Wholesale Local Access Market Review: NGA Cost Modelling

Network & Cost Module Documentation

V2

30 March 2017

Prepared for:

Ofcom

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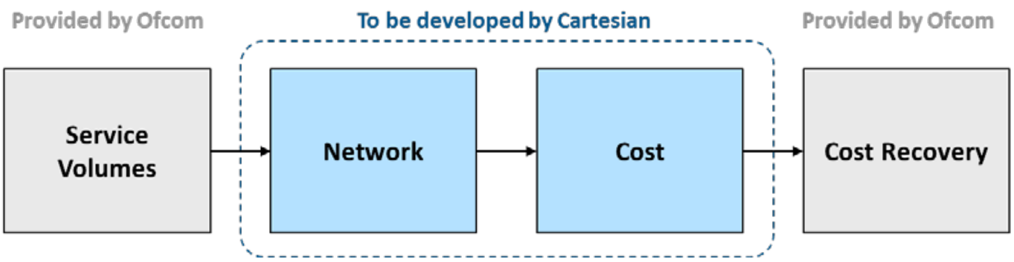
1 Introduction

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

1.2 As part of the March 2017 WLA Consultation Ofcom is considering its regulatory approach for access to GEA services. Ofcom has engaged Cartesian to assist with the construction of a new bottom-up cost model for GEA services ('the bottom-up 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 bottom-up 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 capacity, coverage and traffic demand inputs and how this network dimensioning drives costs. The section also describes the outputs that are then used to calculate the unit cost of GEA services.

1.5 This bottom-up model documentation v2 accompanies Version 2 of the bottom-up model.

2 Scope

2.1 The scope of the bottom-up 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 bottom-up model is Cabinet-based VDSL2, also referred to as FTTC.

Services

2.3 The number of GEA services supported by the bottom-up model is flexible; the current model version (v2) has space for up to six, which is likely to be sufficient. In this version of the bottom-up model, we consider one of the GEA services which BT currently offers, including both external and internal supply.[2]

2.4 Additionally, ancillary services are considered in the bottom-up model, including customer site installations and service provision.

Geographic coverage

2.5 The geographical scope of the bottom-up 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 bottom-up model covers areas included in BT's commercial deployment, i.e. excludes coverage areas that were partly funded by state aid (i.e. BDUK, SEP). We have used a data set for network coverage from BT which segments the BDUK-funded areas; allowing them to be excluded from the network dimensioning calculations.

Timeframe

2.7 Time periods in the bottom-up model are financial years (FY), i.e. April to March. The Bottom-up model considers a 20-year period, from 2007/08 to 2027/28.

2.8 The bottom-up 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 bottom-up 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 bottom-up model, with only those components that are specific to GEA services modelled on a bottom-up basis. The component costs for the current generation access (CGA) network that are also shared with the GEA services are considered separately in the WLA charge control and are not currently included in the bottom-up model.

[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

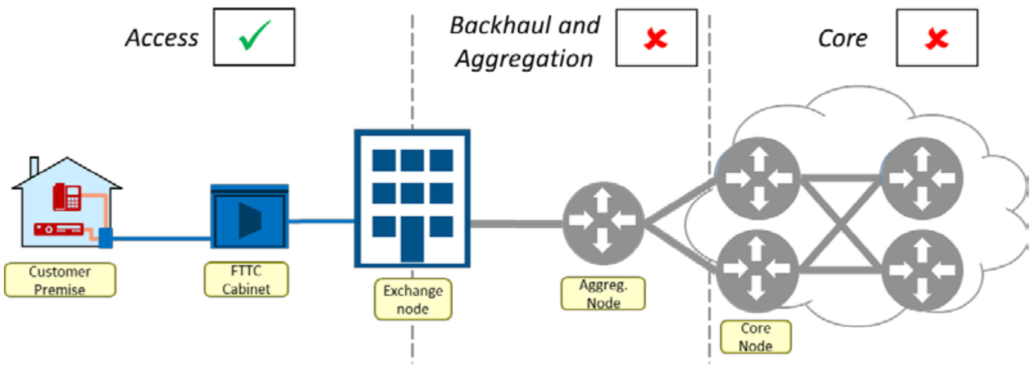
2.10 The network module employs a scorched node approach.[4] In this context, *node* refers to the Exchange, PCP and FTTC Cabinets: The bottom-up model uses route lengths that are derived from the distances between the actual locations of BT's assets.

3 Network Architecture

Overview

3.1 The bottom-up 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***



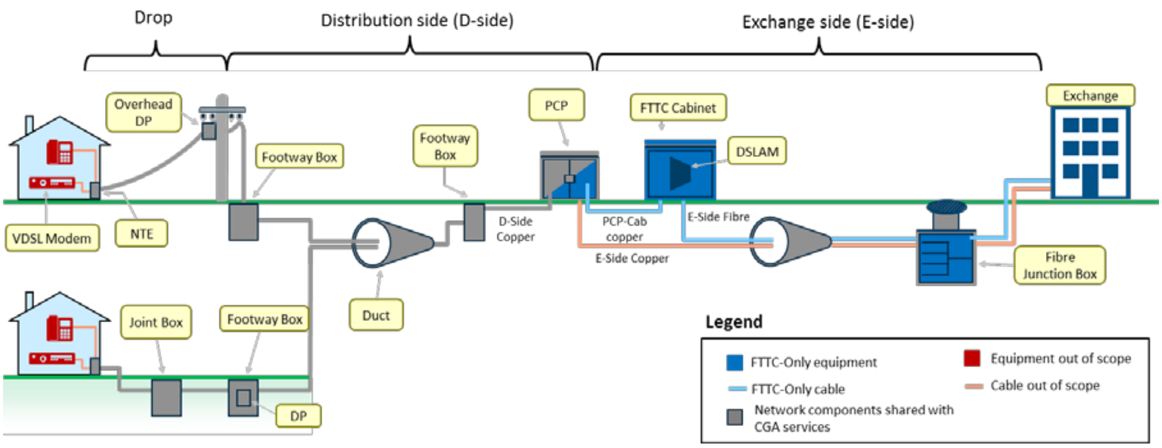
Source: Cartesian

3.1 Figure 3 below shows a more detailed physical architecture diagram of the access network considered in the bottom-up 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 2.9, those network elements which are shared between GEA services and CGA services are not included in the bottom-up modelled network (grey in the diagram).

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

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 are considered elsewhere in the Wholesale Local Access Market Review Consultation and are not included in the bottom-up model.

PCP Cabinets and PCP-to-FTTC Cabinet

3.4 PCP cabinets are used for both NGA and CGA services. The cost of this network component is therefore not included in the bottom-up model, with the exception of two subcomponents which are incremental to NGA:

- A PCP connector is required to connect the copper cables from the DSLAM.
- In circumstance where the free capacity from the PCP Shell type is less than the capacity required for the tie cables then a PCP Re-shell will be required. The number of PCPs that would require a re-shell has been assumed to be [✂] (10% to 30%) of the total number of PCPs, using actuals figures provided by BT for the period from October 2009 to September 2012.

3.5 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 GEA services, therefore these costs are modelled on a bottom-up basis.[5]

3.6 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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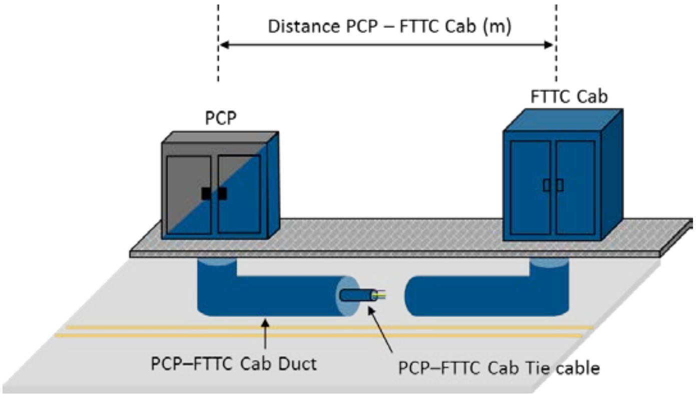
[5] In reality, if the PCP and FTTC Cabinet are relatively far apart, in addition to new duct there may be some re-use of existing duct. However, only new duct is included in the BU Cost Model.

[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

3.7 Using input data provided by BT[7], the average PCP-FTTC Cabinet duct length used in the bottom-up model is [✂] (~8.4) metres. The general planning rule is that the distance should be less than 50 meters.

3.8 Using data provided by BT[8], the average PCP-FTTC Cabinet Tie Cable length used in the bottom-up model is [✂] (~19.8) metres[9]. The cable length is dependent on the number of copper cable pairs. In turn, the number of copper cable pairs is dependent on the PCP size, therefore the bottom-up model includes a different cable type for each PCP size: [✂] (~297) pairs for Type 1, and [✂] (~624) pairs for Type 2.

