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Final report for Ofcom

Estimating the cost of a broadband Universal Service Obligation

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Abbreviations used

The following acronyms and abbreviations are used in this report.

Term	Meaning
BDUK	Broadband Delivery UK
Carrier pre-selection	A network service whereby the consumer can pre-select which carrier is to be used for different call categories (for example calls to mobile versus local)
CIR	Committed information rate
CMTS	Cable model termination system
CPE	Customer premises equipment
CPPC	Cost per premises connected
CPPP	Cost per premises passed
DCMS	Department for Culture, Media and Sport
Distribution layer	Refers to copper (or fibre in an FTTP network) between the cabinet (or splitter) and distribution point. Also known as D-side
Distribution point	The final flexibility point in the access network. This connects the end-user, via a 'final drop' to the access network
DOCSIS	Data Over Cable Service Interface Specification
DSLAM	Digital subscriber line access multiplexer
EAD	Ethernet Access Direct
ECC	Excess construction charge
EIRP	Equivalent/effective isotropically radiated power
eNodeB	Evolved Node B
EoL	Exchange only line
Feeder layer	Refers to copper or fibre link between the exchange and cabinet. Also known as E-side
Final drop	Also known as lead-in. The portion of the network connecting the subscriber premises to the distribution network in the street
FDD	Frequency division duplexing
FTTC	Fibre to the cabinet
FTTdp	Fibre to the distribution point
FTTP	Fibre to the premises
FWA	Fixed wireless access
Gbit	gigabit
Gbit/s	gigabit per second
GE	Gigabit Ethernet
G.fast	Fast access to subscriber terminals
GHz	gigahertz
GPON	Gigabit passive optical network
HFC	Hybrid fibre coaxial
Hz	hertz

IEEE	Institute of Electrical and Electronics Engineers
IMT-Advanced	International Mobile Telecommunications Advanced
IP	Internet Protocol
ITU-R	International Telecommunication Union Radiocommunication Sector
ITU-T	International Telecommunication Union Telecommunication Standardization Sector
km	kilometre
m	metre
mm	millimetre
ms	milliseconds
LTE	Long-term evolution
LR-VDSL	Long reach very high bitrate digital subscriber line
Mbit	megabit
Mbit/s	megabit per second
MDF	Main distribution frame
MDU	Multi dwelling unit
MHz	megahertz
MIMO	Multiple-input and multiple-output
MNO	Mobile network operator
MTP	Market Test Pilot
NTD	Network termination device
ODF	Optical distribution frame
OLT	Optical line terminal
ONT	Optical network terminal
RF	Radio frequency
SF	Superfast
SFBB	Superfast broadband
sqm	square metre
sqkm	square kilometre
TDD	Time division duplex
USO	Universal service obligation
USP	Universal service provider
VDSL	Very high bitrate digital subscriber line
VDSL2	Very high bitrate digital subscriber line 2
VoIP	Voice over Internet protocol
VSAT	Very small aperture terminal
WiMAX	Worldwide Interoperability for Microwave Access

0 Executive summary

0.1 Introduction

DCMS has asked Ofcom to provide "*a detailed preliminary estimate of the costs arising from implementation of the broadband USO based on different types of network architectures and technologies*."[1] To enable it to respond to DCMS, Ofcom has commissioned Analysys Mason to carry out a detailed analysis to explore how the costs of implementing the USO might vary according to the choice of key parameters (such as technology, take-up and busy-hour throughput) and according to geospatial factors.

Based on the data about eligible premises available at the start of the study, Ofcom asked Analysys Mason to consider the costs relating to three possible USO scenarios as well as a Superfast scenario, as specified in Figure 0.1.

Figure 0.1: Scenarios for broadband USO technical specification [Source: Ofcom, 2016]

	Scenario 1	Scenario 2	Scenario 3	Superfast scenario
Download sync speed[2]	Sync speed 10Mbit/s – best efforts	Achieving at least a similar distribution of actual speeds as a current fixed service with 10Mbit/s predicted speed		Sync speed 30Mbit/s
Upload sync speed	None defined	0.5Mbit/s	1Mbit/s	6Mbit/s*
Latency	None defined	Medium Response Time	Medium Response Time	Fast Response Time
Contention ratio/ committed information rate (CIR)	None defined	50:1	50:1	10Mbit/s

* This is the median for all SFBB lines, including Virgin Media.

In this study we identified a number of candidate technologies, their key cost components and cost drivers. We considered wireline technologies (FTTP GPON, FTTP PTP, FTTC VDSL2, FTTC LR-VDSL, FTTdp G.fast, HFC), wireless technologies (fixed wireless access, also known as FWA) and satellite. All of the candidate technologies are capable of meeting the requirements of all of the three USO options scenarios and the Superfast scenario *if dimensioned appropriately*, with the exception of satellite which is limited with respect to latency and the total available capacity (which would limit the number of premises it could serve at the CIRs specified). The cost-modelling work

1 See http://stakeholders.ofcom.org.uk/binaries/consultations/broadband-USO-CFI/annexes/DCMS_Letter.pdf

2 Sync speed is the maximum speed that the line between a subscriber's router and its parent exchange is capable of sustaining absent any other traffic or traffic management policies.

described below explored the relative costs of each technology on its own, and as a mix of technologies that minimises total cost.

0.2 Stylised cost model results

Figure 0.2 below summarises the incremental cost to deploy and operate the incremental network required to serve the specification for eligible premises in each of the four scenarios. The model assumes deployment in 2018.

The total deployment costs include the capex required to deploy the incremental network assets to serve eligible premises. The annualised cost result takes into account an annual annuity charge as well as annual opex to operate the incremental network. This is particularly relevant to wireless technologies where upfront capex is relatively low, but ongoing opex is higher than for wireline technologies.

The total deployment costs modelled range from around GBP1.2 billion to around GBP2.5 billion depending on the scenario. In annualised terms this ranges from approximately GBP313 million per year to approximately GBP701 million per year depending on the scenario. These costs are based on the lowest-cost technology deployed in each modelled geographic area.

Modelling of FTTC VDSL2 and FTTC LR-VDSL estimates that a single technology deployment would cost between approximately GBP1.7 billion and GBP2.8 billion depending on the scenario. The model deployment cost results for an FTTP-only deployment range from around GBP7.2 billion to GBP9.6 billion. For FWA the modelled deployment costs range from about GBP1.9 billion to GBP30.0 billion (in the Superfast scenario) based on the assumed spectrum and site specification.[3]

The stylised cost model is conservative in that it does not aim to capture *all* the efficiencies that might be possible from sharing new and existing infrastructure; this is because we do not have sufficient information on existing networks to do so. The cost model also makes conservative estimates on network topology, equipment capacity, utilisation and reuse of existing infrastructure. As such, the costs calculated form a likely upper bound on the cost of deploying a network to serve each scenario; in reality, we would expect any real deployment to be achieved at a lower cost than the figures shown in Figure 0.2.

The total costs are dominated by the costs of the access network and therefore Figure 0.2 focuses on these. The additional customers connected to a higher specification access network would also generate additional traffic in the core and we have therefore also estimated the magnitude of these additional costs. We estimate that additional core network costs add a further 3–5% to the access network costs, as shown below.

3 Excluding spectrum costs. These costs could be considerable (whether opportunity or actual costs).

Figure 0.2: Total deployment cost and annualised cost [Source: Analysys Mason, 2016]

Technology	Total deployment cost (GBP billion 2016 real terms)				Annualised cost [4] (GBP billion 2016 real terms)			
	Scn1	Scn2	Scn3	SF*	Scn1	Scn2	Scn3	SF*
FWA – sub-1GHz	2.0	3.1	4.8	29.9	1.1	1.7	2.6	17.1
FWA – 5.8GHz	1.9	2.6	4.0	20.8	1.0	1.4	2.1	11.8
FTTC VDSL2	1.7	1.9	2.2	2.8	0.3	0.4	0.5	0.6
FTTC LR-VDSL	1.4	1.5	2.0	2.5	0.3	0.3	0.4	0.5
FTTP	7.2	7.6	8.5	9.6	1.0	1.0	1.2	1.4
Lowest-cost (access network only)[5]	**1.2**	**1.4**	**1.8**	**2.4**	**0.3**	**0.3**	**0.4**	**0.5**
Lowest-cost (including access and core networks)	**1.2**	**1.4**	**1.9**	**2.5**	**0.3**	**0.4**	**0.5**	**0.7**
Eligible premises (million)	*1.6*	*2.1*	*3.5*	*5.5*	*1.6*	*2.1*	*3.5*	*5.5*

*SF = Superfast scenario

0.3 Key findings

Our key findings are summarised below:

- The stylised cost model results suggest that FTTC is likely to be a major part of the lowest-cost technology mix in all scenarios, including the Superfast scenario, because it formed the most significant part of the modelled lowest-cost technology mix. Interestingly, FTTP could play a small role in the lowest-cost technology mix, in areas where eligible premises are relatively closely clustered. Similarly, FWA could play a small role, although in annualised terms it is very rarely the lowest-cost technology.[6] In practice this may mean that FWA is only seldom considered by the universal service provider(s), also known as USP(s), for individual hard-to-reach premises.

- We did not directly model FTTP PTP, HFC or FTTdp. These technologies could potentially play a limited part in the USP network but are unlikely to introduce significant cost savings compared to the modelled technologies. FTTdp in particular is likely to be similar in cost to FTTP GPON due to the requirement to build fibre almost to the distribution point close to the subscriber premises. However, it could be used to reduce the costs in some of the areas identified as lowest-cost for FTTP GPON. Since the overall proportion of FTTP GPON is expected to be

4 Tilted annuity charge and annual opex combined.

5 This represents the national cost should the lowest-cost technology for each cabinet area be deployed.

6 We also note that spectrum licence costs have not been considered in the cost model. These costs could be considerable (whether opportunity or actual costs).

a small part of the lowest-cost technology mix this is unlikely to have a significant impact on the total cost of the USO.

- For all three USO scenarios and the Superfast scenario there is a tail of very expensive-to-serve premises. Specifically, the cost of the final 10% of eligible premises (covering c. 160 000 premises in Scenario 1 to c. 550 000 premises in the Superfast scenario) rises very significantly. Satellite may be able to address some of these premises, though it has only a limited overall capacity in the context of the CIR in the specifications that we have modelled and in the timeframe envisaged for the USO. The commercial satellite services that we have examined are unlikely to be able to meet the higher proposed latency specifications.
- The wireline technology costs are very sensitive to the level of reusable infrastructure and trenching costs, both of which are key areas of uncertainty in the modelling. Deploying new fibre aerially offers scope for cost savings and this may be more acceptable in very rural areas than it is in urban environments.
- Core network costs are relatively small compared to the overall incremental access network costs. The additional traffic in the core network carried as a result of serving the subscribers that take-up the modelled service (80% in the base case) is relatively small compared to the traffic already being carried in the core network. We have modelled these costs for completeness but they do not impact the lowest-cost technology mix.
- FWA is sensitive to the CIR specification. There is relatively little spectrum available in the sub-1GHz range, which constrains the capacity that individual sites could provide. In the 5.8GHz band, limited propagation distance limits the area that each site can cover. In both cases this means a large number of sites is required to serve all eligible premises, resulting in high deployment and operational costs, particularly in the Superfast scenario which requires a 10Mbit/s CIR per subscriber.
- Reducing the take-up rate assumption only reduces total deployment costs by a relatively small proportion as a network must still be built to pass all premises that may potentially request the service. For example, lowering take-up from 80% of eligible premises to 55% in Scenario 1 results in a reduction in deployment costs and annualised costs of only 4%.
- Wireline technologies benefit from economies of scale as the number of eligible premises increases. They are also largely invariant to the CIR specified hence the cost per premises connected (CPPC) reduces between Scenario 1 and the Superfast scenario. However, FWA becomes increasingly more expensive per premises as the specification is raised due to the limited capacity that each FWA site can serve and the shared nature of the radio access layer. The poor scalability of FWA does not pass through to the lowest-cost technology deployment since it makes up only a very small part of the mix.

0.4 Technology mix

Figure 0.3 to Figure 0.6 below illustrate, for a sample region, how the lowest-cost network (according to deployment cost or annualised cost) uses a mix of technologies to serve different areas for the least-demanding USO scenario (Scenario 1) and the high-specification Superfast scenario.

Notably in Figure 0.3, for Scenario 1, FWA is the lowest-cost technology for a large area. However, this corresponds to a small number of premises since FWA is most suitable in areas where eligible premises are dispersed over a larger area. In annualised terms for Scenario 1, FWA is never the lowest-cost technology across a cabinet area due to high opex compared to the wireline technologies offsetting the initial low deployment costs (Figure 0.4). In the Superfast scenario (Figure 0.5 and Figure 0.6), FWA is unattractive in both deployment terms and annualised terms due to the large number of sites required to serve the high CIR specification.

These diagrams also show that FTTP has a role to play in the technology mix in relatively isolated clusters.[7] The two variants of FTTC that have been modelled are the lowest-cost technology in most areas in both deployment cost and annualised cost terms in both Scenario 1 and the Superfast scenario (which represent the least and most onerous specifications modelled).

[7] Figure 0.3 to Figure 0.6 show FTTP appearing in only very small isolated areas which tend not to be contiguous.

