengths stay constant from FY2015/16.

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3.39 The same fibre slack loop factor as described in paragraph 3.34 needs to be applied to the backhaul duct distance in order to calculate the total backhaul fibre cable length (this factor has not been included in the draft model). The final values will be updated following input from CPs. These estimates could also be used to calculate the cost of the connection between exchanges.

## Exchange

### *Overview*

3.40 At the Exchange, the 2016 NGA modelled network includes: the Optical Consolidation Rack (OCR), the Optical Line Termination (OLT), the Level 2 Switch (L2 Switch or L2S), and the Tie Cables between them. Figure 15 below illustrates the topology to be modelled.

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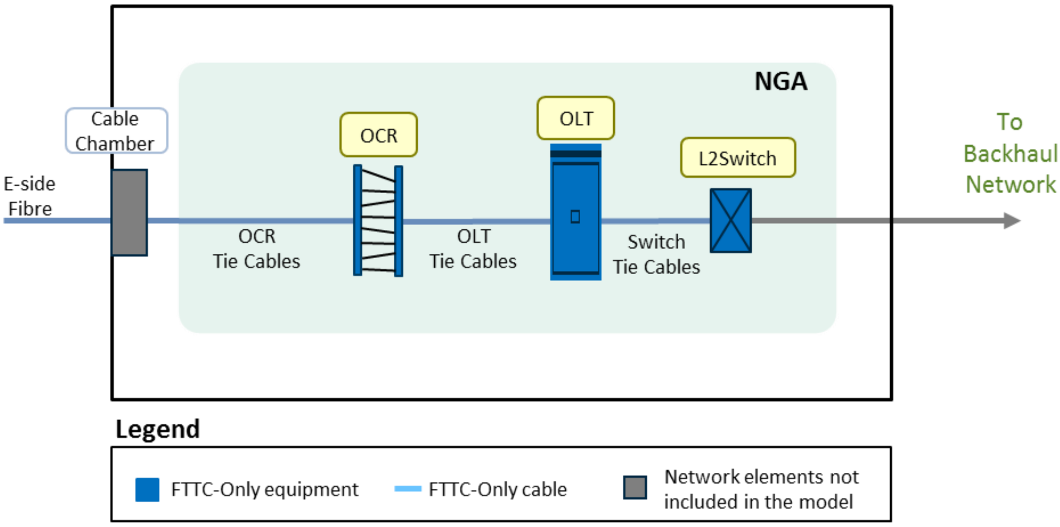
Figure 15. ***NGA Network topology inside the Exchange***




Source: Cartesian

*OCR (Optical Consolidation Rack)*

3.41 The OCR is used for the splicing of the OCR Tie Cable into fibre cables for direct connection to the active equipment (in this case, the OLT). The OCR constitutes an efficient alternative to the traditional Optical Distribution Frame (ODF). The OCR is comprised of a few subcomponents, which are listed separately in the 2016 NGA model. The table below lists the subcomponents, as well as typical capacity values. Note that these values will be updated in the next iteration of the 2016 NGA model, following input from CPs.

---

Figure 16. ***OCR elements used in The 2016 NGA model***

| Element | Description | Example of typical capacity |
|---|---|---|
| Chassis | Metal cabinet enclosure to host the subcomponents | 8 Sub-racks |
| Sub-Rack | The sub-rack slots into the rack, and is used to facilitate the splicing of fibres | 144 fibres |
| Straight connector | Terminates the OLT Tie Cable into the Sub-Rack | 1 fibre |
| Splice protector | Protects the fibre splice at the Sub-Rack | 1 fibre |
| OCR Tie Cable | Extends the E-side fibre from the Cable Chamber to the OCR | 144 fibres |

Source: Cartesian

*OLT (Optical Line Termination)*

3.42 The OLT is used for aggregating the signals from the FTTC subscribers. A GE port from each FTTC Cabinet is used as the equipment input. The upstream outputs of the OLT are 10 GE ports, which connect to the L2 Switch. The table below shows the OLT sub-parts which are used in the 2016 NGA model and typical capacity values. Note that these values will be updated following input from CPs.