3.9 The table below shows the PCP components in the cost model, and their subcomponents, following input from BT[10]:

[7] BT's Chief Engineer Model
[8] BT's Chief Engineer Model
[9] The reason why we assume a longer tie copper cable length (with respect to a tie duct) is because we assume a two-way duct of [✂] (~8.4m) of length each, so [✂] [~16.8m] of new duct. The additional [✂] [~3m] are required to connect from the duct to the Cabinets.
[10] BT's Chief Engineer Model

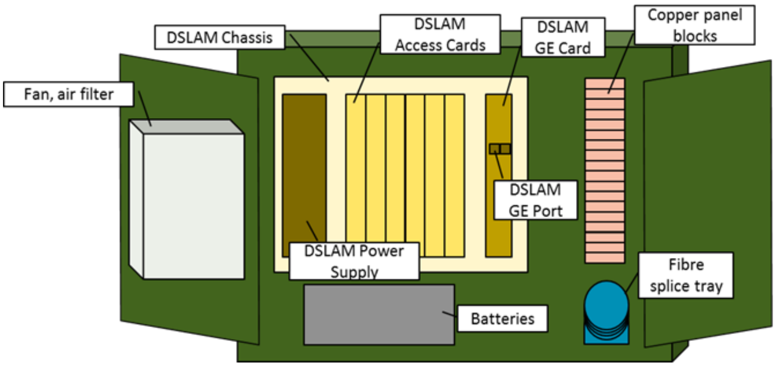
Figure 5. ***PCP elements used in the bottom-up model***

Network elements in the Bottom-up model	Subcomponents
PCP Re-shell	- PCP Reshell - PCP Build
PCP Connectors	- Connector - Mounting Column in PCP
PCP_Duct to FTTC Cab	- Duct installation (blended cost for different surfaces, following input from BT)
PCP_Copper to Cabinet (for each cabinet type)	- Cable ([✂] (~624 pairs)) - Cable joints/terminations

FTTC Cabinet

3.10 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 6 below shows the DSLAM with its subcomponents, as well as other equipment required in the FTTC Cabinet.

Figure 6. ***Diagram with key network components inside an FTTC Cabinet***



Source: Cartesian

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

Figure 7. ***FTTC Cabinet elements used in the bottom-up model***

Network elements in the Bottom-up model	Subcomponents
DSLAM Cabinet	- FTTC Cabinet - Copper panel blocks - Fibre splice tray - Fan, air filter system - Battery back-up - Security system - Frame - Control Board - Power Supply Unit
DSLAM Access Card	- Access Card - GE Port, Small Form-factor Pluggable (SFP)[11]
DSLAM GE Port	- None, as the cost included in the DSLAM Access Card (this element is only used for modelling purposes)
Certification Managed Service	- Survey and pre-work - Power Certification - Electricity Meter supply - Telemetry Line
Civils	- Concrete Base - Earthing mat - Tube Intercept Joint
Power Connection	- Power Duct (6m, using blended surface from BT) - Power Joint - Management of power connection

Source: Cartesian

3.12 BT has stated that virtually all] of its FTTC Cabinets – except for two, out of a total of ca. 70,000 cabinets[12] – have a single 1 GE link connecting them to the Exchange. Considering that DSLAMs typically support no less than four GE ports (depending on the size of the DSLAM), we conclude that GE interfaces are sufficient at the FTTC Cabinet, and that as such there is no need to model 10GE interface cards.

[11] We note that Access Cards and GE Ports are modelled as separate network elements for dimensioning purposes but their costs have been aggregated given that BT indicated that the cost of GE ports is included in the price of an Access Card.
[12] This figure reflects BT's full FTTC coverage in the UK, including BDUK areas.

3.13 Using information from BT[13], Version 2 of the bottom-up model includes two types of FTTC Cabinets, a Type 1 (small) and a Type 2 (large) cabinet, with a [✂] (10% - 40%) and [✂] (60% - 90%) share respectively. BT uses two vendors for each cabinet type. As the bottom-up model is vendor-agnostic, we have analysed the capacity of the cabinets:

- Both Type 1 cabinets currently have the same port capacity.
- BT's Type 2 cabinets have different port capacity. We have calculated a blended capacity, using the share of cabinets from each vendor.

3.14 The equivalent cabinet capacity in the model for 2015/16 is shown in the figure below:

Figure 8. ***DSLAM Capacity for each Cabinet type***

Cabinet Type	Network components in the bottom-up model	Capacity	Total Capacity
Type 1	FTTC Cabinet	1 DSLAM Chassis	128 subscribers
	DSLAM Chassis	4 DSLAM Access Cards	
	DSLAM Access Card	32 subscriber lines	
Type 2	FTTC Cabinet	1 DSLAM Chassis	276 subscribers
	DSLAM Chassis	6 DSLAM Access Cards	
	DSLAM Access Card	46 subscriber lines	

Source: Cartesian

3.15 Additionally, BT has provided information about the evolution of the port capacity of their cabinets over time, for each vendor type[14]. For instance, the small cabinets of one of the vendors has increased from [✂] ports in FY 12/13, to [✂] currently, and it is planned to increase to [✂] ports from FY16/17. The large cabinet of one of the vendors will also increase its capacity from [✂] to [✂] ports from FY16/17.

3.16 As the port capacity of the FTTC cabinets in the model is fixed (as part of the model design), we have modelled the variations in capacity using MEA (Modern Equivalent Asset) adjustments. These adjustments consist of calculating the equivalent capex and opex unit cost reduction of the FTTC cabinets and their Access cards achieved by the increase in port capacity. We have calculated this for each FTTC cabinet type. We have spread the equivalent unit cost reduction over a period of three years. See Figure 29 for a table with the MEA adjustments used in the bottom-up model.

[13] BT's actual data
[14] BT's Chief Engineer Model

FTTC Cabinet Rollout

3.17 As discussed in paragraphs 2.5 and 2.6, Version 2 of the bottom-up model reflects the number of FTTC cabinets in BT's actual FTTC commercial (i.e. non-BDUK) rollout up to FY 2016/17[15].[16] The table below shows the FTTC Cabinet rollout and premises covered in the bottom-up model:

Figure 9. ***FTTC Cabinet rollout used in the bottom-up model***

Actual / Estimate	FY	New FTTC Cabinets	Total FTTC Cabinets	% Premises covered
Actual	FY09/10	[✂] (~1,441)	[✂] (~1,441)	0-10%
Actual	FY10/11	[✂] (~7,277)	[✂] (~8,718)	10-20%
Actual	FY11/12	[✂] (~9,607)	[✂] (~18,325)	30-40%
Actual	FY12/13	[✂] (~16,062)	[✂] (~34,387)	50-60%
Actual	FY13/14	[✂] (~9,714)	[✂] (~44,101)	60-70%
Actual	FY14/15	[✂] (~1,938)	[✂] (~46,039)	70-80%
Actual	FY15/16	[✂] (~1,146)	[✂] (~47,185)	70-80%
Estimate	FY16/17	[✂] (~553)	[✂] (~47,738)	70-80%
Estimate	FY17/18	0	[✂] (~47,738)	70-80%
Estimate	FY18/19	0	[✂] (~47,738)	70-80%
Estimate	FY47/48	0	[✂] (~47,738)	70-80%

Source: BT Actuals

E-side Duct

3.18 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.[17] Taking this into account, we would expect an efficient operator deploying FTTC would maximise the re-use of existing duct infrastructure. Therefore, the bottom-up 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. As a result, as with D-side ducts, shared E-side Duct costs are not included in the bottom-up model.

3.19 Incremental costs associated with repairing existing ducts or installing new ducts due to congestion are added in the Cost Recovery module as a top-down allocation.