Figure 0.3: Lowest-cost technology by deployment cost for Scenario 1 in South Wales and the South West [Source: Analysys Mason, 2016]

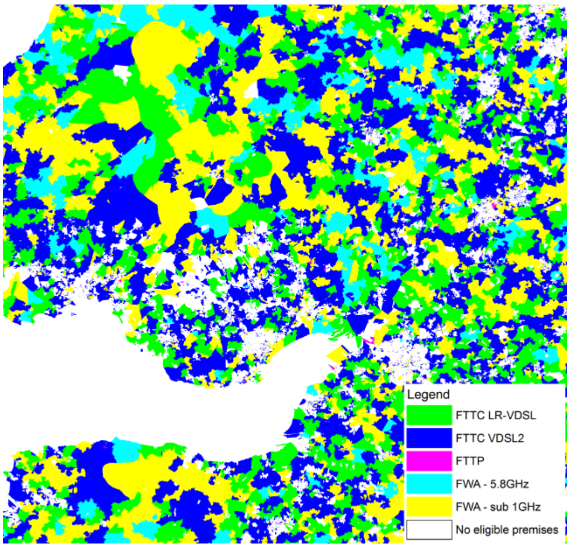


Figure 0.4: Lowest-cost technology by annualised cost for Scenario 1 in South Wales and the South West [Source: Analysys Mason, 2016]

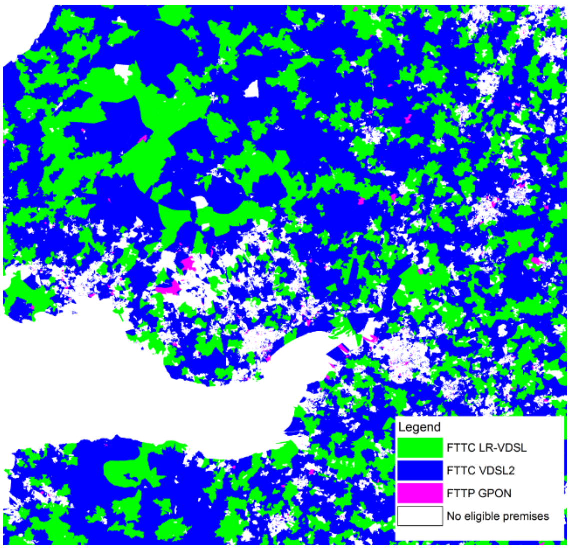


Figure 0.5: Lowest-cost technology by deployment cost for the Superfast scenario in South Wales and the South West [Source: Analysys Mason, 2016]

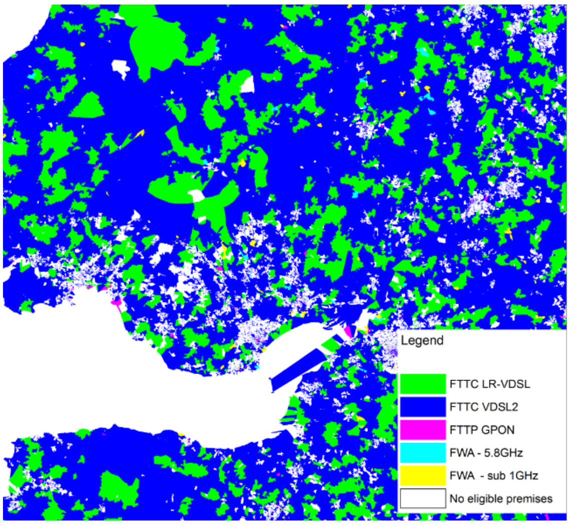
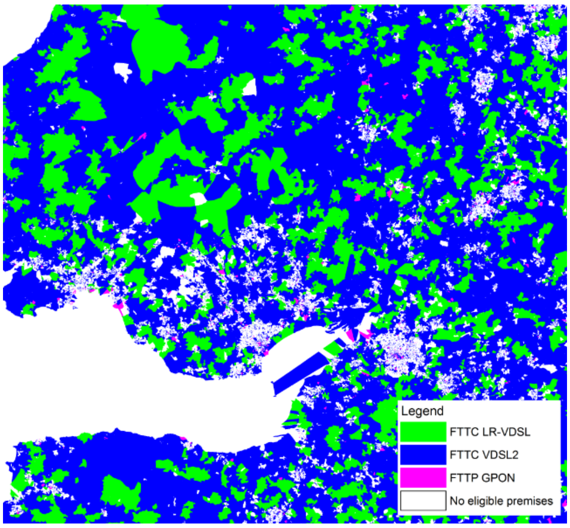


Figure 0.6: Lowest-cost technology by annualised cost for the Superfast scenario in South Wales and the South West [Source: Analysys Mason, 2016]



0.5 Limitations in the modelling and key areas of uncertainty/potential future improvements

We consider that the stylised cost model is sufficient to provide a preliminary estimate of the likely range of costs that would be incurred in deploying a network to serve a broadband USO, the key drivers of costs and the way in which they influence the overall total. However, the accuracy of the conclusions could be improved by conducting a more detailed cost modelling exercise based on actual premises data and a better understanding of certain key parameters. Below we outline some key areas for further study that would enable the above estimates to be refined if a more detailed analysis was required at a later stage. These are described in more detail in Section 5.6.

0.5.1 Premise-by-premise modelling

Ideally modelling would be carried out on a premise-by-premise level but data to support this was unavailable at the time work was carried out. Premise-by-premise modelling would enable an optimised distribution network to be designed. This optimised distribution network could:

- take into account the dispersion of premises and therefore the most appropriate network routeing and splitter strategies (e.g. two-way split, splitter close to exchange, or splitter close to subscriber)
- allow for a more accurate estimate of copper line lengths for USO-eligible premises which would enable a more precise estimation of the coverage provided by upgrading existing passive cabinets and enable optimisation of the location of new cabinets
- it may even be possible to consider the extent to which hybrid deployments of overlapping technologies might form part of the solution to serving a future USO.

0.5.2 Reusable infrastructure

The location and reusable capacity of existing infrastructure is an area of significant complexity and uncertainty. The stylised cost model estimates the proportion of premises that could be served by upgrading existing cabinets and it uses estimates of the proportion of reusable duct, poles and FWA sites to calculate a cost for deploying each technology. A better understanding of both the proportion of each type of infrastructure that could be reused and its location relative to USO-eligible premises would enable the accuracy of the cost estimate to be refined.

0.5.3 Detailed radio planning for FWA

The stylised cost model uses relatively simple capacity and coverage calculations to estimate the number of sites required based on a generic link budget for each band. A full radio planning exercise could refine the estimates made by the cost model, particularly in relation to the longer-range sub-1GHz case, to better take into account terrain, clutter and interference. This could also allow for a better understanding of required site type (e.g. tower, rooftop) and the availability of suitable locations. However, we would note that a full radio planning exercise on the scale of all premises in the broadband USO would be a significant undertaking.

The FWA cost calculations also do not account for the cost of acquiring and holding the requisite spectrum licences.

0.5.4 Technical capabilities of LR-VDSL

The stylised cost model used assumptions on the range and capabilities of LR-VDSL based on information available in the public domain. However, LR-VDSL is a technology that is still under development and therefore its precise specifications and performance are yet to be determined.

1 Introduction

DCMS has commissioned Ofcom to undertake detailed analysis of the key factors that will help inform the design of a potential broadband Universal Service Obligation (USO). Specifically, Ofcom has been asked to provide "*a detailed preliminary estimate of the costs arising from implementation of the broadband USO based on different types of network architectures and technologies*."[8] To enable it to respond to DCMS, Ofcom has commissioned Analysys Mason to carry out a detailed analysis to explore how the costs of implementing the USO might vary according to the choice of key parameters (such as technology, take-up and busy-hour throughput) and according to geospatial factors.

1.1 Background

The UK government intends to introduce a broadband USO to ensure that households and businesses can access the broadband speeds they need to do business online and access key services. The proposed Digital Economy Bill in the government's programme of legislation for this year includes a power for the government to introduce a new broadband USO, which would give households and businesses the legal right to a broadband connection of a certain minimum speed, upon reasonable request.

The scope of the USO, including specific requirements such as the minimum speed and consumer experience specifications, as well as details regarding the design of the USO, has not yet been finalised. The government intends to specify the detailed requirements of the USO in secondary legislation. DCMS has commissioned Ofcom to undertake detailed analysis of the key factors that will help inform the design of the USO.

In accordance with these requirements, Ofcom wishes to identify the key cost components for different potential technology solutions, and the key drivers affecting those costs. As part of the analysis of the cost drivers, it wishes to understand how geospatial factors are likely to influence the choice of technology used to serve premises in different areas, and the resulting costs. This has involved analysis of postcode-level data to try to determine the extent to which variations in local circumstances will have an impact on the choice of the technology used for implementing the USO and its costs.

1.2 Approach

Our approach is first to identify candidate technologies and their key cost components and cost drivers. We discuss how these technologies could play a role in the delivery of a broadband USO, based on the technical specifications being explored by Ofcom.

8 See http://stakeholders.ofcom.org.uk/binaries/consultations/broadband-USO-CFI/annexes/DCMS_Letter.pdf

We have developed a stylised cost model which directly models the costs of serving each cabinet serving area with a variety of technologies. Ofcom is analysing three possible specifications for the USO, as well as a Superfast scenario and therefore we model each of these scenarios with each technology and consider variations in certain key parameters. The output from the stylised cost model is a series of estimated costs per premises to serve the USO in each postcode group. We combine this with a qualitative analysis of technologies that are not directly modelled to expand our model findings to the full range of likely candidate technologies.

1.3 Structure of this report

The remainder of this document is laid out as follows:

- In the remainder of this section we set out the possible scenarios for the broadband USO technical specification that Ofcom has asked us to consider and we provide an overview of the technologies that we believe are most likely to play a significant role in serving the USO
- Section 2 describes **the candidate technologies** in more detail and outlines their key characteristics and cost drivers in the context of the broadband USO
- Section 3 outlines our **geographical approach to modelling** the costs of the broadband USO, including why it is necessary to group postcode areas and how we have done this
- Section 4 explains our **cost modelling methodology** including the network dimensioning and costing assumptions we have made
- Section 5 contains our **conclusions** and the results of our sensitivity analysis.

The report includes a number of annexes containing supplementary material:

- Annex A provides a description of the way in which we estimated the **provisioned throughput** that the USO specifications would require
- Annex B contains a summary of **scenario data pre-processing**
- Annex C contains a description of the **postcode grouping process** used to test the impact of modelling on a common length scale.
- Annex D describes the **duct and pole feasibility study** that we carried out in order to inform our work with the likely extent of reusable passive infrastructure
- Annex E includes a summary of **data provided by industry stakeholders**.
- Annex F discusses **trenching costs** relevant to wireline technologies.

Confidential information in this report is marked with scissor symbols [✂✂].

1.4 Scenarios for the broadband USO technical specification

Based on the data on eligible premises available at the time, Ofcom defined three possible broadband USO technical specifications, as well as a Superfast scenario, representing a range of possible specifications that may be of interest to policymakers. There are summarised below in Figure 1.1.

Figure 1.1: Scenarios for broadband USO technical specification [Source: Ofcom, 2016]

	Scenario 1	Scenario 2	Scenario 3	Superfast scenario
Download sync speed[9]	Sync speed 10Mbit/s – best efforts	Achieving at least a similar distribution of actual speeds as a current fixed service with 10Mbit/s predicted speed		Sync speed 30Mbit/s
Upload sync speed	None defined	0.5Mbit/s	1Mbit/s	6Mbit/s*
Latency	None defined	Medium response time	Medium response time	Fast response time
Contention ratio/ committed information rate (CIR)	None defined	50:1	50:1	10Mbit/s

* This is the median for all SFBB lines, including Virgin Media.

1.4.1 Scenario 1

Scenario 1 is intended to reflect a best-efforts 10Mbit/s connection only. The network should be capable of providing a peak download sync speed of 10Mbit/s, but without a minimum guaranteed throughput[10]. This means that the technology must be capable of providing this speed, but when the network (access, backhaul or core) is loaded, the actual performance experienced will be lower.

1.4.2 Scenarios 2 and 3

Scenarios 2 and 3 introduce a minimum *upload* sync speed of either 0.5Mbit/s or 1Mbit/s in addition to a 10Mbit/s download sync speed.

In addition, it is intended that these scenarios would provide each subscriber with a user experience comparable to that experienced by an average subscriber with a broadband offering a predicted 10Mbit/s sync speed today. To help quantify this expectation, Ofcom estimated the variation in broadband speeds that customers could experience based on measurements conducted as part of its ongoing broadband speeds research.[11]

In order to provide this level of service, the network deployed will require adequate capacity in any shared resources, whether these are in the core network or the access network (e.g. the fibre feeder in the case of FTTC, or the air interface in FWA).

9 Sync speed is the maximum speed that the line between a subscriber's router and its parent exchange is capable of sustaining absent any other traffic or traffic management policies.

10 Throughput is the actual speed experienced by the subscriber, which may be affected by other traffic on the network, the operator's traffic management policies and the response of websites and services that are being accessed.

11 See Annex A.

Required throughput in the access network

For some technologies (e.g. FTTP point-to-point, also known as FTTP PTP) most, or all, of the access network is dedicated to each subscriber. For other technologies resources are shared, and these therefore need to be dimensioned in a way that provides sufficient throughput per subscriber to match the probability distribution of a 10Mbit/s broadband connection today.

Where resources are shared (e.g. on an FWA network), the network performance experienced by a subscriber is driven by the level of contention in the shared parts of the network. This in turn depends not only on the number of active subscribers at a particular moment in time but also by the volume and type of usage, which both change over time.

We have carried out a statistical analysis based on queuing theory to estimate the guaranteed throughput per subscriber that needs to be provided in order to meet or exceed the probability distribution required by Ofcom. We have estimated that a guaranteed throughput of 1.5Mbit/s per subscriber would be sufficient. Our analysis is explained in more detail in Annex A.

Required throughput in the core

A USO provider's core network will in aggregate need to provide enough capacity to serve the additional demand that USO subscribers will generate. We believe that 500kbit/s per subscriber would be sufficient, based on our knowledge of current average throughput in the busy hour in the UK.[12] IP traffic in the core is handled at a sufficiently aggregated level and it is therefore not necessary to consider traffic distribution in the same way as for shared resources in the access network. It is unclear if patterns of traffic would continue to remain smooth in the core if the USO was introduced, and therefore we will run a sensitivity analysis on the impact on the core network of providing a CIR of 1.5Mbit/s per subscriber.

1.4.3 Superfast scenario

The Superfast scenario specifies a minimum download sync speed of 30Mbit/s, with a guaranteed throughput (or CIR) of 10Mbit/s in the downlink. For uploads, a minimum sync speed of 6Mbit/s is specified. The CIR of 10Mbit/s will be used to dimension the access network. It is unclear how much core capacity would be required to serve this level of constant demand, and therefore we sensitivity test a range of levels of provisioning in the core, up to and including the full CIR of 10Mbit/s.

12 Analysys Mason's Research division forecasts that by the end of 2016, average throughput in the busy hour will be 544kbit/s per subscriber. This corresponds to the average monthly usage per subscriber with a 10Mbit/s broadband connection in Ofcom's 2015 Connected Nations report: 77.1GB per month, assuming 30 days per month and a peak-hour-to-average ratio of 2, implies 466kbit/s in the busy hour.

1.4.4 Change over time

We assume that the USO specification will not alter over the medium term and therefore changes to those customers currently served but no longer meeting the required specification over time and changes in evolution in technology are not reflected in our modelling.

1.5 Overview of technologies

Ofcom's approach to the broadband USO is that it could potentially be served by any technology, including wireless technologies. Therefore we have considered a number of wireline and wireless technologies which are currently deployed in the UK, or are currently undergoing trials and are likely to be available by 2018 when the implementation of any USO is expected to be handed to Ofcom.

1.5.1 Wireline technologies

The following technologies are considered in this report:

- FTTP GPON
- FTTP PTP
- FTTC VDSL2
- FTTC G.fast
- FTTC Long Reach VDSL (LR-VDSL)
- FTTdp G.fast
- Hybrid fibre-coaxial (HFC).

These are described in detail in Section 2.1.

1.5.2 Wireless technologies

In this report we consider both fixed wireless access (FWA) and satellite technologies. Since the characteristics of FWA are heavily dependent on the spectrum utilised by the operator, Ofcom has asked Analysys Mason to consider two technology scenarios: a low-frequency scenario and a high-frequency scenario. These are intended to be indicative only, as the scope of this project does not allow for a detailed consideration of the wide variety of factors that would influence an actual FWA deployment. The scenarios have been designed to provide a baseline comparison against the broader set of technologies under consideration.

We assume that in both cases LTE is used, since this is now a well-established technology for providing wireless rural broadband services. Other technologies, such as WiMAX, will have different costs but we would still expect LTE to be sufficiently representative to be useful for Ofcom's purposes in this study.

Low-frequency scenario

The 800MHz and 900MHz bands are currently licensed to, and used by, MNOs to operate their mobile voice and data networks, and there are some LTE networks already operating in these bands in the UK. We understand that the 700MHz band is due to be available from Q2 2020,[13] and this band is supported by current releases of LTE. The 450MHz band is also supported by LTE, but at the moment the UK frequency plan for 450MHz is complex and fragmented, and while Ofcom is reviewing the future of this band,[14] it is not expected to be available for LTE in the medium term.