Figure 17. ***OLT elements used in the 2016 NGA model***

| Element | Description | Example of typical capacity |
|---|---|---|
| Chassis | The housing that hosts the Network Cards and any common equipment cards not listed below (e.g. fan tray, switching module) | 15-20 Rack Unit (RU) slots |
| Access Card | Network Access Card supporting GE ports | 48 x GE ports |
| Access Port | 1 x GE port carrying the aggregated signal from the FTTC Cabinet | 1 Gbps |
| Egress Card | Network Access Card supporting 10 GE ports | 4 x 10 GE ports |
| Egress Port | 10 x GE port carrying the aggregated signal from the OLT Switching module | 10 Gbps |
| OLT Tie Cable | Connects the OLT to the L2 Switch Access Card | 24-fibre pair cable |

Source: Cartesian

### *L2 Switch*

3.43 The L2 Switch is used to segregate the FTTC traffic for each CP offering FTTC services by applying a different Virtual Local Area Network (VLAN) tag for each CP. The provisional list of subcomponents included in the 2016 NGA model, as well as typical capacity values, are listed in the table below. Note that these values will be updated following input from CPs.

---

Figure 18. ***L2 Switch elements used in the 2016 NGA model***

| Element | Description | Example of typical capacity |
|---|---|---|
| Chassis | The housing that hosts the Network Cards and any common equipment cards not listed below (e.g. fan tray, switching module) | 2 Access Cards |
| Access Card | Network Access Card supporting 10 GE ports | 4 x 10 GE ports |
| Access Port | 10 GE port carrying the aggregated FTTC signals from the OLT | 10 Gbps |
| L2S Tie Cable | Connects the OLT to the L2 Switch Access Card | 1 fibre pair |

Source: Cartesian

*Aggregated Rack Property Costs*

3.44 All Exchange buildings are assumed to have the following infrastructure:

- Cable Chamber
- Direct Current (DC) power, battery back-up and generator
- Alternating Current (AC) power and Uninterrupted Power System (UPS)
- Air Conditioning
- Security
- Environmental Alarms
- Fire suppressant
- Cable management
- Management network

3.45 These "property" costs are not modelled individually on a bottom-up basis. Instead, given that the floor space occupied by the FTTC equipment is a small portion of the overall Exchange available floor space, and in order to stay consistent with the 2013 Network Charge Control (NCC) model, an average capital cost per rack is estimated and applied proportionally to the network equipment based on rack space occupancy.[13] A placeholder capex cost of £2,000 per rack per year is used in Version 1 of the 2016 NGA model. The figure will be updated following input from CPs.

*FTTC Exchange Rollout*

3.46 As discussed in paragraphs 2.5 and 2.6, the 2016 NGA Model aims to reflect BT's actual FTTC Commercial rollout up to FY 2015/16, including the fibre-enabled (Head-end) Exchanges' annual deployment.

3.47 From FY15/16 to FY47/48, we assume the number of Head-end Exchanges remains unchanged to meet the FTTC Cabinet rollout figures detailed in Figure 8. The table below shows the placeholder values used in the 2016 NGA Model:

[13] This cost excludes electricity supply costs which are calculated in addition to this. For more detail see section 4 of this document, "Unit operating costs".

Figure 19. ***Fibre-enabled (Head-end) Exchange rollout used in the 2016 NGA Model [Placeholder values]***

| Actual / Estimate | FY | New Head-end Exchanges | Total Head-end Exchanges |
|---|---|---|---|
| Actual | FY09/10 | 100 | 100 |
| Actual | FY10/11 | 200 | 300 |
| Actual | FY11/12 | 400 | 700 |
| Actual | FY12/13 | 200 | 900 |
| Actual | FY13/14 | 50 | 950 |
| Actual | FY14/15 | 25 | 975 |
| Actual | FY15/16 | 5 | 980 |
| Estimate | FY16/17 | 0 | 980 |
| Estimate | FY17/18 | 0 | 980 |
| Estimate | FY18/19 | 0 | 980 |
| Estimate | FY47/48 | 0 | 980 |

Source: Cartesian. The figures above are placeholder values and thus do not represent the actual number of BT's Head-end Exchanges.