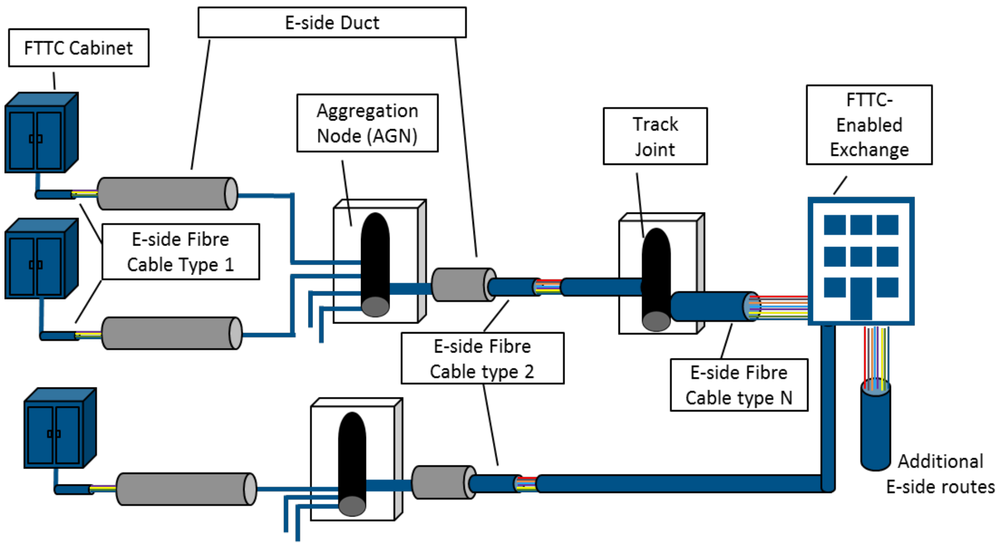
E-Side Fibre

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

[15] Information provided by BT on its FTTC commercial rollout suggests that further FTTC commercial rollout (beyond 2016/17) is likely to be immaterial.
[16] This excludes BT's FTTC rollout partly funded by BDUK. Actual data provided by BT up to September 2016
[17] 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).

3.21 The E-side network topology considered in the cost model consists of a number of fibre cables types, with different fibre-pair counts, and the sub-duct in which the fibre cable is placed. The thinnest cables are used at the egress of the FTTC Cabinet. The cables of various routes are aggregated into larger cables at Aggregation Nodes (AGN) and Track Joints. There may be a number of AGNs and Track Joints between an FTTC Cabinet and the Exchange. The bottom-up model uses the number of AGNs and Track Joints provided by BT[18] (we calculate the number of AGNs and Track Joints per Exchange and use these parameters as the unit driver). Figure 10 below shows the E-side network topology considered in the bottom-up model.

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



Source: Cartesian

3.22 The Aggregation Node (AGN) is the primary joint that aggregates the fibre cables (Type 1) from different FTTC Cabinets into a Type 2 fibre cable. A Track Joint may then be used to aggregate further fibre cables before it reaches the FTTC-Enabled Exchange. Fibre testing is also required at each Cabinet, however, only the fibres that are in use are tested, any spare fibres are not tested.

3.23 Version 2 of the bottom-up model uses six types of fibre cables, ranging from 4 fibres to 256 fibres, following input from BT. The fibre cables are 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, e.g. when an increase in egress bandwidth at the FTTC Cabinet means that additional fibre pairs are required to channel all the bandwidth back to the Backhaul network.

3.24 Figure 11 below shows the fibre cable types and the fibre dimensioning assumptions used in Version 2 of the bottom-up model. Note that based on the demand inputs, one fibre pair per FTTC Cabinet is sufficient to cover the initial bandwidth demands.

[18] BT's actual data

Figure 11. ***E-side fibre cable types and dimensioning rules for initial build***

No fibre routes (min - max)	Fibre cable type
1	4 Fibres
2 – 4	24 Fibres
5 - 8	48 Fibres
9 - 16	96 Fibres
17 - 30	144 Fibres
31 - 64	256 Fibres
> 65	2 x 256 Fibres

Source: Cartesian

3.25 We estimate the routes and lengths of the E-side fibre cables using geospatial analysis of BT's actual FTTC Cabinet and Exchange location data up to FY 2015/16. Cartesian used a combination of open-source software (e.g. R and PostgreSQL), commercial software and Cartesian's proprietary analytics platform, Ascertain, for the geospatial analysis.

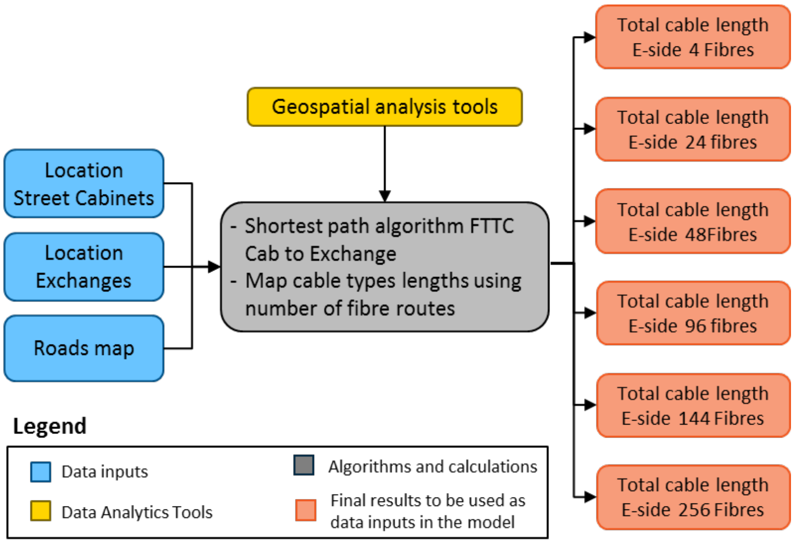
3.26 Figure 12 below shows an example of the geospatial analysis, displaying the cable routes from a sample Exchange to its FTTC Cabinets, using a *shortest route* algorithm which follows existing roads. This version of the model includes the results of the geospatial analysis for the E-side cable.

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

Source: Cartesian

3.27 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;

3.28 The bottom-up model uses the following components and subcomponents:

Figure 14. ***E-side fibre elements used in bottom-up model***

Network elements in the bottom-up model	Subcomponents
Fibre cable	- Fibre cable types (4f, 24f, 48f, 96f, 144f, 256f) - Sub-duct where fibre cable is inserted
Fibre Testing	- Fibre insertion loss testing
Aggregation Node	- Aggregation Node
Track Joint	- Optical Track Joint

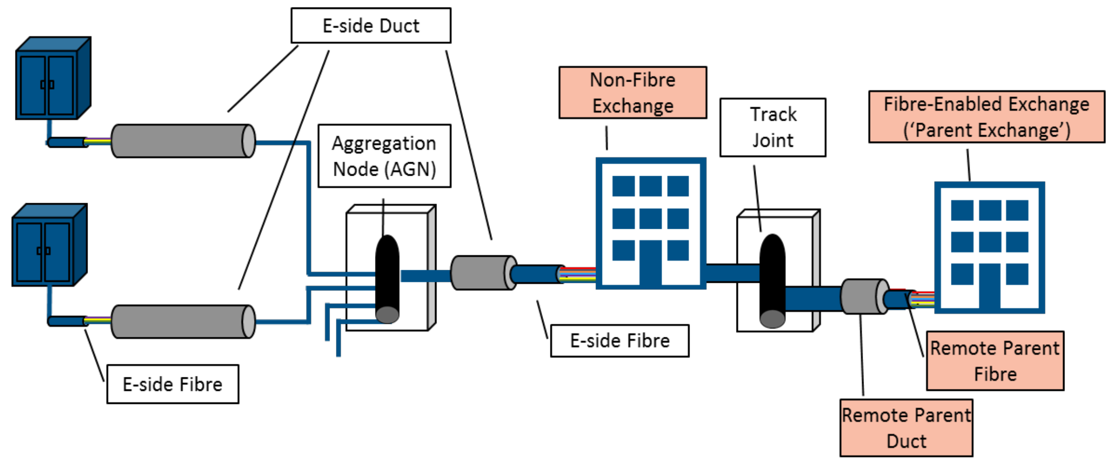
Remote Parent Duct and Fibre

3.29 In the bottom-up modelled network there are two methods of connecting the FTTC Cabinet to the Parent Exchange. The first one 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 method 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 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.

3.30 Incremental costs associated with repairing existing ducts or installing new ducts due to congestion are added in the Cost Recovery module as a top-down allocation. The approach followed by Ofcom to estimate these costs is explained in Annex 12 of the Wholesale Local Access Market Review Consultation document.

3.31 The connection between Exchanges is considered as part of the Remote Parent network. Figure 15 below shows the E-side and Remote Parent network topology in scope. These ducts and fibre may be used by services other than NGA (e.g. leased lines, Remote Parent network for LLU).

Figure 15. ***Network topology with Remote Parent Duct***



Source: Cartesian

3.32 BT provided information of the actual number of Remote parent routes in which existing fibre is reused to deliver GEA services. Using geospatial analysis, we have calculated the average distance of a parent-child Exchange route 8,315] metres[19]. These two parameters have been used to calculate the total amount of additional fibre cable required between child and parent Exchanges.