Given uncertainties around whether the 450MHz and 700MHz bands are available for the purposes of meeting a broadband USO in the timescales envisaged by Government, we assume that a provider meeting the broadband USO with sub-1GHz spectrum would use the 800MHz or 900MHz bands – either spectrum that it is already licensed to use, or frequencies obtained through a spectrum-trading agreement with another licensee. The propagation characteristics and total quantities of spectrum for 800MHz and 900MHz are relatively similar, and therefore either would be fairly representative of the band most likely to be used for providing rural broadband coverage through LTE.

As these bands are already heavily used, we assume that a USO provider would only have access to a relatively small portion of the sub-1GHz spectrum available: we assume that it has use of 2×10MHz of sub-1GHz spectrum.[15] Either 800MHz or 900MHz would be likely, and both these bands have similar propagation characteristics.

High-frequency scenario

Spectrum within the 5GHz band seems likely to be a candidate band that a rural wireless broadband provider would consider, given the availability of unlicensed and lightly licensed spectrum at 5.4GHz and 5.8GHz. In the recent BDUK test pilots, Airwave, AB Internet and Callflow each used spectrum in either 5.4GHz or 5.8GHz for providing FWA coverage. Given that the 5.8GHz band contains lightly licensed spectrum with a higher maximum transmitter power threshold than other potential bands,[16] this band seems to be a suitable candidate band to select for the high-frequency scenario.

Currently in the UK band plan, 5725–5850MHz is allocated to lightly licensed FWA and 5470–5725MHz is allocated to unlicensed FWA. The lightly licensed band is likely to be more suited to a potentially extensive set of FWA site deployments. 125MHz of spectrum is available, but must be shared with other users (and there is potential for some of the band to be reallocated to Wi-Fi[17]);

13 See https://www.ofcom.org.uk/__data/assets/pdf_file/0026/84176/maximising-benefits-of-700mhz-clearance.pdf

14 See http://stakeholders.ofcom.org.uk/binaries/consultations/420-470-mhz/summary/420-470-mhz.pdf

15 For comparison, current assignments are: 2×10MHz of 800MHz for Vodafone and O2; 2×5MHz of 800MHz for Three and EE; and 2×5MHz, 2×4.6MHz and 2×7.6MHz of 900MHz for Vodafone and O2 (i.e. not contiguous). See http://www.analysysmason.com/PageFiles/40373/Analysys_Mason_UK_spectrum_assignments_Mar2013.pdf

16 See http://stakeholders.ofcom.org.uk/consultations/powerlimits/power/

17 See http://stakeholders.ofcom.org.uk/binaries/consultations/5-GHz-Wi-Fi/summary/improving-spectrum-access-consumers-5GHz.pdf

therefore it seems likely that the viable amount of spectrum available for a broadband USO provider would be 40MHz or less. We carried out a simple link-budget analysis[18] and found that, due to the power limit in the 5.8GHz band (4Watts), increasing the amount of bandwidth beyond 20MHz does not further increase the capacity or range of cells. Therefore we assume that a USO provider would use a 20MHz TDD carrier in the 5.8GHz band.

In practice there may be coexistence challenges if this spectrum is used, since it may be shared with Wi-Fi in the future; nonetheless, it seems the most likely band to be used for a rural wireless broadband deployment in the medium term.

18 A link budget analysis calculates the balance between a wireless transmitter's power, gains, losses and receiving transmitter power based on the characteristics of the transmitter, receiver and their environment.

2 Candidate technologies

In this section we outline the access network technologies we have identified as those that could be used to deliver the broadband USO. These technologies have been selected as they are currently being used in the UK to provide broadband services or are in an advanced stage of deployment trials, and they therefore provide a degree of certainty in regards to their availability. For each of these technologies we set out:

- an overview of the technology
- key cost components (unit costs) in terms of capital and operating costs
- for each cost component, whether it is a fixed or variable cost (e.g. a cost that varies with take-up)
  - we also discuss any capacity or coverage limitations to these cost components, as determined by the USO technical specification
- for each cost component, whether it relates to the core, backhaul or local access network.

We also review the performance of each of the technologies against the proposed USO specifications, and consider how USO providers can adapt the way they deploy technologies in order to meet the requirements of the USO. We consider the trade-offs involved in providing infrastructure that can meet the specification. We also explain the impact these decisions may have on key cost components.

2.1 Overview of technologies

2.1.1 FTTP GPON

A Gigabit passive optical network (GPON) is a point-to-multipoint, FTTP-based architecture in which unpowered (passive) optical splitters are used to enable a single optical fibre from the exchange to serve a number of subscribers (typically 32 or 64).

The fibre originates from the local exchange at an optical line terminal (OLT), which marks the boundary between the core and access networks. The OLT converts electrical signals from the service provider's exchange-based equipment and optical signals on the passive optical network (PON). The fibre may also pass through an optical distribution frame (ODF) which organises cable connections within the exchange building.

A splitter placed within the access network layer connects this fibre to multiple end users – typically 32 or 64. Each individual fibre from the splitter terminates at the end-user premises at an optical network terminal (ONT), also referred to as a network termination device (NTD). This converts the optical signal carried over the fibre into an electrical signal that the modem can read and transfer to the customer's equipment. These components are illustrated in Figure 2.1 below.

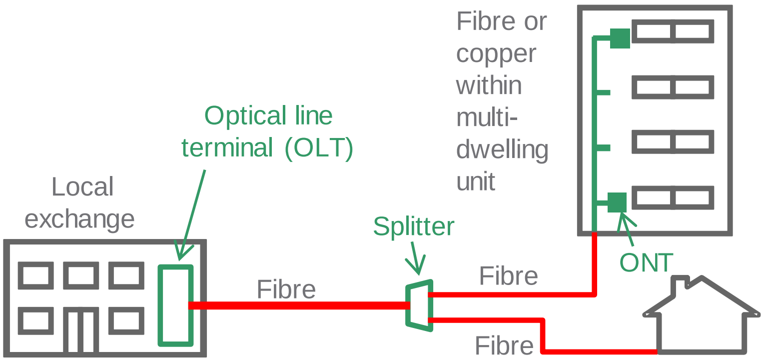


Figure 2.1: Overview of PON technology [Source: Analysys Mason, 2016]

In a PON, the single fibre between the OLT and the optical splitter is shared by all customers connected to the PON; this arrangement significantly reduces the number of fibres required in the network. Some network configurations use two stages of splitting to minimise the number of fibre cables required when premises are located a long way from their parent exchange. The location of the splitter relative to the exchange and subscriber premises can also vary depending on how clustered or dispersed premises are.

FTTP does not face material range limits in practice.[19] GPON can provide asymmetrical bandwidth (2.5Gbit/s downstream and 1.25Gbit/s upstream), shared by all subscribers on the same fibre.[20] The limits are therefore economic, not technical.

Key cost components

The key cost components for a FTTP GPON access network, and the drivers that dimension them, are presented in Figure 2.2.

Figure 2.2: Key cost components for an FTTP GPON deployment [Source: Analysys Mason, 2016]

Cost component	Description/ typical capacity	Unit for costs	Cost driver	Core, backhaul and/or access
OLT at the exchange	1 splitter per port, 8 ports per card, 16 cards per chassis	Per unit	Number of premises connected and splitter ratio (1:x)	Access
Optical splitter at primary splitter node	32 fibres	Per unit	Number of premises connected	Access
Optical splitter at secondary splitter node	16 fibres	Per unit	Number of premises connected	Access
Optical network terminal (ONT)	1 GPON fibre access line	Per unit	Number of premises connected	Access

19 There are theoretical range limits, but these are much larger than the radius of a single exchange area.

20 Speeds are effectively unlimited in the context of contemporary broadband access, as speeds of multiple hundreds of Mbit/s can be achieved for PON, depending on the splitting ratio and electronics used.

Cost component	Description/ typical capacity	Unit for costs	Cost driver	Core, backhaul and/or access
and Customer Splice Point (CSP)				
Distribution point/fibre manifold	Local point where up to a few dozen of fibre start following different routes to customers' premises	Per unit	Typically can serve up to 12 premises but utilisation is usually 50%.[21] These normally only serve premises within a range of around 60m	Access
Fibre cable (blown, including microduct)	2F, 6F, 12F, 24F,48F, 72F, 96F, 192F, 312F	Per m	Variable, by total length (i.e. one fibre all the way from the cabinet/exchange to each premise) to reach all premises	Core, backhaul and access
Fibre cable sheath for ducting	2F, 6F, 12F, 24F,48F, 72F, 96F, 192F, 312F	Per m	Variable, by total length (i.e. one fibre all the way from the cabinet/exchange to each premise) to reach all premises	Core, backhaul and access
Fibre cable sheath for direct burial	2F, 6F, 12F, 24F,48F, 72F, 96F, 192F, 312F	Per m	Variable, by total length (i.e. one fibre all the way from the cabinet/exchange to each premise) to reach all premises	Access (may be used for backhaul as well)
Aerial fibre cable sheath	2F, 6F, 12F, 24F,48F, 72F, 96F, 192F, 312F	Per m	Variable, by total length (i.e. one fibre all the way from the cabinet/exchange to each premise) to reach all premises	Access (may be used for backhaul as well)
Feeder fibre splice	Splicing of a fibre between an exchange and its cabinets	Per unit	Variable by number of cabinets served by the same initial fibre from the exchange	Core, backhaul and access
Distribution fibre splice	Splicing of a fibre between an exchange and its cabinets	Per unit	Where fibre cables are of insufficient length to join nodes, fibre cables can be spliced together. This is therefore only deployed on the longest uninterrupted lengths of fibre cable	Access
Optical distribution frame (ODF)	48 fibres is typical	Per unit	Variable, by number of fibre connections	Core, backhaul and access

In addition to the elements described above, an FTTP GPON also makes use of civil engineering assets such as trenches, ducts, poles and manholes. These may be used solely by the FTTP GPON network or shared with another network in the same area. Such common cost components are

21 See http://www.thinkbroadband.com/news/4440-openreach-gearing-up-for-fttp.html

discussed in Section 2.1.8 below. The extent to which these passive network assets can be reused is a further significant driver of overall deployment cost.

2.1.2 FTTP PTP

FTTP PTP architecture is based on Ethernet technology, whereby a dedicated fibre with dedicated capacity is deployed from the local exchange to the premises for each individual user. A typical PTP architecture is illustrated in Figure 2.3. Unlike a GPON architecture there is no shared fibre component in FTTP PTP: each access network connection is dedicated to a specific subscriber.

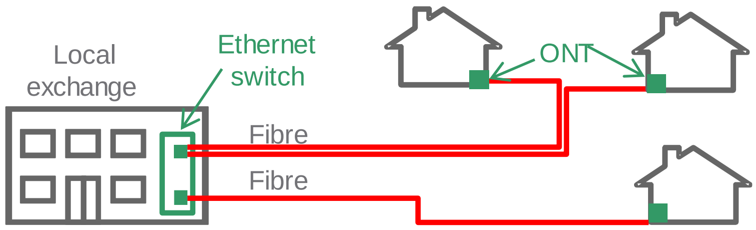


Figure 2.3: Overview of FTTP PTP technology [Source: Analysys Mason, 2016]

PTP active networks can provide the highest level of performance, typically up to 1Gbit/s per customer. There is the potential to increase this in the future as the active equipment at either end of the fibre gets upgraded with new technologies. There are no material range limits in practice.[22]

Key cost components

The key cost components for FTTP PTP are similar to those described above in Section 2.1.1 for FTTP GPON. The main difference is that whereas FTTP GPON uses shared fibres in parts of the access network, in FTTP PTP there is a dedicated fibre for each subscriber and therefore no splitter is required. However, aggregation nodes may be deployed, where multiple fibre cable sheaths are jointed together and combined into a single large fibre cable sheath. FTTP PTP is more expensive to provide than FTTP GPON due to the requirement to provide a dedicated fibre from exchange to subscriber premises.

In addition to the elements described above, an FTTP PTP network also makes use of civil engineering assets such as trenches, ducts, poles and manholes. These may be dedicated to the FTTP PTP network, or shared with another network in the same area. Such common cost components are discussed in Section 2.1.8 below.

22 Although there are theoretical range limits, these are much larger than the radius of a single exchange area.

2.1.3 FTTC

FTTC is an architecture where fibre is deployed from the local exchange to the street cabinet, but the copper sub-loops from the cabinet to customers' premises are still used, as illustrated in Figure 2.4. The street cabinet contains a DSLAM[23] that aggregates electrical signals on each subscriber's copper line onto a single Ethernet connection over fibre to active equipment based at the exchange.

Where lines are served directly from an exchange and not from a cabinet, a new DSLAM will need to be deployed.

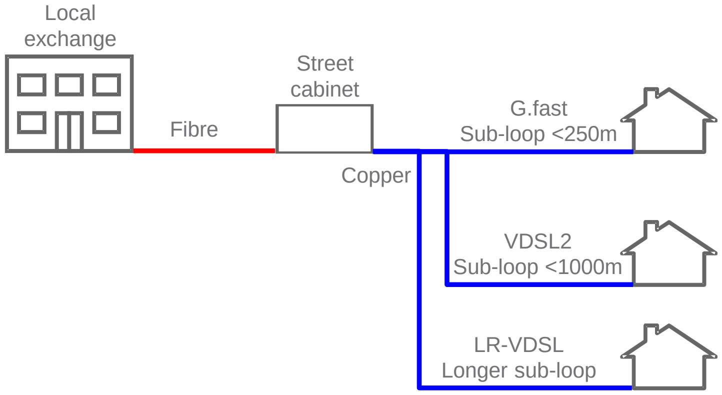


Figure 2.4: Overview of FTTC technology [Source: Analysys Mason, 2016]

The main differences between the different types of FTTC are the bandwidth used in the copper cables, the maximum distance over which the technology is effective (i.e. the distance beyond which performance significantly declines) and the throughput offered. These differences are presented in Figure 2.5. VDSL2 is the predominant current technology. G.fast offers the highest peak speed with the shortest range. We understand that LR-VDSL extends the capabilities of VDSL2 over a longer loop length, although we note that the LR-VDSL technology is undergoing trials and its final specification is to be determined.

23 Digital Subscriber Line Access Multiplexer: A network device located at a cabinet or exchange that receives signals from subscriber lines over copper and multiplexes them onto a single backbone line, thus providing xDSL services. Some more recent deployments use a multi-service access node (MSAN) instead of a DSLAM. This is a more capable device which is able to support other services, such as ISDN or Ethernet, in addition to xDSL. For the purposes of this report we use the terms DSLAM and MSAN interchangeably.

	VDSL2	G.fast	LR-VDSL
Bandwidth (MHz)[26]	8 (profile 8c), 12, 17 (profile 17a), 30 (profile 30a), 35 (profile 35b)	106 (profile 1), 212 in development (profile 2)	We expect the bandwidth to be narrower than for VDSL2
Distance	Effective up to 1900m at 10Mbit/s and 1300m at 30Mbit/s, operates up to 2500m	Effective up to 450m at 10Mbit/s, operates up to 500m	Based on data in the public domain we estimate this can serve 10Mbit/s at 3500m and 30Mbit/s at up to 2800m[27]
Downlink sync speed (Mbit/s)	Up to 150 (profile 17a), up to 400 (profile 35b)	Up to 1000	We estimate that the peak sync speed will be comparable to current VDSL2

Figure 2.5: Main characteristics of VDSL2, G.fast and LR-VDSL [Source: Nokia,[24] Openreach via ISP review[25]]

We note that the ranges can vary from these estimates for a number of reasons (e.g. local line quality).