# 4. Model Implementation and Assumptions

## Overview of Network and Cost Modules

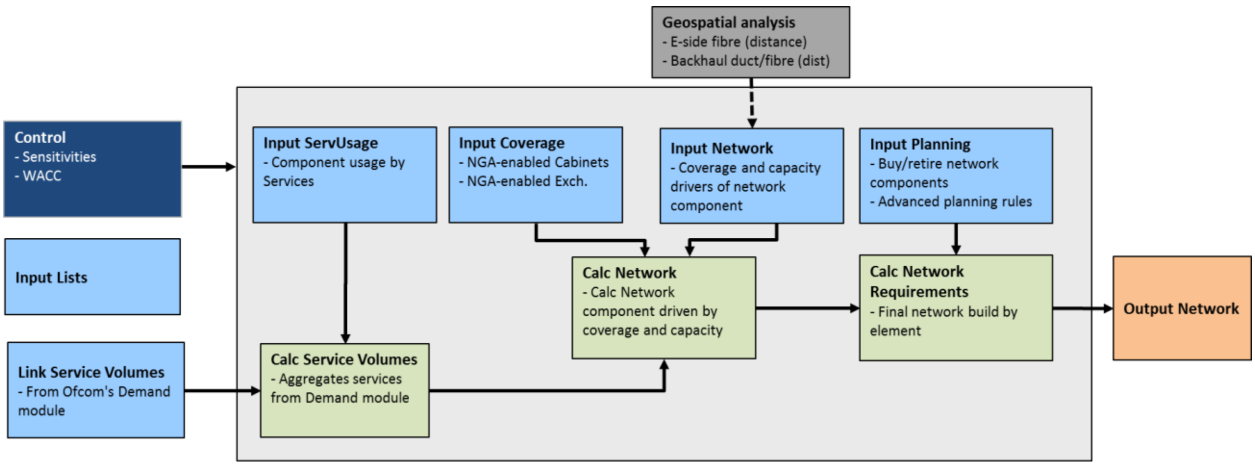
4.1 As outlined in the introduction to this document, Cartesian has developed two modules (the Network and Cost modules) that are components within the 2016 NGA model. The Network module uses the NGA service volumes and coverage forecasts to calculate the volumes of the NGA-specific network components. The Cost module calculates the capital and operating expenditure required to build and operate the NGA-dimensioned network. For those network components which are shared by NGA and non-NGA services, top-down costs are used as inputs to the Cost Module. The outputs from the Cost Module are used by the Depreciation module to calculate how costs are recovered over time and across services.

4.2 In Section 3 of this report, we described the hypothetical efficient modelled network. The remainder of this document discusses how we have modelled this network and determined its costs. Bear in mind that many of the network dimensioning parameters and cost inputs contained in Version 1 of the 2016 NGA model (accompanying this report) will be updated following input from CPs, as explained in paragraph 1.5.

## Network Module

4.3 The Network module takes the network architecture and demand inputs to dimension the NGA network accordingly. An overview of the logic of the network module is shown in Figure 20 below.

Figure 20. ***Network Module Overview***




Source: Cartesian

### *Overview of Network Module sheets*

4.4 Input sheets

- Control

  Allows the user to control and modify key parameters which affect the overall model for scenario modelling and sensitivity analysis.

- Link - Service Volumes

This interface sheet takes the service volumes applicable to the 2016 NGA model from the Demand Module.

- Input - Coverage

  This sheet contains the number of FTTC-enabled Exchanges and FTTC Cabinets for each year, which is used to dimension the minimum number of NGA network components.

- Off-model – Geospatial Analysis

  A number of tools (e.g. R, PostGIS) have been used to calculate model inputs requiring geospatial analysis, including E-side Fibre cable lengths and the PCP – FTTC Cabinet distance (see the analysis approach details in the respective subsections within Section 3 – Network Architecture). The results are populated into the Input_Network sheet.