3.33 Similar to the E-side cables, the following components and subcomponents are included in the bottom-up model:

Figure 16. ***Remote Parent Fibre elements used in bottom-up model***

Network elements in the Bottom-up model	Subcomponents[20]
Remote Parent Fibre	- Fibre cable (blended cost of cable types used, i.e. 48f, 96f, 144f, 256f) - Sub-duct where fibre cable is inserted
Remote Parent Fibre Testing	- Fibre insertion loss testing
Track Joint	- Optical Track Joint

Source: Cartesian

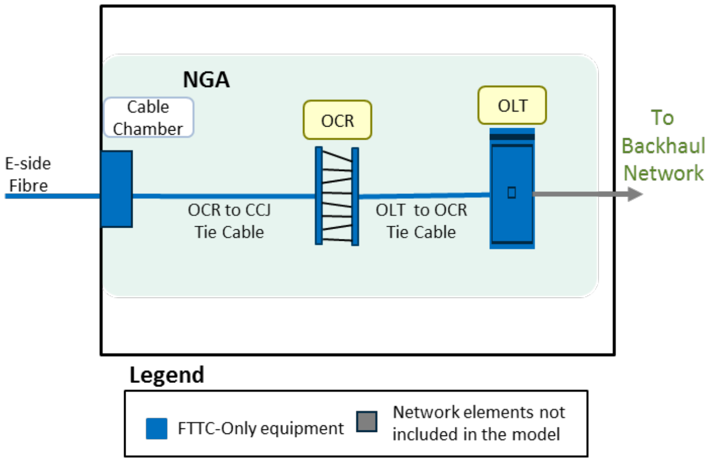
[19] This is a Cartesian estimate based on the geo-location of around 900 BT exchanges, specified by Ofcom.
[B]as per BT's Chief Engineer Model

Exchange

Overview

3.34 At the Exchange, the bottom-up modelled network includes the Optical Consolidation Rack (OCR), the Optical Line Termination (OLT) and the Tie Cables between them. Figure 17 below illustrates the modelled topology.

Figure 17. ***NGA Network topology inside the Exchange***



Source: Cartesian

OCR (Optical Consolidation Rack)

3.35 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 bottom-up model. The table below lists the subcomponents, as well as the capacity values provided by BT.

Figure 18. ***OCR elements used in The bottom-up model***

Element	Description	Capacity
EXCH_OCR_Chassis	Metal cabinet enclosure to host the subcomponents	• 8 Sub-racks
EXCH_OCR_Sub-Rack	The sub-rack slots into the rack, and is used to facilitate the splicing of fibres	• 72
EXCH_OCR_to_CCJ_ Tie Cable	Extends the E-side fibre from the Cable Chamber to the OCR	• 144 fibres[21]
Cable Chamber Joint	Aggregates the fibre cables(s) coming from the E-side and interconnects with the OCR Tie Cable	• 144 fibres

Source: Cartesian, BT planning rules

OLT (Optical Line Termination)

3.36 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 assumed to be [1]GE ports[22]. BT uses two OLT suppliers, with different port capacities. The table below shows the OLT sub-parts which are used in the bottom-up model and the blended capacity of both OLT providers:

Figure 19. ***OLT elements used in the bottom-up model***

Element	Description	Capacity
EXCH_OLT_Chassis	The housing that hosts the Network Cards and any common equipment cards not listed below (e.g. fan tray, switching module)	• 8 OLT Southbound Cards
EXCH_OLT_Southbound Card	Network Access Card supporting GE ports	• 16 x GE ports
EXCH_OLT_Northbound Card	Network Access Card supporting GE ports	• 1 per OLT]
EXCH_OLT_to_OCR_Tie Cable	Connects the OLT to the OCR	• 10 fibres

Source: Cartesian, BT planning rules

Exchange Accommodation Costs

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

[21] We are aware that BT uses multiple cable types, which capacity varies from 24 fibres to 144 fibres (see Figure 1 in BT, 2016. Response to Ofcom consultation on possible approaches to fibre cost modelling). We do not have information about the actual distribution of these cable types across BT's commercial FTTC network. However, given that the cost of installing the fibre cable far exceeds the cost of acquiring the cable, we consider that an efficient operator would install the biggest cable type from the outset. Therefore, we have assumed that the capacity of a OCR to CCJ tie cable is 144 fibres, rather than a blend of different cable type capacities.

[22] BT's actual data

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

3.38 These “Accommodation” 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 as is consistent with the 2013 Network Charge Control (NCC) model, an average capital cost per rack of active equipment at the Exchange (i.e. OLT in this case) is estimated.[23] Following information provided by BT[24], the Capex cost per OLT is estimated at [✂] (~5,083).[25]

FTTC Exchange Rollout

3.39 As discussed in paragraphs 2.5 and 2.6, the bottom-up model aims to reflect BT’s actual FTTC Commercial rollout, including the fibre-enabled (Head-end) Exchanges’ annual deployment. The table below shows the values used in the bottom-up model:

Figure 20. ***Fibre-enabled (Head-end) Exchange rollout used in the bottom-up model***

Actual / Estimate	FY	New Head-end Exchanges	Total Head-end Exchanges
Actual	FY09/10	[✂] (~78)	[✂] (~78)
Actual	FY10/11	[✂] (~258)	[✂] (~336)
Actual	FY11/12	[✂] (~250)	[✂] (~586)
Actual	FY12/13	[✂] (~143)	[✂] (~729)
Actual	FY13/14	[✂] (~66)	[✂] (~795)
Actual	FY14/15	[✂] (~3)	[✂] (~798)
Actual	FY15/16	[✂] (~3)	[✂] (~801)
Estimate	FY16/17	0	[✂]

[23] 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”.

[24] BT’s Chief Engineer Model

[25] These are the capex costs of accommodation associated with installing an OLT.

			(~801)
Estimate	FY17/18	0	[✂] (~801)
Estimate	FY18/19	0	[✂] (~801)
Estimate	FY28/29	0	[✂] (~801)

Source: Cartesian. BT Actuals

Other Costs

3.40 Following input from BT, the bottom-up model also takes into consideration other costs associated with the FTTC rollout. The table below summarises them:

Figure 21. ***Other NGA cost items used in the bottom-up model***

Element	Description	Data source
Provisioning Services	Activities required by BT in order to provision, cancel, amend NGA customers. They have been aggregated into Software Configuration, PCP Jumpering, Engineering Premises Visit	BT's Chief Engineer's model
Planning (DSLAM and Remote parent)	Cost of planning and designing rollout of DSLAMs and Remote Parent cables.	BT's Chief Engineer's model
OSS/BSS Hardware and Software	Costs of the OSS and BSS platforms in order to support the GEA services, e.g. provisioning, monitoring	Ofcom estimate (see Annex 12)
Pre-service launch	Costs of preparation activities required by BT before the NGA rollout, e.g. feasibility studies, proof of concepts, trials	BT's actual data
Access Operation Centre	Costs related to running the NGA Operation Centre	BT's Chief Engineer's model
Fixed Warranty Fee	Warranty Fees for the DSLAM in the FTTC Cabinets	BT's Chief Engineer's model
Network Management System	Incremental cost of BT's Network Management System to support GEA services	BT's Chief Engineer's model
Cabinet Interventions	Repair costs driven by faults due to customer installations at the cabinet	BT's Chief Engineer's model
SLG Payments	Payments BT makes to other CPs when it fails to meet the agreed Service Level Guarantees (SLGs).	Ofcom estimate (see Annex 12)
Cumulo	Business Rate Taxes incremental to GEA services	Ofcom estimates based on VOA and BT data (see Annexes 12)
General Management	Other Management costs specific to NGA	Ofcom estimate (see Annex 12)

Source: Cartesian

4. Model Implementation and Assumptions

Overview of Network and Cost Modules

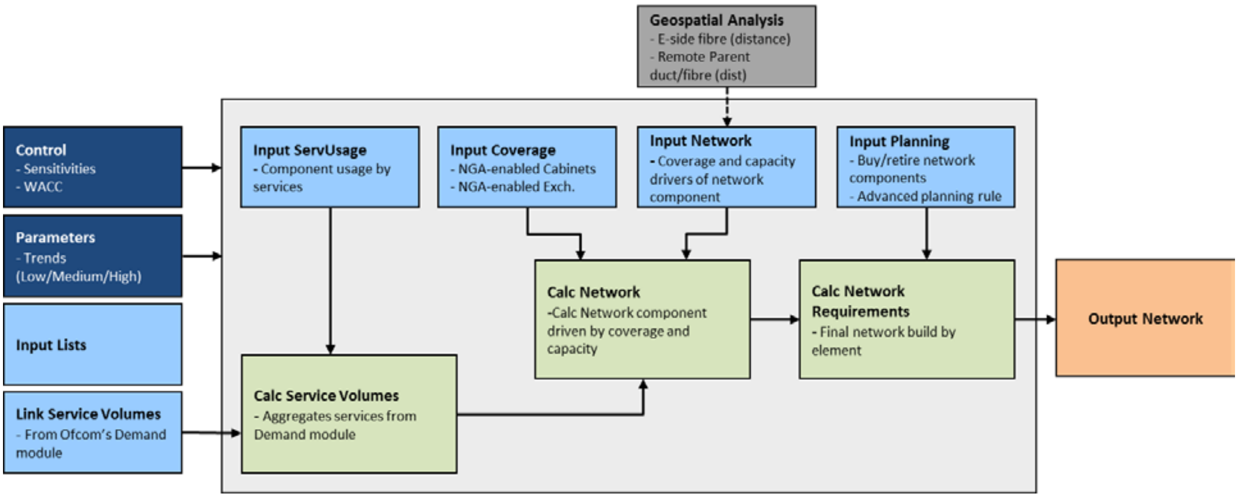
4.1 As outlined in the introduction to this document, Cartesian has developed two modules (the Network and Cost modules) that are components within the bottom-up model. The Network module uses the NGA service volumes and coverage forecasts to calculate the volumes of the NGA-specific network components. 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-GEA services, top-down costs are used as inputs to the Cost Module. The outputs from the Cost Module are used by the Cost Recovery 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.