Typically, only one FTTC technology is deployed in any cabinet, though we understand that VDSL2 and G.fast can be deployed in the same cabinet, with the former serving the long sub-loops and the latter serving the short sub-loops. Both technologies require vectoring[28] to limit the crosstalk interference between copper lines as the take-up of these technologies at a given cabinet increases.

G.fast and LR-VDSL are variations of the classic FTTC deployment and are undergoing trials. These technologies are trying to address different problems:

- G.fast aims to offer increased speed to subscribers who are close to the cabinet (within 250–300m), in order to remain competitive against the speed offered by cable (HFC).

24 See Overview of ITU-T SG15 Q4 xDSL and G.fast, Frank Van der Putten, Nokia, TNO 2016 – 29th June 2016

25 See http://www.ispreview.co.uk/index.php/2016/08/bt-reveal-tech-details-expanded-long-reach-vdsl-broadband-trial.html

26 Profiles refer to the frequency bandwidth which is used to transmit a broadband signal. The selected profile determines the speed and range characteristics of the service provided.

27 See http://www.ispreview.co.uk/index.php/2016/04/bt-openreach-prep-trial-long-reach-vdsl-broadband.html

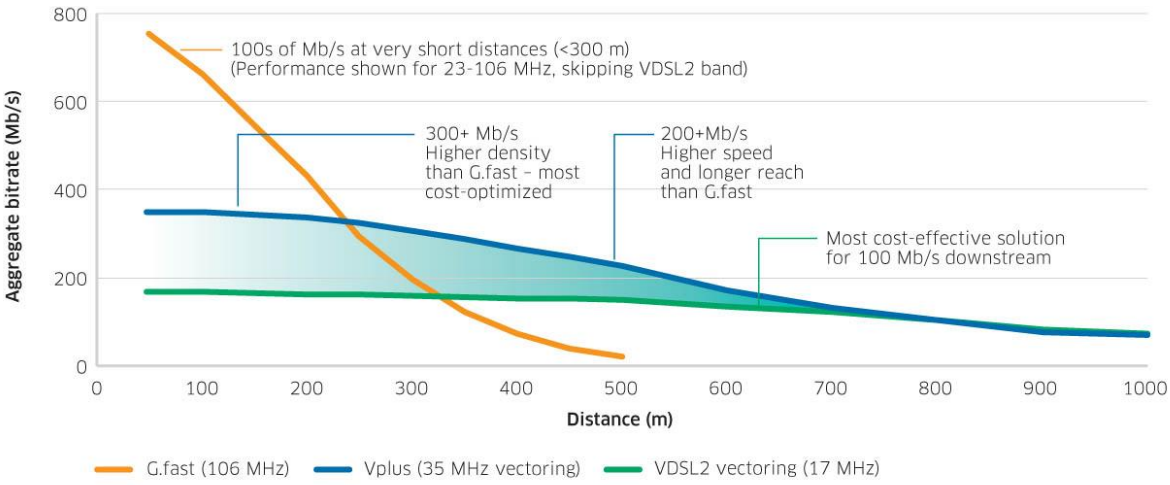
28 Vectoring is a form of noise-cancellation technology which limits interference between lines (‘crosstalk’), allowing for higher speeds to be achieved with VDSL.

- LR-VDSL aims to extend the reach of VDSL networks, offering VDSL-like speeds to consumers who currently live too far away from a fibre cabinet to benefit from this kind of speed with their broadband connection.

Figure 2.6 presents the typical performances (aggregate bit rates, upstream + downstream) that can be expected from VDSL2 17a vectoring (we understand that this is currently implemented by Openreach), Vplus (i.e. VDSL2 profile 35b, an alternative profile that is not considered further since its long-distance performance characteristics are similar to that of the 17a profile) and G.fast (which is primarily used to boost speeds over very short loop lengths).

We understand that LR-VDSL requires vectoring to be enabled in a cabinet, if it has not been done already.

Figure 2.6: VDSL2, Vplus and G.fast speed by distance from the cabinet [Source: Courtesy of Nokia © 2016 Nokia. All Rights Reserved[29]]



Note: .5mm cable

Key cost components

The key cost components common to all FTTC deployments are the components of the street cabinets housing the DSLAM that connects the copper line from each FTTC subscriber. In addition to housing the active equipment, the cabinets also contain power supply, air conditioning and battery backup for the active equipment. These assets are presented in Figure 2.7.

29 See http://insight.nokia.com/vplus-gets-more-out-vdsl2-vectoring

Figure 2.7: Key cost components for an FTTC street cabinet[30] [Source: Analysys Mason, 2016]

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
Cabinet housing and chassis	Typical capacities in Openreach's network are 128, 256 or 288 ports.[31] Larger capacities are available	Per unit	Number of racks and line cards required, in turn dependent on number of subscribers served	Access
Power supply, battery backup, rectifier	–	Per unit	Primarily fixed cost per cabinet, though distance to power source can cause costs to rise. Operating costs increase as subscribers increase	Access
Air conditioning	–	Per unit	Primarily fixed cost per cabinet though operating costs increase as subscribers increase	Access

The key cost components specific to FTTC networks using VDSL2, G.Fast and LR-VDSL are presented in Figure 2.8. Copper cabling, distribution points and network termination points are not included since it is assumed that these are already in place to all premises where FTTC may be deployed, and would be reused.

Figure 2.8: Key cost components for FTTC active equipment [Source: Analysys Mason, 2016]

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
VDSL2				
VDSL2 DSLAM line card	Typically 32 or 48 ports	Per unit	Number of subscribers	Access
VDSL2 DSLAM chassis	Up to 3 shelves of 1 card each	Per unit	Number of line cards deployed	Access
Or				
Integrated VDSL2 DSLAM	Estimated to be 144 ports	Per unit	Number of subscribers	Access
G.fast at the cabinet				
G.fast at cabinet DSLAM line card	Estimated to be typically 32 or 48 ports	Per unit	Number of subscribers	Access
G.fast at cabinet DSLAM chassis	Estimated to be 3 shelves of 1 card each	Per unit	Number of line cards deployed	Access

30 Cabinet, power supply, air conditioning, battery backup, excluding DSLAM and line cards.

31 See http://www.kitz.co.uk/adsl/fttc-cabinets.htm

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
Or				
Integrated G.fast at cabinet DSLAM	Estimated to be 144 ports	Per unit	Number of subscribers	Access
G.fast cabinet extension pod	Extension of a FTTC cabinet to house G.fast equipment (in addition to VDSL2 equipment). Estimated to be 144 ports	Per unit	One per cabinet upgraded to G.fast	Access
LR-VDSL				
LR-VDSL DSLAM line card	Estimated to be typically 32 or 48 ports	Per unit	Number of subscribers	Access
LR-VDSL DSLAM chassis	Estimated to be 3 shelves of 1 card each	Per unit	Number of line cards deployed	Access
Or				
Integrated LR-VDSL DSLAM	Estimated to be 144 ports	Per unit	Number of subscribers	Access

In addition to the assets described above, an FTTC deployment also uses civil engineering assets such as trenches, ducts, poles and manholes. Copper and fibre cabling are also required to connect the elements summarised above. These may be dedicated to the FTTC network or shared with another network in the same area. Those common cost components are presented in Section 2.1.8. Where these existing assets can be reused there is scope for significant savings in deployment costs.

2.1.4 FTTdp G.fast

Fibre to the distribution point (FTTdp), also called G.fast at the distribution point, is similar to G.fast deployed at cabinets, except that remote nodes are deployed at the distribution points for sub-loops that exceed the working range of G.fast (c. 250m).[32] These nodes are served with fibre and a miniaturised DSLAM serving a smaller number of subscribers. In this way the sub-loop is effectively shortened to the distance between subscriber premises and the distribution point, which is commonly under the 250m range of G.fast technology. The technical characteristics are the same as for G.fast at cabinets. An overview of FTTdp is provided in Figure 2.9 below.

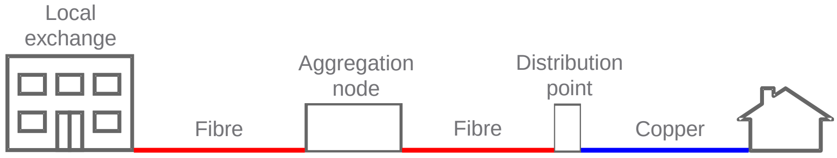


Figure 2.9: Overview of FTTdp G.fast technology [Source: Analysys Mason, 2016]

32 FTTdp is also suited to exchange-only loops which are not served by a cabinet.

Key cost components

The key cost components specific to FTTdp G.fast are presented in Figure 2.10. The number of subscribers per distribution point is small: Openreach ran a trial of FTTdp in North Yorkshire using distribution points serving 16 premises.[33] In terms of distance from the distribution point to customers' premises, Openreach has indicated that most UK homes are within 100m of their local distribution point.[34]

Figure 2.10: Key cost components for FTTdp G.fast equipment [Source: Analysys Mason, 2016]

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
Distribution point for copper network	Capacity dictated by existing distribution point. Typically up to 16 premises. Local distribution point, including box to house active equipment	Per unit	Number of subscribers	Access
Optical splitter (aggregation node)	Typically 1:32 split ratio	Per unit	Number of distribution points connected	Access
G.fast at distribution point DSLAM line card	Estimated as 16 premises	Per unit	Number of subscribers	Access
G.fast at distribution point DSLAM chassis	Estimated to be 1 line card	Per unit	Number of line cards deployed	Access
Or				
Integrated G.fast at distribution point DSLAM	Estimated as 16 premises	Per unit	Number of subscribers	Access

In addition to those assets described above, an FTTdp deployment would also make use of civil engineering assets such as trenches, ducts, poles and manholes. Copper and fibre cabling are also required to connect the assets summarised above. These may be dedicated to the FTTdp network or shared with another network in the same area. Those common cost components are presented in Section 2.1.8. Where these existing assets can be reused there is scope for significant savings in deployment costs.

33 See http://www.ispreview.co.uk/index.php/2015/09/uk-homes-could-in-future-provide-electricity-for-bts-broadband-network.html

34 See http://www.btplc.com/Sharesandperformance/Industryanalysts/Newsletter/Issue39/Feature/index.htm

2.1.5 Hybrid fibre-coaxial (HFC)

In a cable network, Internet services are provided via cable TV infrastructure using the DOCSIS standard, which was developed by CableLabs. The ITU-T has approved various versions of DOCSIS as international standards; here we discuss only DOCSIS 3.0 as this is the latest technology and is being used by Virgin Media in the UK.[35] New deployments in the short-to-medium term are likely to use this version.

Modern cable networks are based on an HFC architecture with the premises on a co-axial bus,[36] which may incorporate line amplifiers every 500m or so to maintain adequate signal levels. A high-level architecture of a cable network is shown in Figure 2.11.

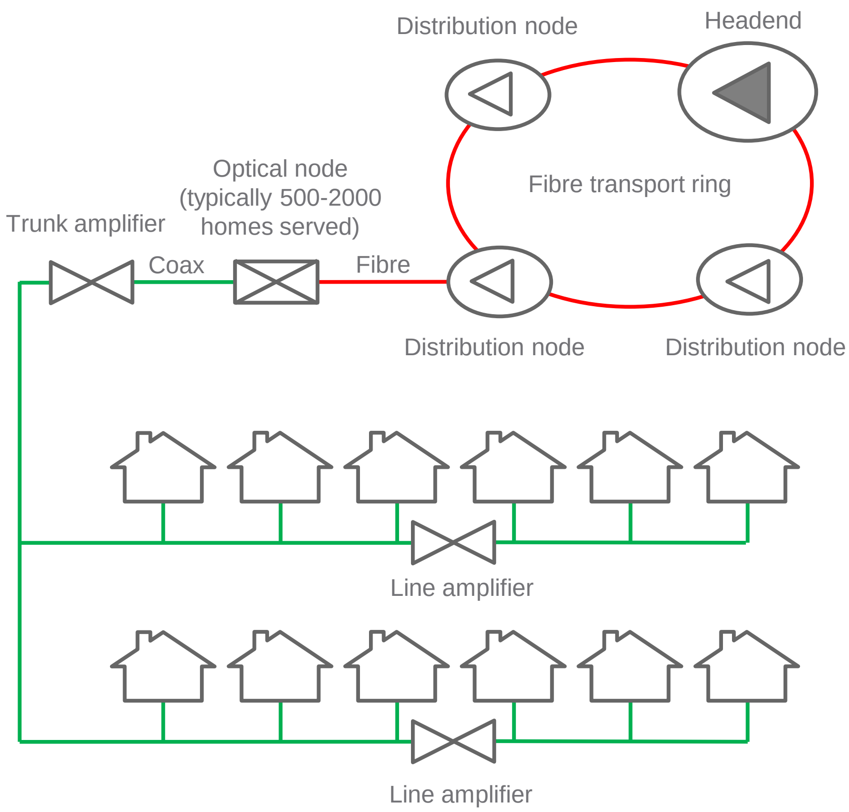


Figure 2.11: Overview of HFC technology [Source: Analysys Mason, 2016]

A fibre transport ring, part of the core network, connects to a distribution node, which is then connected with fibre to an optical node, which forms the interface between the fibre and coaxial media. The depth to which fibre penetrates the cable network varies between operators, but for high-speed broadband each co-axial tree (Figure 2.11 is an example of a single tree) will typically pass 500–2000 homes, located within around 500m of the optical node. The number of homes passed is not restricted by the length of the line (as the signal could simply be re-amplified at regular intervals), but is constrained instead by the

35 We understand that DOCSIS 3.0 has not yet been deployed across Virgin Media's whole network. The operator offers a postcode checker (https://keepup.virginmedia.com/speedupgrade) enabling customers to see whether it is available where they live.

36 A bus topology is a network topology in which all of the various devices in the network (here the broadband modems in the various premises) are connected to a single cable or line.

throughput that the operator wants to offer to each subscriber on the tree, as the total throughput on the coaxial cable is shared between all the simultaneously active subscribers.

A cable modem termination system (CMTS) is deployed at the interface between the fibre and coaxial networks. This serves a similar purpose to a DSLAM in an FTTC network – interfacing the RF signal on the coaxial cable to the Ethernet signal carried over fibre into the fibre transport ring. The configuration of the CMTS determines the number of channels available on the coaxial tree.

DOCSIS 3.0[37] allows several downstream and upstream channels to be bonded together. Common configurations include 4+4 (four downstream and four upstream channels) which delivers up to 222.48Mbit/s downstream and 122.88Mbit/s upstream; and 8+4, which delivers up to 444.96Mbit/s downstream and 122.88Mbit/s upstream.

The maximum throughput available to a particular user is typically limited by the profile[38] within their cable modem, which enables the cable operator to manage quality of service (i.e. the actual throughput experienced by each subscriber) and to sell different tiers of service.

Junction boxes may be deployed at branches in the coaxial network and at the points where individual subscribers' premises are connected to the coaxial cable.

Key cost components

The key cost components specific to HFC are presented in Figure 2.12.