- Input – Network

  This sheet contains the dimensioning drivers for each network element, which can be coverage drivers (e.g. E-side fibre is required when a Cabinet is FTTC-enabled) and/or capacity drivers (e.g. the number of DSLAM cards at the Cabinet increases with the number of FTTC subscribers).

- Input – ServUsage

  Determines which network elements are used by each service in the *Service Usage Factor* matrix. This is used in the Cost Recovery module to calculate the cost of each service.

- Input – Planning

  This sheet includes the asset lives of all the FTTC-only network components and defines the asset replacement purchase rules as well as the advanced planning rules.

## 4.5 Calculation sheets

- Calc - Service Volumes

  This sheet sums the internal and external services volumes provided by CPs, so they can be used for the correct dimensioning of the access network. Additionally, it calculates the service volumes by network component, which output feeds into the Cost Recovery module.

- Calc – Network

  Using the input sheets described above, this sheet calculates the asset count of the NGA network elements.

- Calc – Network Requirements

  Using the network element volumes from *Calc_Network,* and the network planning rules from *Input_Planning,* this sheet calculates the total quantity of NGA network assets that need to be purchased each year.

## 4.6 Module Output

- Output – Network

  This output sheet is a mirror of *Calc – Network Requirement*, and is used as an input by the Cost Module.

*Network Deployment*

4.7 As explained in paragraph 2.6, we have chosen to align the 2016 NGA modelled network to BT's actual commercial NGA deployment, i.e. excluding NGA coverage funded by BDUK.

*Bandwidth Demand*

4.8 The NGA Access network is dimensioned to support the broadband bandwidths used by the FTTC subscribers. The number of subscribers is provided by the Service Volume module. The network is dimensioned to meet the traffic demand that occurs during the busy hour.

4.9 The 2016 NGA model uses the average bandwidth per FTTC subscriber in the peak hour to dimension the network in each year of the 2016 NGA model. This value is used to calculate the total bandwidth at the FTTC Cabinets and the Exchanges, which are used to dimension the network cards and ports at these locations.

*Dimensioning of Elements*

4.10 Each network element type has up to two drivers that determine the quantity of the element required in the 2016 NGA model:

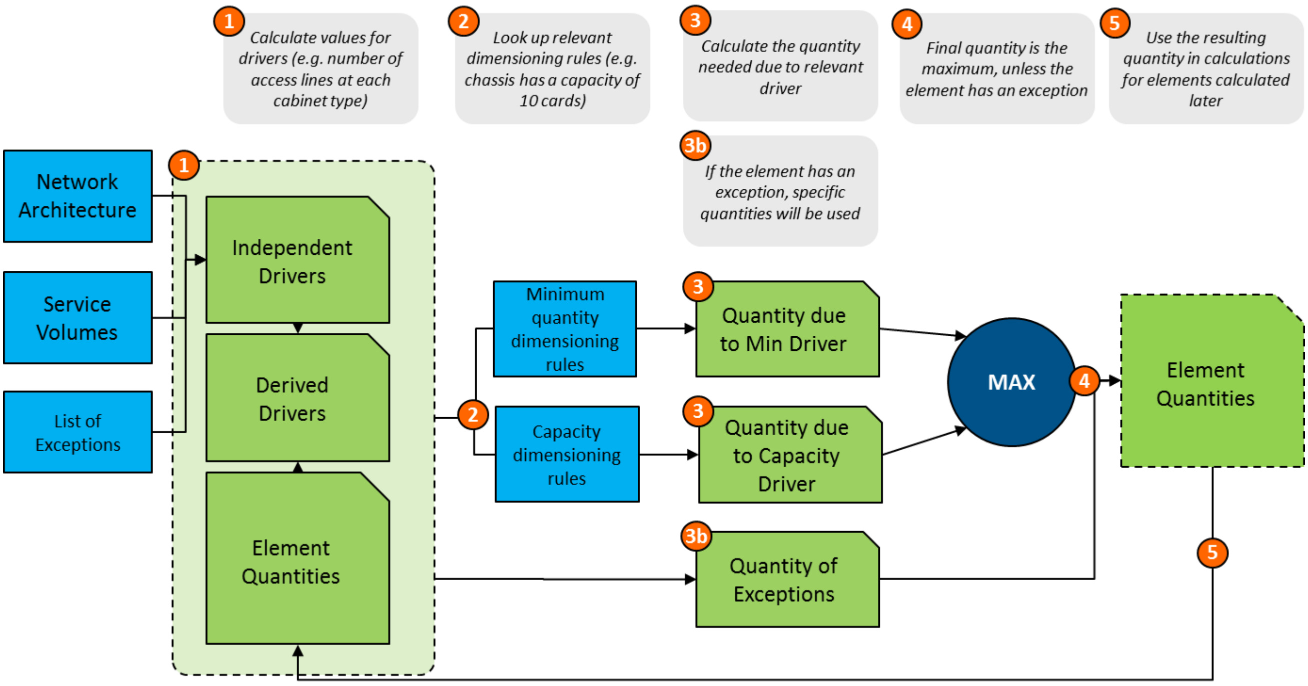
- MinDriver is the minimum number of an element that is required by the network architecture, independent of demand (i.e. the minimum quantity of a network element that would be required if there was no network traffic).
- The Capacity Driver determines how the quantity of the network elements are scaled, i.e. units in excess of those computed as the 'MinDriver'. The capacity drivers are either (a) direct demand inputs (e.g. a function of traffic or lines); or (b) derived inputs (e.g. the number of network elements is derived from the quantity of another network element).