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 22 below.

Figure 22. ***Network Module Overview***



Source: Cartesian

Overview of Network Module sheets

4.4 Input sheets

- Control
  Shows key parameters which affect the overall model for scenario modelling and sensitivity analysis. The control parameters are taken from Ofcom's WLA Control Module.
- Parameters
  Shows the specific parameters for the scenarios and sensitivities selected in Ofcom's WLA Control Module.
- Link - Service Volumes

This interface sheet takes the service volumes applicable to the bottom-up 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, the bottom-up modelled network is aligned 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 bottom-up model uses the average bandwidth per FTTC subscriber in the peak hour (using CP data where available) to calculate the total bandwidth at the FTTC Cabinets and the Exchanges, which are used to dimension the transmission components of the network, e.g. network cards and ports at these locations.

4.10 The average bandwidth growth rate for the first three years of actual data from CPs (2012/13 – 2014/15) has little variability, at 35% - 36%[26], and we have used 35% for this period. We have also applied 35% growth rate for the preceding five years, 2007/08 -2011/12. The CPs forecast for bandwidth in the period from 2014/15 shows a decrease in the growth rate to 23% in 2019/20 and we have used these figures. We do not have forecast data from CPs for the remainder period, and we have agreed with Ofcom to keep the growth rate flat from 2019/18 to 2020/21 and then reduce it to 10% (from 2021/22).[27]

Dimensioning of Elements

4.11 Each network element type has up to two drivers that determine the quantity of the element required in the bottom-up 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).

4.12 The coverage and capacity inputs are indepenent. Care should be taken to ensure that the two sets of inputs are internally consistent if the model is used to explore different scenarios.

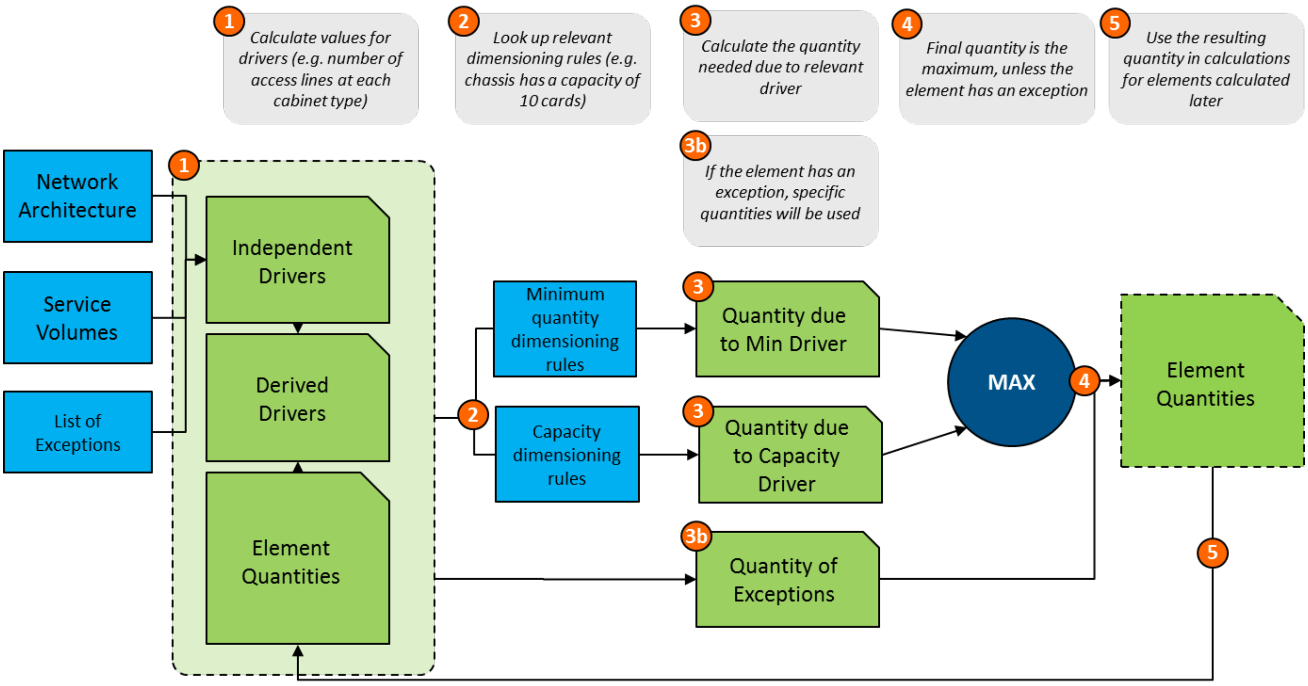
4.13 To simulate the capacity planning and implementation functions of a real-world operator, the bottom-up model incorporates a capacity utilisation threshold. For instance, for the OLT and OCR components, we analysed the number of subcomponents (e.g. OLT Chassis, OLT Southbound cards, OCR Chassis, OCR Subracks) required for each exchange (in turn, driven by the number of GE ports required by each FTTC Cabinet). After calculating the total number of components required over the model time horizon, we calculated the equivalent utilisation factor which will produce the estimated element

[26] Based on data provided by CPs, we have estimated the average bandwidth per subscriber, weighted by the number of GEA subscribers.
[27] We have tested the impact of applying a glide rather than a straight drop from 23% to 10% growth, and the unit LRIC of the GEA rental charge increases by around 2p, which seems immaterial.

count (79%, 72%, 33% and 81%, respectively). Other elements have 100% as the utilisation factor, as the scaling rule is more straightforward (e.g. a new Power Connection will be required for every new FTTC Cabinet). The rationale for using an equivalent utilisation factor for some network elements is to capture variations at a geographic level not picked up by national averages. This approach is explained in further detail in Annex 13 of Ofcom's Wholesale Local Access Market Review Consultation.

4.14 For the majority of elements, we follow a common approach to determine the required quantity for each network element in each year of the bottom-up model. This approach is illustrated in Figure 23.[28]

Figure 23. ***Element Dimensioning Approach***



Source: Cartesian

4.15 The bottom-up model is also able to accommodate exceptions to the above approach. For example, the total lengths of E-side fibre, determined by the geospatial analysis, are entered as exceptions, as well as a number of components in the *Other* category (e.g. OSS/BSS Software). These exceptions are independent of the coverage and capacity inputs; therefore, care should be taken to ensure that the

[28] The calculations of element quantities at step 3 in the diagram are interim results and care must be exercised if analysing 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.

coverage, capacity and exceptions are internally consistent if stakeholders use the model to explore different scenarios.

Calculate the Buy and Retire for Different Elements

4.16 Once the bottom-up 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 bottom-up model also calculates the quantity of network elements retired.

4.17 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 bottom-up model. The table below shows the initial asset lifetimes considered in the draft model which accompanies this document. BT uses these figures when booking FTTC asset purchases in its Management Accounts, except for Rack and Frames, Network Hardware and OSS Software, which were informed by the 2013 NCC model and Ofcom's own analysis[29].

Figure 24. ***Asset Lifetimes by Equipment Type***

Equipment Type	Asset Lifetime in Model (Years)
DSLAM	[✂] (~7.1)]
Street Cabinet	[✂] (~23.4)
Copper cable	[✂] (~16.2)
Opto-electronic Equipment	[✂] (~11.3)
Rack and Frames	10
Network Hardware, warranty fees	5
Fibre cable	[✂] (~22.2)
Duct	[✂](~46.8)
Optical Passive Equipment	[✂] (~20.8)
Depreciation within 1yr	1
OSS Software	10

Source: Cartesian, BT RFS

4.18 The bottom-up model is based on an annual assessment, and as such all lead times are rounded to the nearest whole year. As a result, the bottom-up model assumes a planning lead time of one or zero

[29] For OSS Software, Ofcom assumed a longer asset lifetime than assumed in the 2013 NCC model for Software-related assets (see Annex 12 of the Wholesale Local Access Market Review Consultation.