Figure 2.12: Key cost components for HFC technology [Source: Analysys Mason, 2016]

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
Coaxial cable sheath for ducting	7mm, 10mm, 15mm, 20mm, 30mm, 40mm	Per m	Variable, by total length to reach all premises; the thickness varies by the number of premises on the branch of the tree	Access
Coaxial cable sheath for direct burial	7mm, 10mm, 15mm, 20mm, 30mm, 40mm	Per m	Variable, by total length to reach all premises; the thickness varies by the number of premises on the branch of the tree	Access
Line amplifier	One approx. every 450m	Per unit	Length of the coaxial tree	Access
CMTS line cards	4 downstream ports and 20 upstream ports per line card (these are not the	Per unit	Throughput delivered on the tree shared by all subscribers (indirectly, number of subscribers)	Access

37 ITU-T J.122.0, J.122.1, J122.2, J122.3

38 For example 20Mbit/s or 50Mbit/s, which is the maximum headline speed a customer can get.

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
	number of active subscribers)			
CMTS chassis	8 line cards	Per unit	Number of CMTS line cards required	Access
Network termination point (at subscriber's premise)	Connection point of the coaxial cable at the subscriber's premise	Per unit	Number of subscribers	Access
Junction box and housing	Different sizes based on the number of subscribers on the tree	Per unit	Number of subscribers and network topology	Access

In addition to these assets, an HFC deployment also uses civil engineering assets such as trenches, ducts, poles and manholes. These may be dedicated to the HFC network or shared with another network in the same area. Those common cost components are presented in Section 2.1.8.

2.1.6 Fixed wireless access (FWA)

FWA technologies provide fixed broadband Internet access to end users using wireless technologies. A high-level architecture of an FWA network is illustrated in Figure 2.13. FWA systems can be point-to-point or point-to-multipoint. In this report, in the context of a broadband USO, we consider only point-to-multipoint systems, which provide connectivity to premises located within the cell area of each FWA base station.

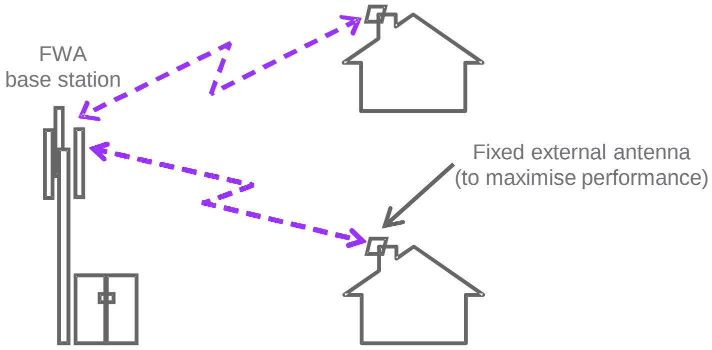


Figure 2.13: Overview of FWA technology [Source: Analysys Mason, 2016]

The most common FWA technologies are WiMAX and, more recently, TDD LTE. WiMAX is a radio access technology standardised by the IEEE and initially designed to provide broadband over a wireless metropolitan area network. TDD LTE is the predominant technology among new FWA deployments and vendors are offering base station products which can migrate from WiMAX to TDD LTE by means of a software upgrade. Therefore we would expect that a large-scale FWA deployment in the context of a broadband USO would be likely to use LTE technology.

The theoretical throughput of an FWA cell is determined by the amount of spectrum allocated (both the total amount of spectrum and the proportion allocated to the downlink); the antenna configuration of the base station and the user terminal; and the combination of modulation and coding schemes used. Higher performance can generally be achieved with a fixed installation using an external antenna, compared to mobile user terminals.

Figure 2.14 summarises the main characteristics that affect the performance of an FWA system.

	Better performance	Worse performance
Frequency band (performance in terms of range)	Low frequency	High frequency
Volumes of spectrum	More spectrum	Less spectrum
Number of antennas	MIMO (multiple-input and multiple-output)	Single antenna
Type of antenna	Fixed external antenna	Mobile or indoor antenna

Figure 2.14: Main characteristics of an FWA system [Source: Analysys Mason, 2016]

Site capacity

Capacity per site is driven primarily by spectral efficiency, the number of sectors per site and the quantity of spectrum available. The total capacity of a site divided by the number of user premises it covers indicates the guaranteed throughput available to each user.

In previous work for Ofcom,[39] Analysys Mason forecast a possible evolution of spectral efficiency for LTE technology. For LTE Release 12 we estimated a central case with spectral efficiency of 3.5bits/s/Hz/sector, and estimated that this would be commercially deployed by 2017 (having already been standardised). Based on expected improvements and the cycle of releases and deployment, we estimated that LTE Release 13 would be commercially deployed by 2019 and would achieve 3.9bit/s/Hz/sector.[40]

Considering a conservative interpretation of these forecasts, we can assume that an LTE-based FWA deployment in the period 2018–2020 could expect to achieve 3.7bit/s/Hz/sector, given the same assumptions on the take-up of MIMO and other new features of LTE. Assuming that standard tri-sector LTE sites are used (as are typical for modern macrocells deployed for coverage purposes) this would mean that a standard 10MHz carrier would achieve a theoretical capacity of 101Mbit/s /Hz/site.[41] This value needs to be adjusted to take account of network overheads (network-generated traffic for signalling and control) and uneven loading (e.g. inefficiencies brought about by non-

39 *Assessment of the benefits of a change of use of the 700MHz band to mobile,* Analysys Mason, October 2014. Available at http://stakeholders.ofcom.org.uk/binaries/consultations/700MHz/annexes/benefits_700MHz.pdf

40 This timetable seems to be confirmed by a recent white paper: see http://www.4gamericas.org/files/1914/3991/4430/4G_Americas_Rysavy_LTE_and_5G_Innovation_PPT.pdf

41 [✂✂]

uniform distribution of served premises within the cell).[42] Once these factors are considered, we can assume a realistic site capacity of 68.7Mbit/s for each 10MHz carrier.

In the sub-1GHz frequency scenario we have assumed that 2×10MHz would be available with one carrier dedicated to the downlink and one to the uplink. This would mean that the available downlink capacity would be 69Mbit/s per site. In the 5.8GHz scenario we have assumed that a total of 20MHz would be used by providers. We further assume that this would be treated as TDD spectrum and that 75% of the clock time would be dedicated to the downlink. This implies a capacity of up to 103Mbit/s per site.

Coverage per site

For sub-1GHz spectrum a simple link-budget calculation suggests that the theoretical cell radius of an FWA site could be as much as 40km, with peak speed at the cell edge of 30Mbit/s (the radius would not necessarily be greater if limited by a 10Mbit/s peak speed as the link may be uplink-limited). In reality this radius may be smaller due to changes in topography and clutter over such a large area. In Australia, NBNCo's rural FWA deployment found that cell sites could only reach 20% of premises within their theoretical range of 14km[43] due to difficulties in obtaining line-of-site. In reality the cell radius varies significantly between locations, and a full radio planning exercise (outside the scope of this work) would be required to define an accurate range. We therefore believe that, for the purposes of this cost modelling work, a 10km cell radius is a prudent assumption for the upper bound to the cell radius for even a sub-1GHz FWA deployment to counter this risk.[44]

For the high-frequency scenario we carried out some simple link-budget modelling to estimate the typical achievable cell radii. The lightly licensed 5.8GHz band has a power limit of 4Watts EIRP;[45] for a typical rural FWA deployment[46] using a 20MHz downlink carrier we would expect that to provide a 10Mbit/s download sync speed – the realistic cell radius would be around 1km. Raising this download sync speed to 30Mbit/s would reduce the cell radius to the order of 0.5km.

Key cost components

The key cost components common to an FWA deployment are presented in Figure 2.15. A base station needs to be deployed to serve the premises connected, and this includes:

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42 We assume these are scalars of 80% (overheads) and 85% (network loading) as in the original 700MHz study (http://stakeholders.ofcom.org.uk/binaries/consultations/700MHz/annexes/benefits_700MHz.pdf). However, an FWA network may be more or less efficient in practice than the wireless network the 700MHz study modelled.

43 See http://www.nbnco.com.au/content/dam/nbnco/documents/nbnco-fixed-wireless-and-satellite-review-07052014.pdf

44 In practice this may be an overestimate in some areas. This could be identified with radio planning which is beyond the scope of this study.

45 Corresponding to EIRP of 36dBm

46 Assuming outdoor coverage with a 30m mast, 5m high outdoor antenna at the subscriber premise and 2×2MIMO (which is already common); also assuming a 90% cell edge probability which is common in the industry. This estimate was made using the Extended Hata model.

- a mast (tower)
- antennae, located on the mast: typical towers for wide-area coverage use a three-sector arrangement, with each antenna covering an arc of approximately 120°
- active equipment required to manage the wireless connections and process the wireless signal
- a shelter, to house the active equipment and ancillary equipment (power, air conditioning and battery backup).

The area of the cell served by a base station is determined by the characteristics of the spectrum deployed and the environment in which it is positioned (e.g. clutter, topography).

An FWA operator may also need to pay spectrum fees if the spectrum it uses is licensed. The fees for the lightly licensed 5.8GHz band are relatively small, but sub-1GHz spectrum is likely to be expensive. However, estimation of these costs is outside the scope of this report.

Figure 2.15 outlines the key cost components for an FWA deployment at a high level. We note that there is further complexity with respect to the type of site that an operator is able to use. For example, a traditional site with mast can be built, or space on an existing mast could be leased. Depending on the position of the universal service provider(s), also known as USP(s), it may also be possible to share active equipment with another operator, though we conservatively assume that this is unlikely in the context of the USO. Alternatively rooftop sites can also be leased. The mix that the USP(s) could use would depend on the availability in their deployment area, the commercial terms and the location of potential sites. The commercial and technical conditions at each site could vary significantly (e.g. it may be more costly to provide power to remote sites or for engineers to attend).

Figure 2.15: Key cost components for an FWA deployment [Source: Analysys Mason, 2016]

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
Mast for FWA base station (including antennae)	Tower, including tri-sector antennae	Per unit	Fixed cost per base station though with variability related to the mast height and wind loading characteristics in some environments Commercial terms for leased sites or shared sites Availability of power infrastructure Where suitable rooftop locations may offer lower costs than a traditional full-size lattice tower	Access
Wireless equipment shelter	Houses the active equipment, power, air conditioning and battery backup	Per unit	Fixed cost per base station. Cost savings possible if shared	Access

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
Active equipment at FWA base station	Includes transmitters, amplifiers, eNodeB, backhaul router, power supply and associated vendor/software fees as an opex item	Per unit	Number of antennas deployed and spectrum band used by the equipment	Access
Fixed external antenna (at customers' premises)	To receive/send the wireless signal at the customers' premises	Per unit	Fixed cost per subscriber. Cost usually borne by the subscriber	Access

2.1.7 Satellite

High-throughput satellites typically operate in the Ka band from 18.3GHz to 31GHz. There is significantly more spectrum available for satellite services in the Ka band than at lower frequencies, and it is possible to build Ka-band satellites with a large number of separate spotbeams, allowing the frequencies to be reused in different geographical areas, similar to the approach in a 2G cellular network. Connectivity is provided directly to a fixed satellite dish, typically 0.7–0.8m in diameter, which is mounted on the user's property and connected via coaxial cable to an internal modem. A high-level illustration of this architecture is provided in Figure 2.16.

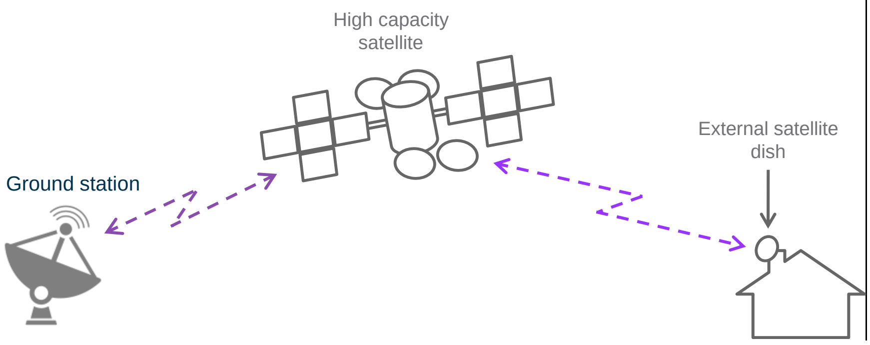


Figure 2.16: Overview of satellite technology [Source: Analysys Mason, 2016]

The total capacity of a high-throughput satellite is determined by the number of spotbeams that the satellite can support and the amount of spectrum allocated to each spotbeam. These factors are dependent in turn on the power available from the satellite's solar panel, the diameter of the reflector antennas that can be deployed, and the total amount of spectrum available to the operator.

As an example, the KA-SAT satellite launched by Eutelsat in late 2010 uses 82 spotbeams to cover the whole of Europe together with parts of North Africa and Western Asia.[47] We understand that

47 See http://www.eutelsat.com/en/satellites/the-fleet/EUTELSAT-KA-SAT.html

four spotbeams cover the UK, while another two are focused respectively on Ireland and the north of France and partially cover Northern Ireland and part of the south-east of England. Figure 2.17 and Figure 2.18 show the coverage offered by KA-SAT and each of its spotbeams. The total capacity of the satellite is approximately 90Gbit/s, and Eutelsat is offering maximum download sync speeds of up to 22Mbit/s and upload sync speeds of up to 6Mbit/s for residential customers, while business customers can get up to 50Mbit/s download and 10Mbit/s upload.

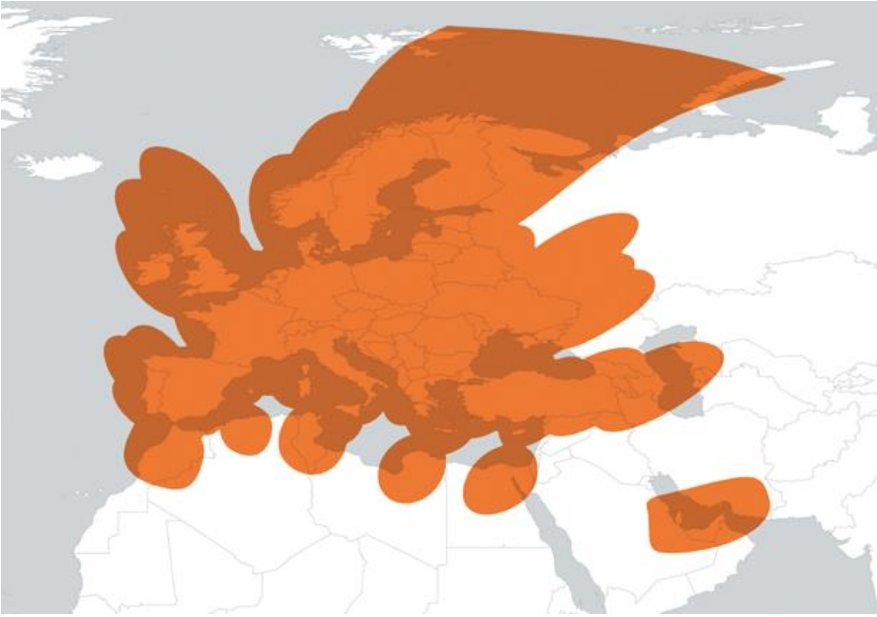


Figure 2.17: KA-SAT coverage [Source: Eutelsat[48]]

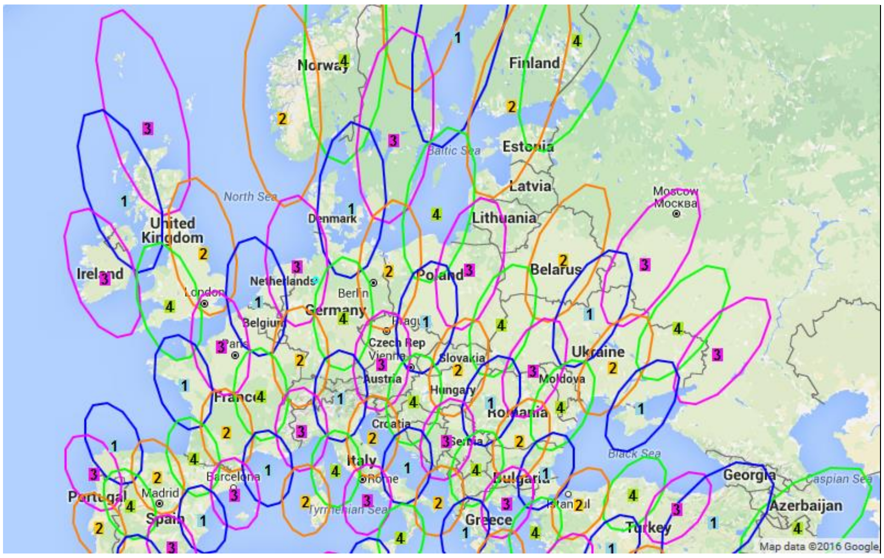


Figure 2.18: KA-SAT spotbeams [Source: Satellite Signals[49]]

A number of other satellites also cover the UK. Avanti, with its HYLAS 1 and HYLAS 2 satellites operating in the Ka band, offers services with download sync speed up to 15Mbit/s and upload sync

48 See http://www.dxsatcs.com/sites/default/files/ka%20band/druzice/EUT%20KA%20Sat%209A-9e/dxsatcs-eutelsat-ka-sat-9a-9-east-ka-band-footprint-coverage-beam-european.jpg

49 See http://www.satsig.net/tooway/satellite-dish-pointing-ka-sat-tooway-europe.htm

speeds up to 2Mbit/s.[50] The satellite ISP Avonline Broadband recommends Avanti over Eutelsat (under the brand Tooway) for satellite broadband subscribers in the UK, asserting that in England and Wales Eutelsat only has "limited availability",[51] which we understand is due to high utilisation of the available capacity. Figure 2.19 and Figure 2.20 illustrate the coverage of HYLAS 1 and HYLAS 2.