4.11 To simulate the capacity planning and implementation functions of a real-world operator, the 2016 NGA model incorporates a capacity utilisation threshold. The 2016 NGA model (v1) includes a utilisation threshold of 70% for most of the active equipment (e.g. DSLAM, Layer2 Switch, OLT and their subcomponents). This initial value is consistent with other models Cartesian has built for its clients, including for Ofcom (e.g. the 2013 NCC model). We will review the utilisation thresholds of all network components in the next phase of the 2016 NGA modelling exercise, following input from CPs.

4.12 For the majority of elements, we follow a common approach to determine the required quantity for each network element in each year of the 2016 NGA model. This approach is illustrated in Figure 21.[14]

[14] The calculations of element quantities at step 3 in the diagram are interim results and care must be exercised if analyzing these figures as they may appear inconsistent in isolation due to the sequence of calculations. On a standalone basis, only the final results (after calculating the maximum figure) are meaningful.

Figure 21. ***Element Dimensioning Approach***




Source: Cartesian

4.13 The 2016 NGA model is also able to accommodate exceptions to the above approach. For example, the total lengths of E-side fibre and Backhaul Duct, determined by the geospatial analysis, are entered as exceptions.

*Calculate the Buy and Retire for Different Elements*

4.14 Once the 2016 NGA model has calculated the total number of elements required, it calculates the additional quantities required in each year given advance-planning requirements, the elements purchased for additional capacity and those purchased to replace retired equipment. The 2016 NGA model also calculates the quantity of network elements retired.

4.15 Assets in the network model are retired at the end of their useful lives and replaced if still required. As in real-world operations, there is variation between the useful lives of different network elements in the 2016 NGA model. The table below shows the initial asset lifetimes considered in the draft model which accompanies this document. These initial Cartesian estimates, informed by our work in previous network cost models, will be updated following input from CPs.

Figure 22. ***Asset Lifetimes by Equipment Type***

| Equipment Type | Asset Lifetime in Model (Years) |
|---|---|
| DSLAM | 5 |
| Street Cabinet | 20 |
| Inter Cabinet cabling | 40 |
| Opto-electronic Equipment | 10 |
| Rack and Frames | 10 |
| Servers & Software | 5 |
| Intra Exchange Cabling | 40 |
| E-side Fibre | 40 |
| Duct | 40 |
| Property | 40 |
| Optical Passive Equipment | 40 |

Source: Cartesian

4.16 The 2016 NGA model is based on an annual assessment, and as such any lead times are rounded to the nearest whole year. As a result, the 2016 NGA model assumes a planning lead time of one or zero years, depending on the network element. Those elements mostly driven by coverage drivers, which tend to require civil works and planning persmission (e.g. E-side fibre, FTTC Cabinets), are purchased and installed a year before their activation. Other network elements requiring less planning and lead time for their installation (e.g. access cards) are purchased and installed the same year as they are going to be utilised, effectively allowing from 0 up to 12 months of real planning time.