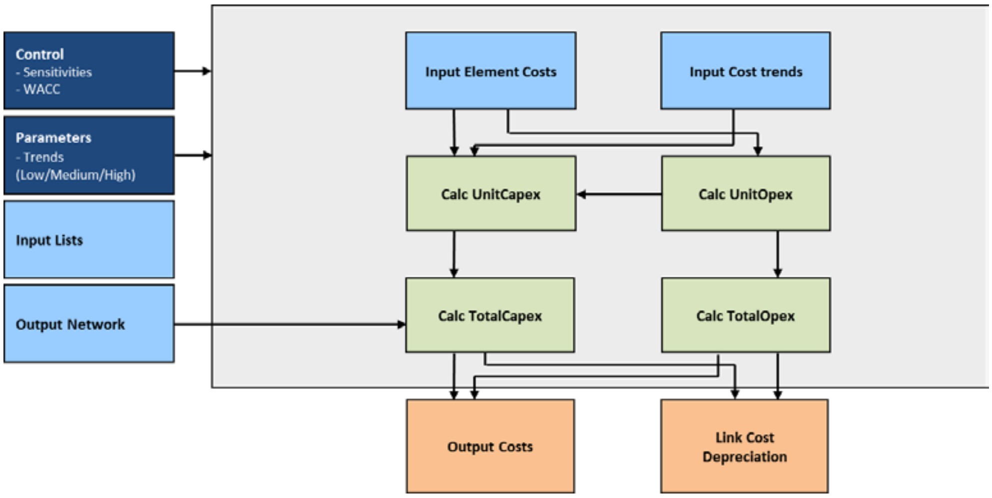
years, depending on the network element. Those elements mostly driven by coverage drivers, which tend to require civil works and planning permission (e.g. E-side fibre, FTTC Cabinets), are modelled with a planning lead time of 1 year. Other network elements requiring less planning and lead time for their installation (e.g. access cards) are modelled with a planning lead time of zero years (i.e. less than 6 months).

4.19 We accept that in a real network deployment, the planning lead times of the individual elements will vary. However, we believe this model simplification to be reasonable: we have run a sensitivity analysis, setting all access cards to 1-year planning lead time instead of 0, and the delta in Capex and Opex spend over the 20-year period 2007/08 – 2027/28 is 2% (£45m) and 0.1% (£4.5m) respectively.

Cost Module

4.20 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 25 below.

Figure 25. ***Cost Module Overview***



Source: Cartesian

Overview of cost Module sheets

4.21 Input sheets

- Control

  Shows key parameters which affect the overall model for scenario modelling and sensitivity analysis. The control parameters are taken from Ofcom's WLA Control Module.

- Parameters

  Shows the specific parameters for scenarios and sensitivities selected in Ofcom's WLA Control Module.

- 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), including any MEA price adjustments where appropriate. These inputs are used in conjunction with *Element Costs* sheet to calculate the evolution of Capex and Opex unit costs over time.

4.22 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*, C*ost Trend* and *UnitCapex* as inputs (the latter is used because some of the Opex cost can be capitalised, depending on the bottom-up 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.

4.23 Output sheets

- Output – Costs

  This output sheet summarises the total Capex and Opex costs incurred to deliver GEA 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.

Unit Capital Costs

4.24 BT provided the evolution of unit capital costs of all the NGA subcomponents and activities for the 2008-16 period (actual data). We then mapped BT's list of subcomponents into the list of elements of the bottom-up model, calculating the blended unit capital cost for the base year, 2015/16.

4.25 The installation unit costs have already been included in the unit capital costs, following input from BT. The asset retirement costs have been set to zero, as the model assumes that an asset is retired at the same time it gets replaced (thus effectively assuming zero retirement costs). This is because we would expect an efficient operator to align both tasks (in the vast majority of the cases) in order to minimise costs and to keep a certain quality of service (i.e. the network operator would have to temporarily drop the service in the affected area if it were to separately carry out the retirement and replacement activities).

Unit Operating Costs

4.26 Operating costs for each network element in the model are captured by an absolute figure. In the majority of cases, this figure is informed by the assumptions underpinning BT's Chief Engineer's Model, which is described in Annex 12 of the Wholesale Local Access Market Review Consultation. The cost items comprising the unit operating cost by network element are shown in Figure 26.

Figure 26. ***Composition of unit operating costs in the bottom-up model***

Network element	Cost items
OLT_Chassis	-Warranty fees
OLT_Southbound Card	-Warranty fees -Repair costs -SMC costs
OLT_Northbound Card	-Warranty fees -Rrepair costs -SMC costs
OLT_to_OCR_Tie Cable	-Repair costs -SMC costs
EXCH_Accommodation	-Accommodation costs -Electricity
OCR_to_CCJ_Tie Cable	-Repair costs -SMC costs
E-side cable	-Fault repair costs -SMC costs
CAB_Power Connection	-Disaster recovery
CAB_Civils (concrete Base)	-RCD maintenance -SMC costs -Disaster recovery
CAB_Certification Managed Service	-Electricity meter reading -Electricity meter maintenance
DSLAM Cabinet	-Maintenance -Repair costs -SMC costs -Disaster recovery -Battery replacement
DSLAM Access Card	-Warranty fees -Repair costs -SMC costs -Disaster recovery
DSLAM GE port	-Repair costs -SMC cost
PCP_Extra faults at PCP/Copper	-Repair costs
PCP_Duct to FTTC Cab	-Repair costs, -SMC costs

PCP_Copper to Cabinet	-Repair costs, -SMC cost
Remote Parent Fibre	-Repair costs -SMC cost
Other_OSSBSS_Software	-OSS/BSS operating costs
Other_Access Operations Centre	-AOC labour costs
Other_Fixed Warranty Fee	-Warranty fee
Other_Software Configuration	-SMC costs
Other_Engineer PCP Jumpering	-Transport and fuel -Labour costs (including travel)
Other_Engineer Premise Visit	-Transport and fuel -Faceplate -Wires -Labour costs (including travel)
Other_Cabinet Interventions	-Repair costs arising from customer installations
Other_SLG Payments	-SLG payments to telecoms providers
Other_Cumulo	-Cumulo
Other_General Management	-Incremental GM costs

Source: Cartesian

4.27 Based on the total cost of Power attributed by BT to GEA services in the 2014/15 RFS[30], the equivalent average power per Cabinet was calculated and included in the model. [31] The cost of Power consumed at the exchange is included in the cost of Accommodation.

Element Unit Costs Trends

4.28 The bottom-up model calculates the unit costs (both capital and operational) of each network element over the life of the network.

4.29 For those elements for which we received cost information from BT[32], we have analysed the unit capital cost evolution over time. For most cost elements, the resulting trend can be modelled through linear regression. If similar components have a similar cost trend, we have grouped them into a linear

[30] BT response to section i) of the 7th WLA s.135 request.

[31] We note that the average power consumption per cabinet implied in BT's 2015/16 RFS is significantly higher. This is because electricity costs attributed to GEA services were around 3-4 times higher than in 2014/15, while the number of commercial cabinets did not increase in the same proportion. This suggests a cost reallocation in BT's accounts rather than a genuine increase in the power consumed per FTTC cabinet. Moreover, the power consumption assumed in the BT Model appears consistent with the average power consumption per cabinet implied in BT's 2014/15 RFS. Therefore, we have used 2014/15 RFS data to inform cabinet power consumption in the BU Cost Model. We note that the model outputs do not appear sensitive to this assumption, as the forecasted unit cost stays relatively flat after flexing power consumption per cabinet by 50% (see Annex 14 of Ofcom's Wholesale Local Access Market Review Consultation).

[32] For the Labour and OSS/BSS network elements we did not receive cost trend information. For labour we applied the same cost trend assumed in Ofcom's top-down model. For OSS/BSS costs we assumed unit costs stay flat in nominal terms.

trend category (e.g. E-side Track Joint and Remote Parent Track Joint grouped into Track Joint). See Figure 27 for the list of linear cost trend categories (capital costs) in the bottom-up model.