Figure 2.19: HYLAS 1 coverage [Source: Avanti[52]]

Figure 2.20: HYLAS 2 coverage [Source: Avanti[53]]

Astra (under the brand SES), with its ASTRA 2E and ASTRA 2F satellites operating in the Ka band, offers services with download sync speed up to 20Mbit/s and upload sync speeds up to 2Mbit/s.[54] Figure 2.21 and Figure 2.22 below illustrate the coverage of these two satellites.

50 See http://avonlinebroadband.com/choose-your-package and http://www.ispreview.co.uk/isp_list/ISP_List_Satellite.php

51 See http://avonlinebroadband.com/about-satellite-broadband/our-broadband-coverage/

52 See http://www.avantiplc.com/sites/default/files/hylas-1-tech-sheet.pdf

53 See http://www.avantiplc.com/sites/default/files/hylas-2-tech-sheet.pdf

54 See http://www.onastra.com/16802073, http://www.broadbandeverywhere.co.uk/page/footprint and http://www.ispreview.co.uk/isp_list/ISP_List_Satellite.php

Figure 2.21: ASTRA 2E coverage [Source: SES[55]]

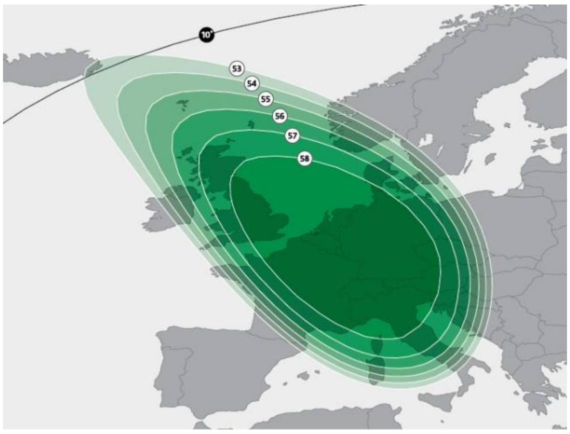
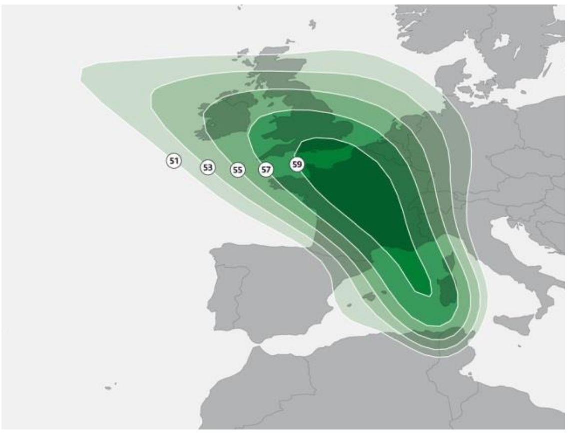


Figure 2.22: ASTRA 2F coverage [Source: SES[56]]



Our view is that satellite speeds are unlikely to increase for any significant number of subscribers by 2020 for a number of reasons:

- the Eutelsat spotbeams are nearly at full capacity
- we do not expect ViaSat to launch its ViaSat-3 satellite covering Europe and the Middle East until 2020 at the earliest[57]
- Avanti currently only offers bandwidths of up to 15Mbit/s and its HYLAS 3 and HYLAS 4 satellites launching in 2017 will share their capacity across the EMEA region[58] (limiting the capacity available for potential USO subscribers in the UK).

Key cost components

The key cost components common to a satellite deployment are shown in Figure 2.23. Subscribers will need a VSAT dish and CPE but typically this is a cost borne directly by the subscriber. Pricing of wholesale satellite capacity can be structured in a variety of ways (e.g. by volume, by guaranteed throughput, by transponder).

55 See http://www.ses.com/fleet-coverage#?posId=198&satId=345#satelliteDetails

56 See http://www.ses.com/fleet-coverage#?posId=198&satId=344#satelliteDetails

57 ViaSat says ViaSat-3 will be delivering a 100+ Mbit/s residential Internet service (source: https://www.viasat.com/products/high-capacity-satellites) with launch in early 2020 (source: http://www.satellitetoday.com/telecom/2016/02/10/dankberg-viasat-3-satellites-will-have-more-capacity-than-the-rest-of-the-world-combined/)

58 See http://www.avantiplc.com/fleet-coverage/coverage.html

Figure 2.23: Key cost components for a satellite deployment [Source: Analysys Mason, 2016]

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
VSAT dish	1 dish per subscriber premise	Per unit	Fixed cost per subscriber. Cost usually borne by the subscriber	Access
Satellite capacity	Maximum satellite capacity estimated to be approximately 90Gbit/s per satellite	Per Mbit/s per GB	Different capacity units may be bought: a given throughput (in Mbit/s), a given volume (in GB per month), or a whole transponder (which is essentially a large throughput increment). There may also be a fixed cost for interconnection at the satellite operator's ground station	Access

2.1.8 Components common to multiple technologies

Many of the various types of broadband access networks discussed above have elements that may be shared between networks, and in many cases these assets – such as trenches and ducts – are common across different technologies. These common cost components are listed in Figure 2.24 below, which presents them in the following order:

- **Civil engineering components**: These components are common to all the wireline access technologies. They are also used for the backhaul of all wireline technologies and may be used for the backhaul of FWA. (Further, they are used for the core networks of all technologies, but it is unlikely that these core networks will require additional civil engineering work to provide the broadband USO.) These assets could be deployed specifically for the purposes of serving the broadband USO, or reused from existing infrastructure. They are dimensioned based on the requirements of the fibre cable needed.

- **Fibre cables and nodes**: These components are common to FTTP GPON and FTTP PTP access technologies, as well as for fibre backhaul and core links for the other technologies. These assets are dimensioned based on the distance and capacity required between the nodes in each of the network architectures.

- **Microwave backhaul and core**: Microwave backhaul is likely to be used only by FWA, whereas the other components in this category can be used in a core network for any of the access technologies. Additional active equipment in the core may be required if the broadband USO will generate significant extra traffic on the provider's core network.

Figure 2.24: Key cost components common to multiple technologies [Source: Analysys Mason, 2016]

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
Civil engineering components				
Trench	Wide range of sizes, from accommodating one sub-duct for a final drop to several 110mm ducts	Per m	Varies by incremental length to reach all premises and number of ducts it contains (which drives trench and reinstatement width). Surface needing reinstatement also significantly influences costs. Other factors such as planning consent and wayleaves can also influence the costs	Core, backhaul and access
Duct	Wide range of sizes, from a 14mm sub-duct to a 110mm duct	Per m	Variable, by incremental length to reach all premises and number of copper or fibre lines it contains	Core, backhaul and access
Pole (including fixing hardware)	Used to lay aerial cables. Typically deployed every 40m	Per pole	Variable, by length of aerial cable route to reach all premises	Access (may be used for backhaul as well)
Pole rental (including fixing hardware)	Used to lay aerial cables. Typically deployed every 40m although spans do vary	Per pole	Variable, by length of aerial cable route to reach all premises	Access (may be used for backhaul as well)
Manhole	Underground space where ducts/cables can be easily accessed. Different sizes available	Per unit	Dimensioned by the number of ducts to be accommodated and/or the size of the equipment housed (e.g. splitters)	Core, backhaul and access
Fibre cables and nodes				
Fibre cable (blown, including microduct)	2F, 6F, 12F, 24F,48F, 72F, 96F, 192F, 312F	Per m	Variable, by total length (i.e. one fibre all the way from the cabinet/exchange to each premise) to reach all premises	Core, backhaul and access
Fibre cable sheath for ducting	2F, 6F, 12F, 24F,48F, 72F, 96F, 192F, 312F	Per m	Variable, by total length (i.e. one fibre all the way from the cabinet/exchange to each premise) to reach all premises	Core, backhaul and access
Fibre cable sheath for direct burial	2F, 6F, 12F, 24F,48F, 72F, 96F, 192F, 312F	Per m	Variable, by total length (i.e. one fibre all the way from the cabinet/exchange to each premise) to reach all premises	Access (may be used for backhaul as well)

Cost component	Description/ capacity	Unit for costs	Cost driver	Core, backhaul and/or access
Aerial fibre cable sheath	2F, 6F, 12F, 24F,48F, 72F, 96F, 192F, 312F	Per m	Variable, by total length (i.e. one fibre all the way from the cabinet/exchange to each premise) to reach all premises	Access (may be used for backhaul as well)
Feeder fibre splice	Splicing of a fibre between an exchange and its cabinets	Per unit	Variable by number of cabinets served by the same initial fibre from the exchange	Core, backhaul and access
ODF	Various sizes. Sizes between 48 and 1920 are common	Per unit	Variable, by number of fibre connections	Core, backhaul and access
Microwave backhaul and core				
Microwave point-to-point backhaul	Wireless backhaul to nearest easily accessible fibre (e.g. at fibre cabinet or local exchange). Various capacities	Per link	Number of hops required to maintain direct line of sight, and throughput required	Backhaul
Ethernet Aggregation Switch chassis	Aggregation switch chassis. 7-card or 12-card capacities are common	Per unit	Number of switch line cards that need to be housed in a given local exchange	Core
Ethernet switch line card: 60-port 10/100 Ethernet	Card which can connect up to 60 copper cables at a speed of up to 100Mbit/s	Per unit	Number of connections which require a port of this capacity (10 or 100 Mbit/s)	Core
Ethernet switch line card: core facing	Typical sizes include • 10 port 1GE • 20 port 1GE • 1 port 10GE • 2 port 20GE	Per unit	Number of connections which require a port of each capacity	Core

2.2 Review of the technologies against the USO specifications

In this section we review the performance of each of the technologies discussed above against the proposed broadband USO specifications, and how USO providers can adapt the way they deploy technologies in order to meet the requirements of the USO. We consider the trade-offs involved in providing infrastructure that can meet the specification, and also explain the impact that these decisions may have on key cost components.

2.2.1 USO specification

Based on the data on eligible premises available at the time, Ofcom considered three possible scenarios for the broadband USO and has also asked us to model a Superfast scenario. The main features of the corresponding specifications are presented in Figure 2.25. For more details, please refer to Section 1.4.

Figure 2.25: Scenarios for broadband USO product specification [Source: Ofcom with Analysys Mason additions, 2016]

	Scenario 1 10Mbit/s sync speed	Scenario 2 10Mbit/s sync + upload	Scenario 3 10Mbit/s sync + upload	Superfast scenario 30Mbit/s sync + upload
Download sync speed	Sync speed 10Mbit/s – best efforts	Sync speed 10Mbit/s – achieving at least a similar distribution of actual speeds as a current service with a 10Mbit/s sync speed		Sync speed 30Mbit/s
Upload sync speed	None defined	0.5Mbit/s	1Mbit/s	6Mbit/s*
Latency	None defined	Medium response time	Medium response time	Fast response time
Contention ratio/ committed information rate (CIR)	None defined	50:1/1.5Mbit/s	50:1/1.5Mbit/s	10Mbit/s

* This is the median for all Superfast lines, including Virgin Media.

2.2.2 Download sync speed

Each of the technologies under consideration is able to meet the required peak speed for each of the three USO scenarios and for the Superfast scenario– within a certain range. However, technologies that use shared resources (e.g. FWA, satellite) are constrained in terms of the CIR that they can provide, as discussed below.

- **FTTP GPON** and **FTTP PTP**: Both of these technologies are able to provide download sync speeds in the range of gigabits with no practical limitation on range in the context of an access network

- **FTTC**: Each of the variants of FTTC is able to meet the download sync speed requirement of 10Mbit/s or 30Mbit/s over a short range. The different profiles used by each of the variants of FTTC being considered do limit the range (in terms of the length of the copper sub-loop) over which each can provide 10Mbit/s or 30Mbit/s. As each copper loop is dedicated to the subscriber there is no constraint on the CIR in the sub-loop. However, the fibre feeder to the exchange that serves the DSLAM in the street cabinet must be adequately provisioned to meet the target CIR.

 – **VDSL2**: Openreach's VDSL2 connections can offer a download sync speed above 10Mbit/s up to about 1.9km from the cabinet, and above 30Mbit/s up to about 1.3km from the cabinet.

 – **LR-VDSL**: Based on data in the public domain we estimate this can serve 10Mbit/s at 3.5km and 30Mbit/s at up to 2.8km[59]

 – **G.fast at the cabinet**: As shown in Figure 2.6, G.fast can offer a download sync speed above 10Mbit/s up to about 500m from the cabinet, and above 30Mbit/s up to about 450m from the cabinet. In the context of the USO specifications considered in this report this offers no advantage over LR-VDSL in terms of coverage.

- **FTTdp G.fast**: We understand G.fast offered from the distribution point has the same speed and range capabilities as G.fast at the cabinet. The distribution point is typically located less than 100m from a subscriber's premises and therefore, when deployed in line with this dimensioning, FTTdp G.fast is capable of meeting both the sync speed and CIR requirements.

- **HFC**: As explained in Section 2.1.5, HFC can offer up to 444.96Mbit/s downstream (assuming 8 channels), which can be used by any subscriber connected to the tree, up to the cap defined in their modem profile. Therefore the maximum number of subscribers on each tree must be capped adequately in order for the relevant CIR to be met. The use of line amplifiers within the tree ensures that range limitations can be overcome.