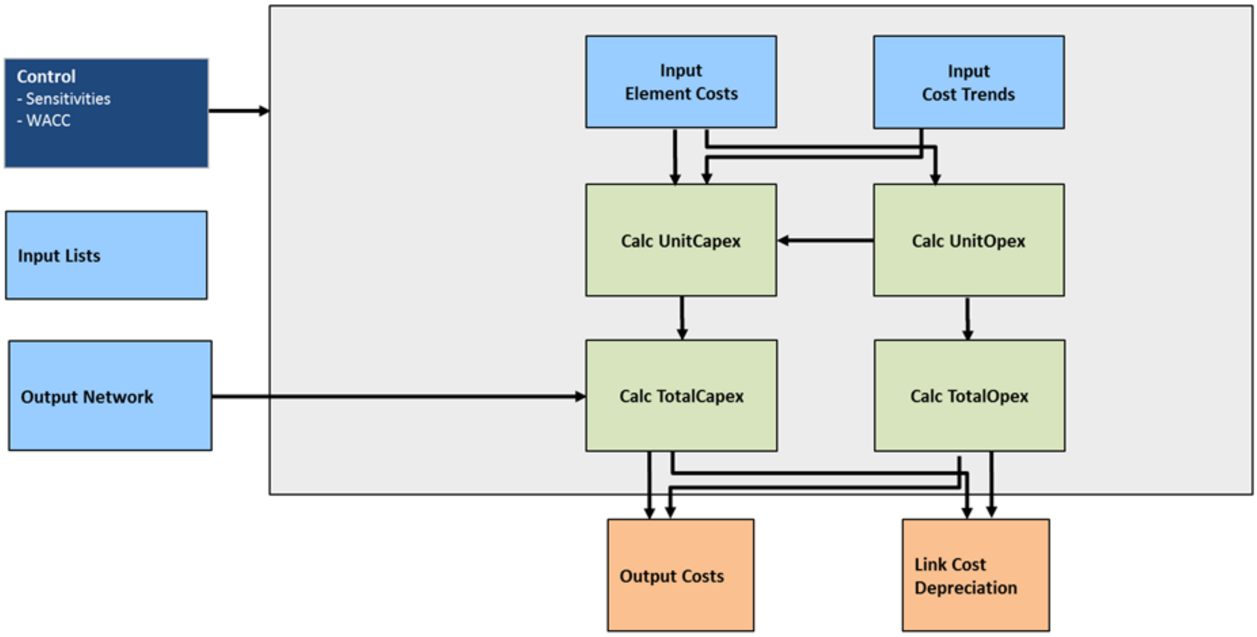
4.17 When deploying new FTTC Cabinets, the 2016 NGA model applies the one year planning rule to the cabinet, the DSLAM chassis and the GE card and port, but not to the Access Cards, which it assumes are installed the year they are required. In a real network deployment, though, one or two Access Cards would actually be installed at the same time as the other DSLAM components, whereas any additional access card would follow the standard capacity planning rules.

4.18 In order to understand the impact of this simplification, if one assumes that the total number of FTTC cabinets is c.51,000 (73% of a total figure of ca. 70,000 cabinets) and the purchase cost of an Access Card is assumed to be £700, the total cost of two Access Cards in each Cabinet is c.£71M. The impact of delaying this expenditure by one year is approximately £7M. Assuming a linear FTTC rollout over a period of 7 years (2009 – 2016), this translates to c.£1M/year which is not significant given the overall cost of the 2016 NGA modelled network. We will re-run the impact assessment when we obtain accurate data of BT’s actual FTTC rollout, to check that the impact is still insignificant.