Figure 27. ***Linear Cost Trends by Category in bottom-up model (capital costs)***

Trend Category	Cost Trend
Labour	3.1%
OLT Chassis	[✂] (~-3.3%)
OLT Southbound Card	[✂] (~-9.8%)
OLT Northbound Card	[✂](~-4.7%)
OLT to OCR Tie Cable	[✂] (~-3.2%)
Racks and Space	[✂] (~0.2%)
OCR to CCJ Tie Cable	[✂] (~-0.1%)
Cable Chamber Joint	[✂] (~0.8%)
Fibre Cable from Cabinet	[✂] (~0.0%)
Aggregated Fibre Cable	[✂] (~-1.5%)
Fibre testing	[✂] (~0.0%)
Track Joint	[✂] (~0.0%)
Aggregation Node	[✂] (~-1.7%)
Power works and services	[✂] (~3.1%)
Civils	[✂] (~0.7%)
Copper	[✂] (~0.8%)
Duct	[✂] (~1.6%)
Remote Parent Planning	[✂] (~0.0%)
Access Operation Centre	[✂] (~0.0%]
DSLAM Type 1 Access Card	[✂] (~-1.7%)
DSLAM Type 2 Access Card	[✂] (~-1.6%)
OSSBSS	0.0%

Source: Cartesian

4.30 For those GEA elements whose costs do not behave linearly, the cost trend has been treated as an exception and has thus been modelled as a year-on-year change. See below a table with two examples of non-linear cost trends in the bottom-up model (capital costs).

Figure 28. ***Examples of Non-linear Cost Trend (Non-Linear)***

Category	2011/12	2012/13	2013/14	2014/15	2015/16
DSLAM Type 1 Cabinet	[✂] (~-22.2%)	[✂] (~-25.3%)	[✂] (~-16.5%)	[✂] (~0%)	[✂] (~0%)
DSLAM Type 2 Cabinet	[✂] (~-20.7)	[✂] (~-30.7%)	[✂] (~-15.4%)	[✂] (~6.3%)	[✂] (~-0.5%)

Source: Cartesian

4.31 The cost trends sheet also includes a table with the MEA adjustments for capacity (as explained in paragraph 3.16). See below a table with the MEA adjustments included in the bottom-up model.

Figure 29. ***MEA cost adjustments***

Category	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
DSLAM Type 1 Cabinet	[✂] (~-4.4%)	[✂] (~-4.4%)	[✂] (~-4.4%)	[✂] (~-7.8%)	[✂] (~-7.8%)	[✂] (~-7.8%)
DSLAM Type 1 Access Card	[✂] (~-4.4%)	[✂] (~-4.4%)	[✂] (~-4.4%)	[✂] (~-7.8%)	[✂] (~-7.8%)	[✂] (~-7.8%)
DSLAM Type 2 Cabinet	[✂] (~0.0%)	[✂] (~0.0%)	[✂] (~0.0%)	[✂] (~-4.5%)	[✂] (~-4.5%)	[✂] (~-4.5%)
DSLAM Type 2 Access Card	[✂] (~0.0%)	[✂] (~0.0%)	[✂] (~0.0%)	[✂] (~-4.5%)	[✂] (~-4.5%)	[✂] (~-4.5%)

4.32 The final element cost trend will combine the linear/non-linear cost trends with the MEA adjustments.

4.33 The bottom-up model uses the Consumer Price Index (CPI) to convert the nominal values for Capex and Opex to real 2015/16 values. Historical CPI values are sourced from the Office for National Statistics (ONS). For FY 2015/16 to FY 2020/21 we use CPI forecasts from the Office for Budget Responsibility (OBR)[33]. Forward-looking CPI for the period FY 2020/21 to FY 2027/28 is held at 2.0%, as per OBR's forecast for 2020.

4.34 For the majority of network elements, we use Ofcom's pay and non-pay inflation estimates, presented in Table A15.8 of Annex 15 of the Wholesale Local Access Market Review Consultation, to inform the Opex trend assumptions in the model. The bottom-up 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.

[33] OBR's Economic and fiscal outlook, September 2016

Calculation of Total Costs and Module Outputs

4.35 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.

4.36 The total annual operating expenditure is calculated as follows:

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

4.37 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. Addendum: Responses to model consultation

Overview

5.1 In May 2016, Ofcom issued a public consultation[34] in relation to the Wholesale Local Access (WLA) Market Review. In particular, Ofcom consulted on the cost modelling approach used to estimate the costs of fibre based access services: the first version of the bottom-up model and the Model documentation accompanied the consultation.

5.2 Cartesian has carefully considered the points raised by the respondents to the consultation in relation to the network and cost modules of the model, and to the extend necessary we have amended our approach. This section summarises these stakeholder comments and Cartesian's responses.

5.3 Where applicable, we have combined similar points raised by multiple CPs and highlighted relevant differences where significant. Issues are discussed in no particular order.

Missing costs

5.4 In their responses, BT[35] and Virgin Media[36] argued that a number of cost items had not been captured in the first draft of the bottom-up model.

Cartesian response

5.5 A cost model is only ever a simplified version of reality and we would therefore not expect it to explicitly capture all costs. However, by calibrating the model, costs that are not explicitly captured in our bottom up inputs are still included in the model (see Annex 13 of Ofcom's Wholesale Local Access Market Review Consultation).

5.6 Having said this, the version of the bottom-up model that was published alongside the consultation had a number of placeholder cost items. Since then, we have received a considerable amount of cost data from BT for the NGA FTTC commercial rollout (actual, modelled and RFS data). The bottom-up model has been updated to include a number of NGA costs which had not been specified in the earlier version.

5.7 The table below summarises the cost items raised as missing by the CPs, and the element of the bottom-up model V2 where they are included:

CP raising issue	Missing cost highlighted by CPs	Bottom-up model V2 Cost Component
BT	Business rates	Other_Cumulo
BT	Service Management Centres	Included in opex unit cost of NGA elements
BT	Disaster Recovery	Included in opex unit cost of NGA elements
BT	Asset Mean Time Between Failure	Included in opex unit cost of NGA elements

[34] https://www.ofcom.org.uk/consultations-and-statements/category-3/wholesale-local-access-market-review-fibre-cost-modelling
[35] BT, 2016. Response to Ofcom consultation on possible approaches to fibre cost, pages 25 to 26, https://www.ofcom.org.uk/__data/assets/pdf_file/0029/83099/openreach.pdf.
[36] Virgin Media, 2016. Response to Ofcom's WLA – Consultation on Possible Approaches to Fibre Cost Modelling – May 2016, page 10, https://www.ofcom.org.uk/__data/assets/pdf_file/0024/83517/virgin_media.pdf.

	(MTBF), repair and maintenance	
BT	Fuel, Fleet	Included in opex unit cost of NGA elements
BT	Modems	Not in scope for the NGA model
BT	Access Operation Centres (AOC)	Other_Access Operations Centre
BT	Sub-duct for the spine cable	E-side cable
BT	Aggregation Nodes at the spine	E-side_Aggregation Node
BT	Meters and telemetry line, earthing components (mats, spikes, RCD), DNO power connection	CAB_Power Connection CAB_Civils (concrete Base) CAB_Certification Managed Service
BT	PCP uplift work (e.g. re-shell, deload/load)	PCP_Re-shell (load/de-load costs considered immaterial based on the evidence presented by BT on its modelled and actual costs)
Virgin Media	Setup costs associated with connecting electricity to the FTTC Cabinet	CAB_Power Connection
BT	Space, additional power, cabling, and trunking	EXCH_Accomodation
BT	Capacity management costs	Other_General Management
Virgin Media	Preparatory work to release space for new equipment, expanding space while maintaining existing services	EXCH_Accomodation

Model / documentation errors

5.8 Vodafone reported two inconsistencies: the first one, between the Cartesian report and the Excel model as the report assumed constant real prices from 2027/28 but the model showed constant nominal prices[37]; the second one referred to the calculation of unit costs for non-rental services, which in their consideration did not seem driven by volumes in the model.[38]

5.9 BT asked for clarification regarding the statement that "rack cost is a yearly recurring capex cost".[39]

Cartesian response

5.10 These were confirmed as errors in the model and the model documentation. We note that the first issue has been superseded by Ofcom's decision to shorten the model's time horizon to 20 years. The second issue reported by Vodafone was a formula error: the wrong cell was referenced for dimensioning the number of "Engineer Premise Visits" in the "Calc_Network" sheet, Lines 412 – 414. The formula has been corrected in the last version of the bottom-up model accompanying this document.

5.11 Regarding BT's point, a "yearly recurring capex" is a typographic error indeed. The text has been changed to "The Capex cost per OLT is estimated at […]".

[37] Vodafone, 2016. Response to Ofcom's Consultation: Wholesale Local Access Market Review: Approaches to fibre cost modelling, paragraph 3.27, page 16, https://www.ofcom.org.uk/__data/assets/pdf_file/0034/82789/vodafone.pdf.
[38] Vodafone, 2016, paragraph 3.34, page.18.
[39] BT, 2016, page 28.