- **FWA**: The theoretical throughput of an FWA cell is determined by the amount of spectrum allocated (both the total amount and the proportion allocated to the downlink[60]); the antenna configuration of the base station and the user terminal; and the combination of modulation and coding schemes in use. Higher performance can generally be achieved with a fixed installation using an external antenna, than with mobile user terminals – hence FWA cells tend to be larger than macrocells for mobile data services if using the same spectrum. The environment can also influence the cell size – topography, clutter and, in some bands, even weather conditions can influence the propagation characteristics and hence speed achievable. In practice, when dimensioning coverage with FWA there is a trade-off between (a) the intended speed and capacity of the service, and (b) the total amount of spectrum available and the cell size (and hence number of sites required).

- **Satellite**: Offerings sold as residential services only offer download sync speeds of up to 22Mbit/s. Nevertheless, the peak speed requirements of all but the Superfast scenario are commercially available via satellite, and we understand that peak download sync speeds of up to 30Mbit/s are theoretically possible. However, the capacity on satellites is limited and the CIRs set for Scenarios 2 and 3 and the Superfast scenario are difficult to achieve with the satellite capacity that is expected to be available in the period 2018–2020. For example, if satellite was used to provide a USO service to 100 000 subscribers at the CIR of 1.5Mbit/s, this would require

59 See http://www.ispreview.co.uk/index.php/2016/04/bt-openreach-prep-trial-long-reach-vdsl-broadband.html

60 Although we note that when power limitations are in place (as in the 5.8GHz band) more spectrum may not necessarily allow for increased range with a given speed or capacity.

a throughput of 150Gbit/s whereas the total capacity of a satellite is currently of the order of 90Gbit/s. There are therefore severe limitations on the number of subscribers that could be served by satellite given the current forecasts of available capacity.

Figure 2.26 summarises the ability of each access technology to deliver the download sync speed and CIR required by each USO scenario.

Figure 2.26: Download sync speed by access technology in relation to USO scenarios [Source: Analysys Mason, 2016]

	Scenario 1 **10Mbit/s sync speed**	**Scenario 2** **10Mbit/s sync + upload**	**Scenario 3** **10Mbit/s sync + upload**	**Superfast scenario** **30Mbit/s sync + upload**
FTTP GPON	Meets both peak speed and CIR requirements across all scenarios			
FTTP PTP	Meets both peak speed and CIR requirements across all scenarios			
FTTC VDSL2	Met, up to a range of about 1.9km from the cabinet			Met, up to a range of about 1.3km from the cabinet
FTTC LR-VDSL	Met, up to a range of about 3.5km from the cabinet. Final specification to be determined.			Met, up to a range of about 2.8km from the cabinet. Final specification to be determined.
FTTC G.fast at cabinet	Met, up to a range of about 500m from the cabinet			Met, up to a range of about 450m from the cabinet
FTTdp G.fast	Met, up to a range of about 500m from the distribution point			Met, up to a range of about 450m from the distribution point
HFC	Meets peak speed requirement. Number of subscribers on a HFC tree may need to be limited in order to meet the CIR requirements; the number possible varies according to the CMTS deployed			
FWA	Can be met. In practice there are trade-offs between peak speed in the cell and its total capacity against the bandwidth available, environmental factors and technology deployed. Some limits can be overcome by deploying additional cell sites or optimising their locations. The propagation characteristics (i.e. cell range) are also heavily influenced by the band that is used. The challenges increase significantly when the speed requirements are increased			
Satellite	Met	Met, but only a limited number of subscribers could be served		Theoretically possible but not currently commercialised

2.2.3 Upload sync speed

The upload requirement in the USO specifications is set as peak sync speed in the upload direction. Each of the technologies is therefore capable of meeting this requirement, though there are trade-offs in network design between the upload and download sync speeds as well as the range over which the speed can be offered.

- **FTTP GPON** and **FTTP PTP**: Both of these technologies are able to provide upload sync speeds in the range of gigabits, with no practical limitation on range in the context of an access network (for comparison a submarine cable is able to carry over 10Tbit/s per fibre and requires a repeater only every 80km or so). In the case of FTTP PTP, symmetric services are possible in which upload and download sync speeds are the same.

- **FTTC**: As with download sync speeds, there is a limited range (in terms of copper sub-loop length) over which a given upload sync speed can be provided. This varies between the various FTTC profiles that are available. VDSL2 upload sync speeds for premises located close to a cabinet can reach 20Mbit/s.[61] We understand that the decline of upload sync speed as the distance from the cabinet increases is not as steep as the decline of *download* sync speed, and therefore the upload sync speed requirements do not impose more stringent distance limitations than the download sync speed requirements. For example, in cases where Openreach can offer a 10Mbit/s download sync speed using VDSL2, it can offer over 1Mbit/s upload sync speeds. We expect that this applies equally to FTTC LR-VDSL and FTTC G.fast at the cabinet but we have been unable to confirm this.

- **FTTdp G.fast**: As with cabinet-based versions of G.fast, we understand that downlink services of 10Mbit/s and 30Mbit/s are distance-constrained more quickly than an uplink service of 1Mbit/s. In addition, given that FTTdp is typically deployed where premises are within 100m of the distribution point, we do not believe there is a practical limitation on upload sync speed when the commensurate download sync speed is met.

- **HFC**: As explained in Section 2.1.5, HFC can offer up to 122.88Mbit/s upstream (assuming four upstream channels), which can be used by any subscriber connected to the tree up to the cap defined in its modem profile. Range limitations can be overcome by using line amplifiers within the tree. Virgin Media claims that its services advertised as “up to 100 Mbit/s” deliver an average upload sync speed of around 6.3Mbit/s, and its “up to 200 Mbit/s” services deliver around 12.6Mbit/s,[62] therefore we do not expect the upload sync speed requirement to be a practical limitation.

- **FWA**: FWA typically uses a TDD arrangement, in which the downlink:uplink ratio can be selected to alter the throughput offered in each direction. This is a direct trade-off, as one can only be increased at the expense of reducing the other (for a given amount of spectrum). Typically a 75:25 ratio is used for wireless broadband purposes, which suggests the uplink requirement set in the four scenarios under consideration could be met, given that their downlink requirements are more than four times higher than this figure. Where the spectrum used is planned as frequency division duplexing (FDD) the uplink and downlink carriers are of equal

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61 See http://www.increasebroadbandspeed.co.uk/2015/what-is-gfast

62 See http://www.virginmedia.com/shop/broadband/speeds.html

size and it is the power of the user terminal that is the main constraint on the uplink sync speed. [✂✂] This suggests that the primary limitation on upload speeds is total cell loading.

- **Satellite:** The residential services sold today offer upload sync speeds of up to 6Mbit/s. Theoretically, much higher uplink speeds are possible but these incur a trade-off with the downlink capacity of the satellite.

Figure 2.27 below summarises the ability of each access technology to deliver the upload sync speed required by each USO scenario.

Figure 2.27: Upload sync speed by access technology in relation to each USO scenario [Source: Analysys Mason, 2016]

	Scenario 1 10Mbit/s sync speed	Scenario 2 10Mbit/s sync + upload	Scenario 3 10Mbit/s sync + upload	Superfast scenario 30Mbit/s sync + upload
FTTP GPON	–	Meets requirement across Scenarios 2, 3 and the Superfast scenario		
FTTP PTP	–	Meets requirement across Scenarios 2, 3 and the Superfast scenario		
FTTC VDSL2	–	Meets requirement (distance limitation due to download sync speed)		
FTTC LR-VDSL	–	Expected to meet requirement although full specification to be determined (distance limitation due to download sync speed)		
FTTC G.fast at cabinet	–	Meets requirement (distance limitation due to download sync speed)		
FTTdp G.fast	–	Meets requirement (distance limitation due to download sync speed)		
HFC	–	Meets requirement		
FWA	–	Can be met. In practice there are trade-offs between peak speed in the cell against the bandwidth available, environmental factors and technology deployed. Some limits can be overcome by deploying additional cell sites or optimising their locations. The propagation characteristics (i.e. cell range) are also heavily influenced by the band that is used. The challenges increase significantly when the speed requirements are increased		
Satellite	–	Meets requirement		

2.2.4 Latency

Latency occurs primarily due to switching, queuing and buffering delays in the access network and the Internet. Ofcom's research suggests that latency is typically under 20ms[63] for FTTC and HFC,[64] and under 55ms for LTE[65] (which can be used to deliver FWA). FTTP and FTTdp are likely to offer similar performance to FTTC and HFC. This indicates that all wired technologies and potentially FWA offer a latency that satisfies the requirements of all three USO scenarios and the Superfast scenario.

For satellite services, latency is much greater due to 36 000km distance from a ground station to the satellite, and the same distance to the user. In addition, the same switching, queuing and buffering delays that introduce latency to terrestrial technologies are also a factor in the context of satellite

63 20 milliseconds

64 See http://stakeholders.ofcom.org.uk/binaries/research/broadband-research/nov2015/fixed-bb-speeds-nov15-report.pdf

65 See http://consumers.ofcom.org.uk/news/4g-significantly-outperforms-3g/

services. The latency is usually 500–700ms overall. This creates a noticeable delay for applications such as a VoIP/video call and is unsuitable for applications that require real-time connectivity, such as first-person shooting video games for a residential user. This would not meet the requirements of any of the two USO scenarios that specify a latency requirement, nor would it meet the requirements of the Superfast scenario. However, we note that new techniques may reduce the subscribers' experience of the measured latency.[66]

2.2.5 Contention ratio

The contention ratio is the ratio between the peak speed of a service and the CIR provisioned for each user. Contention can be implemented at all levels of the network, whether this is the access, backhaul or core. Ofcom has defined a contention ratio 50:1 for Scenarios 2 and 3. Scenario 1 and the Superfast scenario do not have a contention ratio requirement.

The requirement of 50:1 can be met by all technologies, simply by provisioning enough bandwidth per user for a given headline speed (e.g. 200 kbit/s per user for a service of up to 10Mbit/s). The required contention ratio is not technically difficult to meet but it is a requirement that can have a significant impact on the economics of the network.

In Section 1.4 we described how the CIR required in the access network to meet the required quality of service for Scenario 2 is 1.5Mbit/s. The contention ratio between the 10Mbit/s sync speed and the 1.5Mbit/s CIR (10:1.5) is therefore a much more stringent requirement than the 50:1 set in Ofcom's specification. For technologies that share a backhaul service, this minimum needs to be used to dimension the backhaul provided (in practice this means upgrading electronics, or lighting additional fibre). For those technologies where the access network is shared (e.g. FWA, satellite) that part of the network needs to be dimensioned accordingly and the number of users in a cell area or spotbeam limited accordingly. For FWA this means that additional cell sites need to be dimensioned to meet the contention ratio requirement. Given the limited number of additional satellites planned in the medium term, satellite technology can therefore only serve a relatively low number of subscribers at the suggested specifications, most notably in the case of the Superfast scenario.

2.2.6 Summary

All of the candidate technologies are capable of meeting the requirements of all of the three USO scenarios and the Superfast scenario if dimensioned appropriately, and the cost-modelling work described in the following chapters of this report explores the relative costs of each technology. However, some technologies are better suited than others to meeting the USO requirements. We make the following observations:

- **FTTP**: Within the context of a broadband USO with peak speeds in the range of 10–30Mbit/s, FTTP GPON and FTTP PTP are both easily capable of meeting all of the requirements, and the

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66 http://www.ispreview.co.uk/index.php/2016/10/europasat-interview-broadband-uso-unfeasible-without-satellite.html/2

differences in their performance are minimal. In this context, we note that FTTP PTP is more expensive to deliver than FTTP GPON and offers little additional benefit in relation to the USO requirements. Since FTTP needs to provide fibre to each premises served, it is best suited to deployments where the premises are clustered and where reusable ducting is available on appropriate routes.

- **FTTC**: Generally cheaper to implement than FTTP since it reuses the existing copper sub-loop. Where the sub-loops are not long enough to provide the required speed, a new cabinet with a fibre feeder from the exchange would be required closer to the end-user premises in order to make use of this technology. G.fast deployed at the cabinet is primarily aimed at increasing peak speeds for subscribers close to the cabinet and would not increase the number of premises that could be covered at 10Mbit/s or 30Mbit/s, compared to VDSL2. LR-VDSL could potentially increase the range of FTTC compared to VDSL2, and if all loops are within the appropriate range then it seems likely that an upgrade to the active electronics at the cabinet may be the only requirement. It is possible that a cabinet may not be able to host multiple FTTC variants simultaneously and it may require all lines to be upgraded. We have not been able to conclusively confirm this, however.

- **FTTdp**: A trade-off between FTTC and FTTP in that it requires new fibre to be deployed beyond the cabinet, to the distribution point (within 100m of subscribers premises), but reuses the existing copper loop beyond this point (the final drop).

- **HFC**: Limited in the number of subscribers it can serve per distribution node, primarily by the total capacity of the distribution tree, since the available bandwidth (set by the configuration of the CMTS at the distribution node) is shared by all premises. The use of line amplifiers means that range limitations are alleviated, compared to FTTC.

- **FWA**: Suited to serving relatively dispersed premises. The capacity of each cell in terms of the number of premises it can serve with the CIR depends strongly on the quantity of bandwidth utilised and the spectral efficiency of the technology deployed. The total area that a cell can serve, which is a function of its radius, is determined by the peak speed requirements (i.e. all else being equal, 10Mbit/s can be provided over a wider area than 30Mbit/s), and is very dependent on local environmental conditions as discussed in Section 2.1.6. Cell range limitations can be overcome by deploying more FWA cell sites. However, this would incur additional costs due to the need to provide additional fibre or microwave backhaul.

- **Satellite**: Cannot meet the measured latency requirements for the USO specifications but can meet the other requirements for a small total number of users (in the order of hundreds of thousands subscribers or fewer in Scenarios 2 and 3 given the current launch plans that we are aware of). The total capacity expected to be available in the period to 2020 is not expected to increase significantly, so satellite could only serve a very limited number of premises across the UK. Given its broad coverage, and ignoring the shortcomings related to latency, satellite is best suited to serving only the most dispersed of premises.

Figure 2.28 presents a summary of the ability of each access technology to deliver the specifications required by each scenario.

Figure 2.28: Summary of the ability of each access technology to meet the USO specification scenarios [Source: Analysys Mason, 2016]

	Scenario 1 10Mbit/s sync speed	**Scenario 2 10Mbit/s sync + upload**	**Scenario 3 10Mbit/s sync + upload**	**Superfast scenario 30Mbit/s sync + upload**
FTTP GPON	✓	✓	✓	✓ with possible additional backhaul requirements
FTTP PTP	✓	✓	✓	✓ with possible additional backhaul requirements
FTTC VDSL2	✓ with distance limitations	✓ with distance limitations	✓ with distance limitations	✓ with distance limitations and possible additional backhaul requirements
FTTC LR-VDSL	✓ with distance limitations	✓ with distance limitations	✓ with distance limitations	✓ with distance limitations and possible additional backhaul requirements
FTTC G.fast at cabinet	✓ with distance limitations	✓ with distance limitations	✓ with distance limitations	✓ with distance and limitations and possible additional backhaul requirements
FTTdp G.fast	✓ with distance limitations	✓ with distance limitations	✓ with distance limitations	✓ with limitations and possible additional backhaul requirements
HFC	✓	✓	✓	✓ with limits related to number of users on a tree and possible additional backhaul requirements

	Scenario 1 10Mbit/s sync speed	Scenario 2 10Mbit/s sync + upload	Scenario 3 10Mbit/s sync + upload	Superfast scenario 30Mbit/s sync + upload
FWA	✓ with distance limitations	✓ with distance limitations	✓ with distance limitations	✓ with limitations on number of users connected to a base station, volume of spectrum, distance and possible additional backhaul requirements
Satellite	✓	✗ due to latency requirement	✗ due to latency requirement	✗ due to latency and download sync speed requirements

Modelling the technologies

In Sections 3 and 4 we describe in detail the cost modelling methodologies we have used. Due to the broad similarities between some technologies we know that their costs vary in similar ways (e.g. FTTP PTP is typically 10–20% more expensive than FTTP GPON for the same deployment due to the need to install additional fibre cables between the exchange and aggregation node). Therefore, we have simplified the number of technologies explicitly modelled in order to reduce the complexity of the modelling work and allow for more sensitivity testing of key parameters.