## Cost Module

4.19 The Cost module takes its inputs from the Network module and produces total network cost estimates. The outputs from this sheet are then used as inputs in the Cost Recovery module. An overview of the cost module logic is shown in Figure 23 below.

Figure 23. ***Cost Module Overview***




Source: Cartesian

## *Overview of cost Module sheets*

4.20 Input sheets

- Control
  The user is able to control and modify key parameters which affect the overall model for scenario modelling and sensitivity analysis.
- Input – Output Network
  This sheet contains the total FTTC-only asset count to be purchased each year and is used as an input sheet to calculate the total service costs.
- Input – Element Costs
  This sheet details the current unit costs of all the NGA network elements (Capex and Opex) and is used in conjunction with the *Input Cost Trend* sheet to calculate the evolution of Capex and Opex unit costs over time.
- Input – Costs Trends
  This sheet contains the projected evolution of costs of the NGA network elements (e.g. cost of active equipment tends to decrease overtime). These inputs are used in conjunction with *Element Costs* sheet to calculate the evolution of Capex and Opex unit costs over time.

4.21 Calculation sheets

- Calc – UnitCapex
  Calculates the unit Capex cost of the NGA-only network elements, using *Element Costs* and *Cost Trend* as inputs.
- Calc – UnitOpex

Calculates the unit Opex cost of NGA-only network elements, using *Element Costs*, *Cost Trend* and *UnitCapex* as inputs (the latter is used because some of the Opex cost can be capitalised, depending on the 2016 NGA model scenario).

- Calc – TotalCapex

  Multiplies the Capex unit cost from *UnitCapex* by the number of network elements to determine the total Capex costs.
- Calc – TotalOpex

  Multiplies the Opex unit cost from *UnitOpex* by the number of network elements to determine the total Opex costs.

4.22 Output sheets

- Output – Costs

  This output sheet summarises the total Capex and Opex costs incurred to deliver NGA services. This sheet is used in the Cost Recovery module.
- Link – Cost Depreciation

  This output sheet contains output tables required by the Cost Recovery module for calculating the asset cost depreciation over time.

### *Element Unit Costs Trends*

4.23 The 2016 NGA model calculates the unit costs (both Capex and Opex) of each network element over the life of the network. After FY 2027/28 unit Capex and Opex are assumed to remain constant for the remainder of the 2016 NGA modelling period in real terms. There are nine cost trend categories in the 2016 NGA model. The cost trend categories are shown in Figure 24 below. The initial Cartesian estimates shown below are used as placeholders in the model which accompanies this document, and have been informed by our work in previous network cost models. These values will be updated following input from CPs.

Figure 24. ***Cost Trends by Category***

| Trend Category | Nominal Capex Trend | Nominal Opex Trend |
|---|---|---|
| Property | 2% | 2% |
| Labour | 3% | 3% |
| Racks and Cooling | -2% | -2% |
| Copper cable | -2% | -2% |
| Fibre cable | -3% | -3% |
| Duct | -3% | -3% |
| Active Equipment | -5% | -5% |
| Passive Equipment | -1% | -1% |
| Software and platforms | -2% | -2% |

Source: Cartesian

4.24 The 2016 NGA model uses the Consumer Price Index (CPI) to convert the nominal values for Capex and Opex to real 2015/16 values. Historical values, obtained from the Office for National Statistics (ONS), are used where available. For FY 2015/16 to FY 2020/21 we use CPI forecasts from the Office for Budget Responsibility (OBR). Forward-looking CPI for the period FY 2020/21 to FY 2047/48 is held at 2.0%, as per OBR's forecast for 2020.

4.25 The 2016 NGA model includes a Capex and Opex trend for Labour to allow for installation costs to be capitalised and retirement costs to be trended for each network element.

*Unit Capital Costs*

4.26 The base year for asset costs in the 2016 NGA model is FY 2015/16. Asset costs for other years are determined by using the historical actuals, or by applying forward-looking cost trends based on historical actuals, depending on the amount and quality of data received from the stakeholders.