Cabinet power

5.12 BT suggested that "It would be better to calculate per port power including base power and low-power state ports, which were implemented in a firmware upgrade during the Commercial deployment".[40]

Cartesian response

5.13 In the updated version of the model we no longer use power usage assumptions to estimate cabinet power costs. Instead we use the actual costs reported in BT's RFS to calculate a unit power cost per cabinet.

FTTC Costs

5.14 In its response, BT recommended that "each type of FTTC build, by year, will need separate capex and opex unit costs".[41]

Cartesian response

5.15 The approach we have taken to model the evolution of costs is to use unit costs for 2015/16 for each element in the model (e.g. each type of FTTC Cabinet), and use annual cost trends, which can be linear or non-linear, as explained in paragraph 4.28. We have used BT capex and opex unit cost data to inform such cost trends. Therefore, any yearly variation in BT's capex and opex unit costs by network element should be picked up in our assumed cost trends; implying a different capex and opex unit cost by year, as suggested by BT.

OCR Tie Cable length

5.16 BT stated that the OCR tie cable quantity was "fixed at 30m until 2036/37" in sheet 'Calc_NetReq'.[42]

Cartesian response

5.17 In the updated version of the model, and following information received from BT, the unit cost of the OCR Tie Cable represents the cost of [✂] (~14.4) m of cable.

Fibre cable cost inputs

5.18 BT noted that Openreach's largest fibre spine is 276 fibres, and that it uses two types of fibre in the E-Side, "COF200 in sub-duct and Blown Fibre Bundle in Blown Fibre Cable".[43]

Cartesian response

[40] BT, 2016, page 27.
[41] BT, 2016, page 28.
[42] BT, 2016, page 22
[43] BT, 2016, page 26.

5.19 The largest fibre spine in the updated version of the NGA 2016 model is 256 fibres. Following data received from BT, we have calculated a blended cost, using BT's cost figures for the 240 and the 276 fibre cables.

5.20 Following input from BT, the bottom-up model includes two types of fibre on the E-side: Blown Fibre tube for the slimmest fibre cable (4f) and COF200 for the rest. The unit cost of these components includes, where relevant, the cost of sub-duct, connector installation.

Approach to vendor-specific costs

5.21 BT believed that element dimensioning approach would need to be vendor specific, e.g. four types of DSLAM, two from each vendor. Additionally, BT said that "the use of 'All-in-one cabs, which are a result of CuRe[44] needs to be included".[45]

5.22 BT pointed out that Openreach also deployed a significant number of large 256 max capacity ECI DSLAMs.[46]

Cartesian response

5.23 In the updated version of the bottom-up model we have calculated a blended cost of the network elements with more than one vendor (e.g. FTTC Cabinets) based on the volumes and capacity (e.g. port capacity of various FTTC cabinet models) of each vendor's equipment. We have used BT cost and volume data by vendor.

5.24 In the discussions that followed the first consultation of the NGA model, BT confirmed it has not used CuRe nor All-in-One cabinet types in the c.48k PCPs specified by Ofcom, and which are located within BT's commercial FTTC rollout.

FTTC Cabinet rollout

5.25 In its response, TalkTalk said that FTTC take-up in the initial roll-out areas already exceeds 30%, and that it therefore does not make sense to dimension the network on the basis of a take-up which will be exceeded even in the short term.[47] TalkTalk recommended dimensioning the network based on the lowest cost network over the long term. TalkTalk said there was a conflict between '*following input from BT*' and the bottom-up methodology, as bottom-up is based on most efficient network structure, whereas constructing FTTC cabinets for 30% take-up appears to be based on BT's internal assumptions.

5.26 TalkTalk also believed that the proposed bottom-up approach is likely to inflate the proportion of 'Type 1' FTTC cabinets within the network, and recommended that Ofcom conduct a sensitivity assessment of whether a network solely or primarily using 'Type 2' fibre cabinets would be lower cost over the long run.[48]

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[44] Copper Rearrangement (CuRe): work required so that lines from customers directly connected to the exchange are modified in order to be connected to an FTTC cabinet instead

[45] BT, 2016, page 26.

[46] BT, 2016, page 26.

[47] TalkTalk, 2016. Response to consultation on possible approaches to fibre cost modelling, paragraph 4.6, page 8, https://www.ofcom.org.uk/__data/assets/pdf_file/0026/82691/talktalk.pdf.

[48] TalkTalk, 2016, paragraph 4.8 , page 8.

5.27 Expressing similar concerns, Vodafone did not agree with the approach of fulfilling additional capacity requirements with FTTC cabinets with a constant 38% share of small cabinets. Vodafone believed that it would be more efficient to deploy large cabinets from day one.[49]

Cartesian response

5.28 The 30% take-up ratio used in the previous version of the bottom-up model was a placeholder assumption in lieu of information from BT. Since then, BT has provided actual figures of the FTTC commercial rollout (see paragraph 3.17 for more details), and we have used them in the updated version of the bottom-up model. The rationale for taking this approach is explained in Annex 12 of the Wholesale Local Access Market Review Consultation.

Duct PCP-Cabinet

5.29 Vodafone argued that PCP-Cabinet tie cables do not always need new ducts and that existing duct infrastructure could be re-used.[50]

5.30 BT observed that the calculations of cable length in the PCP-Cab were incorrect, as the model considered the length up to the top of the duct, whereas the cable actually lies at the bottom of the duct.[51] Additionally, regarding the excavation of the PCP-Cab duct, BT pointed out that the DSLAM might be across the road which would involve excavating different surface types, attracting different costs (soft, footway and carriageway rates).

Cartesian response

5.31 The revised version of the bottom-up model uses updated assumptions of [✂] (~16.8)m[52] of new duct and [✂] (~19.8)m of copper cable, following modelled data provided by BT.

5.32 We have calculated a blended unit cost of digging the PCP-Cab duct, using BT's FTTC model surface mix.

Duct cost allocation

5.33 BT argued that in the E-side segment new duct is required for no-duct routes or when ducts are full, and civils are required for both congested ducts and to allow for duct blockages.[53] BT also highlighted that new pole routes could be required.[54]

Cartesian response

5.34 E-side duct and civil costs are included in the Economic Recovery module, via a top-down allocation of BT's accounting costs attributed to commercial FTTC services.

5.35 After further investigation with BT, we have concluded that pole routes are not material in the GEA commercial deployment.

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[49] Vodafone, 2016, paragraph 3.22, page 14.
[50] Vodafone, 2016, paragraph 3.23, page 14.
[51] BT, 2016, page 26.
[52] 2 x [✂] (~8.4m) of new two-way duct
[53] BT, 2016, page 25.
[54] BT, 2016, page 26.

Modelling approach for second cabinets

5.36 In its response, BT pointed out that any cost trend will need to account for vendor volume discounts or structural changes to costs, and also highlighted that civils are likely to be more complex if a second cabinet is required.[55]

Cartesian response

5.37 Using additional cost data from BT, we have refined the assumptions in the updated bottom-up model: the cost trends now use historical actual cost data for the period 2009-16. With regard to the cost of the second cabinet, after analysing the cost breakdown in detail, we conclude that the cost items driving the majority of the civil costs of a second cabinet are the same as for the first cabinet (e.g. management of the power connection, power jointing charges, concrete base, earthing mat, survey, power certification, etc). As a result, the bottom-up model uses the same civil costs for the first and the second cabinet.

Day-one configuration of FTTC cabinets

5.38 BT pointed out that the DSLAM capacity for each DSLAM type ignores early-programme configuration (day one type) and it argued this would result in understated costs.[56]

Cartesian response

5.39 The bottom-up model assumes that on day one, two Access Cards are installed in the FTTC Cabinet. BT confirmed that this is the usual day-one configuration of FTTC cabinets, reflecting the trade-off between day-one capacity, number of engineer visits and cost of Access cards.

Further clarification points

5.40 BT questioned how the ‘utilisation threshold’ is used in the model.

5.41 BT noted that when changing the service volumes, the E-side and Backhaul distances stayed constant.

Cartesian response

5.42 We have updated the main body of the model documentation to clarify these points: see paragraph 4.13 for the utilisation factor, and paragraphs 4.12, 4.15 for the use of coverage, capacity and exception drivers in the model.

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[55] BT, 2016, page 28.
[56] BT, 2016, page 26.

6. 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
CuRe	Copper Rearrangement
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	Layer 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
RFS	Regulatory Financial Statements
RU	Rack Unit
SEP	Superfast Extension Programme

SFP	Small Form-factor Pluggable
SLG	Service Level Guarantee
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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