4.27 Installation costs are represented in the 2016 NGA model through estimates of man-hours and labour rates to install each network element. The Cartesian estimates used in the model which accompanies this document have been informed by our work in previous network cost models. These values will be updated following the input from CPs.

4.28 In addition, the retirement cost of assets has also been included as part of capital expenditure.[15] This cost to decommission each network element is based on the number of man hours required and the cost of labour.

4.29 The 2016 NGA model also includes the capital cost of Business and Operations Support Systems (BSS/OSS) that is incremental for NGA. BSS/OSS support fulfilment, assurance and billing processes for the wholesale voice and data services.

*Unit Operating Costs*

4.30 Operating costs (excluding power) for each network element in the draft model are captured by either an absolute figure where available or they are estimated as a percentage of the capital costs. The initial value used as a placeholder in the draft model is Opex costs at 20% of the capex costs, which is in line with other models (e.g. 2013 NCC model). These values will be updated following input from CPs.

4.31 We calculate the cost of power based on per-network element power usage and the trended cost per kWh in the UK for industrial power supply. The network element power usage assumptions in the model are based on equipment vendor guidelines.

4.32 Air conditioning requirements are assumed to be proportional to per element power consumption. We assume that each kW of power required by network equipment produces heat that requires 0.8 kW of cooling. This estimate is benchmarked to equipment vendor guidelines.

*Calculation of Total Costs and Module Outputs*

4.33 The total annual capital expenditure for each network element is calculated as follows:

- The product of that year's unit capex figures (including equipment and labour costs) and the number of network elements purchased in that year.

4.34 The total annual operating expenditure is calculated as follows:

[15] Functionality has been included to allow retirement costs to be treated as capital or operating expenditure. By default, retirement costs are treated as capital expenditure.

- The product of that year's unit Opex figures and the number of network elements in operation during that year.

4.35 The total network Capex and Opex provide inputs to the Cost Recovery module. In addition to the total cost outputs, the element unit Capex and Opex trends, and element quantity outputs from the cost module are also used by the Cost Recovery module. Finally, the Service Usage factors from the Network module are also used to allocate the costs of network element output to network services.

# 5. Glossary

| Abbreviation | Definition |
|---|---|
| AC | Alternating Current |
| BDUK | Broadband Delivery United Kingdom |
| BSS | Business Support Systems |
| BT | British Telecommunications plc |
| Capex | Capital Expenditure |
| CGA | Current Generation Access |
| CJ | Cable Joint |
| CP | Communications Provider |
| CPI | Consumer Price Index |
| DC | Direct Current |
| D-side | Distribution side |
| DSL | Digital Subscriber Line |
| DSLAM | Digital Subscriber Line Access Multiplexer |
| E-side | Exchange side |
| FTTC | Fibre To The Cabinet |
| FY | Financial Year |
| GE | Gigabit Ethernet |
| HH | Households |
| L2S , L2 Switch | Level-2 Switch |
| LLU | Local Loop Unbundling |
| MNO | Mobile Network Operator |
| MSAN | Multi-Service Access Nodes |
| NCC | Network Charge Control |
| NGA | Next Generation Access |
| NTE | Network Termination Equipment |
| OBR | Office for Budget Responsibility |
| OCR | Optical Consolidation Rack |
| ODF | Optical Distribution Frame |
| OLT | Optical Line Termination |
| ONS | Office for National Statistics |
| Opex | Operational Expenditure |
| OSS | Operations Support Systems |
| PCP | Primary Connection Point |
| RU | Rack Unit |
| SFP | Small Form-factor Pluggable |
| SLU | Sub-Loop Unbundling |
| UPS | Uninterruptible Power Supply |

| | |
|---|---|
| VDSL2 | Very high bit-rate Digital Subscriber Line 2 |
| VLAN | Virtual Local Area Network |
| WFAEL | Wholesale Fixed Analogue Exchange Lines |
| WLA | Wholesale Local Access |
| WLR | Wholesale Line Rental |

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