Figure 2.29: Technologies modelled explicitly and technologies not modelled explicitly [Source: Analysys Mason, 2016]

Technology	Modelled explictly	Notes
FTTP GPON	✓	FTTP PTP is very similar to FTTP GPON but typically slightly more expensive. A USO provider is likely to deploy GPON as it is cheaper and has little discernible difference in performance compared to the USO specification
FTTP PTP	✗	
FTTC VDSL2	✓	VDSL2 is an existing technology which could viably be deployed more extensively than it is currently
FTTC G.fast	✗	G.fast improves speeds close to existing cabinets but is unable to match the range of VDSL2 at 10Mbit/s or 30Mbit/s. It is therefore unlikely to be deployed preferentially to VDSL2, which is an existing commercialised technology
FTTC LR-VDSL	✓	The LR-VDSL profile may allow the reach of existing cabinets at 10Mbit/s or 30Mbit/s to be extended sufficiently to additional premises. Therefore its costs are of significant interest

FTTdp G.fast	✗	FTTdp is likely to have a similar cost to FTTP due to the requirement to lay new fibre to the distribution point. In reusing the copper final drop and in-home wiring (which FTTP would need to overlay), FTTdp G.fast avoids recreating that part of the network, but on the other hand the requirement to install active equipment at the distribution point (especially if this is not reverse-powered[67]) could negate these cost savings
HFC	✗	Due to the requirement to lay new coaxial cable to each subscriber, HFC's costs are likely to be similar to those of FTTP GPON
FWA – high frequency	✓	There is a significant degree of variability in the performance achievable by FWA depending on the bandwidth used and other factors. Therefore this technology needs to be considered with a number of sensitivity tests to establish its true likely costs
FWA – low frequency	✓	
Satellite	✗	Satellite is not able to meet the measured latency requirements for the USO specifications and is capacity-constrained. Therefore we consider it as an overlay or fall-back technology, but do not explicitly model it as the main choice by a USO provider in any area

67 Reverse-powered G.fast nodes are powered by the copper line from the subscriber, negating the need to feed a direct power connection to the equipment.

3 Geographical approach to modelling

In this section we outline our geographical approach to the modelling process and outline the input data used to define which premises are predicted to be eligible for a USO connection.

3.1 Selecting a modelling unit

Ideally our modelling would be carried out on a premise-by-premise level. This would allow for the highest degree of optimisation. At the time the modelling work was conducted, this information was not available and the approach would have been highly computationally intensive. Furthermore, it is not strictly necessary for the calculation of an initial estimate of the magnitude of the investment that a broadband USO might require. An area-based approach, such as the approach followed in this study, should allow for a reasonable estimation of costs consistent with the requirement in DCMS's letter to Ofcom.

3.1.1 Postcodes as a modelling unit

Ofcom's data on eligible premises is organised by postcode and this is therefore the logical starting point for selecting a modelling unit. For each scenario, Ofcom has provided a list of all the postcodes which contain premises that, as of June 2016, were believed not to be able to receive a fixed broadband service that met the specification for that scenario. Postcodes can be served by more than one network node (cabinet or exchange) and therefore postcodes can appear more than once in the list. Associated statistics are provided for each postcode, such as cabinet/exchange details and number of premises. A detailed summary of the data provided by Ofcom is given in Annex B.

Postcodes are a well-established approach to classifying geographical areas, and are used for post sorting. Full postcodes (e.g. CB3 0AJ) are highly geographically specific. Because population density varies considerably, the size of such full postcodes varies widely, even within a given area (small in village centres, large in sparsely populated farmland). Postcodes with areas ranging from 0.025sqkm to 3sqkm are not uncommon whereas in remote areas like the Cairngorms these postcodes can reach 80sqkm in size, the vast majority of which is likely to be uninhabited. Furthermore, some postcodes are in multiple 'pieces' (i.e. they may not be contiguous[68]).

3.1.2 Selecting a modelling unit

Ofcom's scenario data is organised by postcode. Postcodes do not always provide a neat match for the modelling of the deployment of fixed broadband technology. Deployments in one postcode could provide coverage in adjacent areas, and consequently modelling by postcode would mean that the

68 An example is MK43 0AU.

fixed costs of the technologies might be incorrectly estimated, unless the costs are analysed for groups of neighbouring postcodes that are of roughly the right scale.

An alternative is to use an approach that generates areas of a similar scale. A complicating factor is that the relevant length scale[69] for the analysis varies by technology (e.g. an FWA site could cover up to a cell radius of 10km with sub-1GHz spectrum and peak sync speeds of 10Mbit/s while FTTC VDSL2 could cover up to a radius of around 1.5km, after accounting for the non-direct routeing of cables, at that specification). With this approach, if the selected scale is too small the coverage or capacity offered by each technology is artificially constrained, resulting in an overestimate of the incremental network assets required. Selecting a scale that is too large would potentially also overestimate the required assets since the postcodes containing premises predicted to be USO-eligible can be non-contiguous or dispersed.

A final alternative is to aggregate postcodes by their serving cabinet (or serving exchange in the case of exchange-only lines (EoLs)) and model those areas. This naturally suits the scale of FTTC VDSL2 and FTTC LR-VDSL, which are cabinet-based technologies. This is also likely to be the scale at which the USP(s) would initially consider designing the incremental network required to serve USO-eligible premises. Since we are modelling the *incremental* network required, the natural way to account for the reuse of existing network infrastructure is to model the existing cabinet serving areas.

Our approach is therefore to aggregate postcodes by their serving cabinet (or serving exchange in the case of EoLs) and model those areas directly. In order to test the impact of the approach described above, we have also tested the impact of modelling on the basis of a common grid scale.[70]

3.2 Input data

Ofcom provided Analysys Mason with input datasets for three broadband USO specification scenarios and a Superfast scenario based on the premises coverage data available at the outset of the study. Data was provided separately for the KCOM coverage area around Hull since this was calculated on a different basis to the main UK and Northern Ireland datasets.

This data is described in detail in Annex B. Below we outline some of the key characteristics and assumptions used in generating the data.

The lists of postcodes provided in these datasets are not unique. This is because a single postcode unit may be served by multiple cabinets and/or exchanges. In such cases Ofcom has provided multiple records in its dataset; the records have identical postcodes but different cabinet/exchange data. The records also contain identical premise data, and therefore it has been necessary to adjust for double counting when summing across the dataset.

69 The 'right size'. Strictly speaking, the concern is about the area naturally served by the infrastructure. But 'area scale' is an unfamiliar concept, so we use the phrase 'length scale' here.

70 The methodology for creating these areas is described in more detail in Annex C

It is also important to highlight a number of assumptions which Ofcom has made in generating its data which have implications for the modelling methodology:

- **Premises are modelled to be uniformly distributed across the postcode unit.** Although the postcode-level dataset identifies the number of homes in a postcode predicted to be eligible for a USO connection, it does not identify their specific location.[71] To address this, our grouping and modelling work has been based on the assumption that USO premises are uniformly distributed within their postcode. This is consistent with the assumptions used to generate this data. In reality, most premises are likely to be clustered within their postcode areas and hence our estimation of cost will tend to overestimate the costs of serving those premises.

- **Premises are modelled as served by the nearest exchange/cabinet that serves their postcode.** Ofcom has identified this by calculating the distances from the assumed uniformly distributed premise locations to each of the serving exchanges/cabinets and selecting the cabinets/exchanges to which the distance is shortest. As noted above, this may result in a single postcode unit being served by multiple cabinets/exchanges.[72]

- **In the KCOM coverage area around Hull, it is assumed that all lines are EoLs**, since no cabinet information has been available. We note that this simplification will have a relatively small effect on the overall results since the KCOM coverage area is only a small proportion of the total area and contains only a small proportion of the eligible premises.

3.2.1 Data processing

There were a number of inconsistencies in the underlying postcode datasets used to produce the scenario data which resulted in a number of omissions and potential incompatibilities and it was necessary to correct them before feeding the data into the grouping and modelling processes. These are summarised below and explained in more detail in Annex B, Section B.2.

- **Postcode co-ordinates:** Where postcode co-ordinates were missing we added the missing data based primarily on Ordnance Survey CodePoint data.

- **Postcodes with no area data:** We added missing area information to three postcodes.

- **Records with no cabinet ID but less than 100% EoLs:** There were a number of records in each scenario which suggested that certain areas contained lines served by cabinets but did not provide a cabinet ID. Since the number of premises affected was small, these records were updated to assume that all lines are EoLs.

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71 This data was not available at the time that modelling was carried out.

72 It should be noted that this assumption is not borne out in the entirety of the dataset since there are some postcodes that are recorded as served by cabinets or exchanges which are a long distance away. The assumption does, however, hold true for the most part.

- **Cabinets with no co-ordinates:** Where cabinet co-ordinates were unavailable we assumed that the postcode centroid considered to be served by each cabinet would be representative of its location.
- **Records with no serving exchange information:** We estimated which exchange a postcode was served by based primarily on exchange coverage mapping held by Analysys Mason.
- **Records with no cabinet or exchange distances:** Where distances were unknown we used the Euclidean distance (i.e. calculated using Pythagoras' theorem) between the centroids to estimate the remaining missing distances, with a cap of 10km.
- **Geotypes:** The scenario data used a different geotyping classification system for postcodes according to their home nation: England and Wales, Scotland or Northern Ireland. In order to have a consistent approach across all four nations for modelling purposes, we have mapped all postcodes to one of two geotypes: urban and rural. The distinction is used in the model to set certain parameters (e.g. proportion of aerial route).

4 Cost modelling methodology

We have built a stylised cost model that calculates the approximate cost of deploying and operating the additional network required to serve the predicted eligible premises defined in the three USO scenarios provided by Ofcom as well as a Superfast scenario. The model uses one of four technologies (FTTP GPON, FTTC VDSL2, FTTC LR-VDSL, FWA). A further three technologies are considered qualitatively (FTTdp G.fast, HFC, satellite). We also estimate possible core network costs (i.e. core-side of the exchange).

The stylised cost model captures the cost of the incremental network required for the hypothetical USP(s) to serve USO-eligible premises, assuming that the USP(s) can make use of Openreach's existing access network infrastructure.[73] The model assumes that the incremental network is to be deployed in 2018.

Modelling assumptions are intended to be relatively conservative such that the stylised cost model represents a central reference case for costs. In the assumptions below we have sought to strike a conservative balance between the highest- and lowest-cost deployment styles and network dimensioning rules. We recognise that a real deployment in response to the USO may make different choices with respect to network architecture, deployment speed and style to that represented in this stylised cost model. These choices could vary with geography, market conditions and with the detailed conditions of the USO obligation. Figure 4.1 outlines the overall model approach.

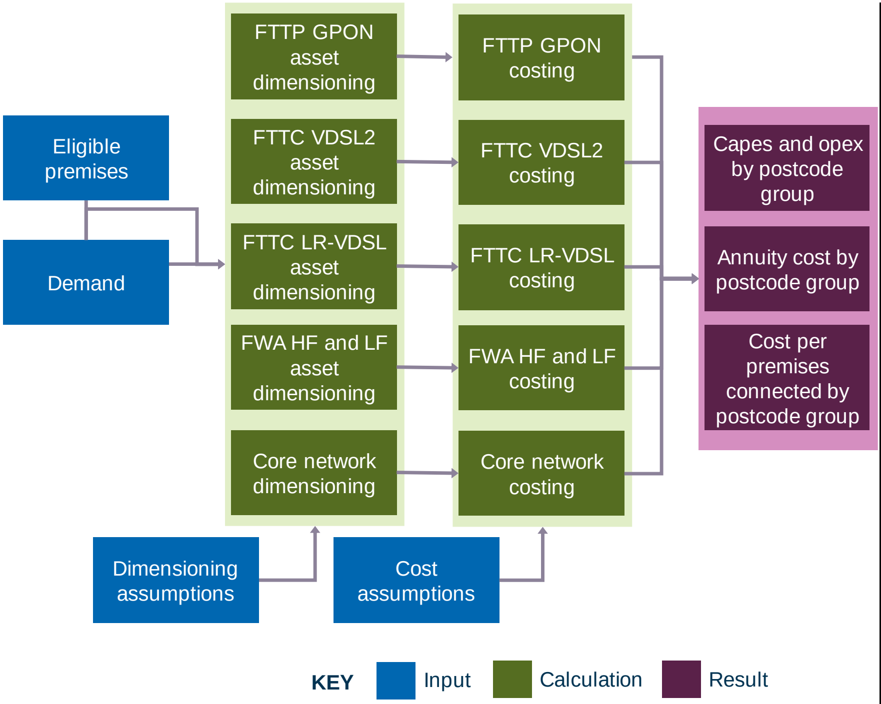

Figure 4.1: Overview of model approach [Source: Analysys Mason, 2016]

[73] This is a modelling simplification and does not imply that the hypothetical USP (or USPs) is intended to be BT Openreach.

Before outlining the network dimensioning calculations for each technology in Sections 4.2.1 to 4.2.5, we first set out some broader modelling topics below.

4.1.1 Model scale

Costs are calculated on a cabinet serving-area basis (with areas served by EoLs grouped together according to their parent exchange and treated as their own cabinet serving area). This is the ‘natural’ building block of the network and allows for a mixture of technologies in each exchange area to be captured.

Since cabinet serving areas can vary significantly in size we have also modelled geographical entities (‘groups’) of a similar length scale as a sensitivity test. This is described in Section 3 and Annex C.

Modelling on this basis allows the lowest-cost technology for each ‘group’ to be identified but it does mean that economies of scale that may be available when larger areas are modelled (e.g. sharing backhaul assets) are not captured (i.e. by constraining the length scale of a group, additional assets are ‘forced’ to be deployed in the network dimensioning algorithm as their coverage area is constrained by the length scale).

4.1.2 Model boundaries

We model the network required to serve all eligible subscribers by deploying additional network from the existing network of the hypothetical USP(s) to the subscriber’s premises, including all necessary equipment up to and excluding the subscriber’s router. This allows a like-for-like comparison between technologies since excluding all CPE (e.g. satellite dishes or external FWA antennae) would ignore costs that would otherwise be additional for some subscribers. This is explained where relevant below.

We assume that the USP(s) would have an available point of interconnection within a 50km radius of each exchange that contains USO-eligible premises and that the core-network-facing demarcation point of the modelled network is before the handover point at this interconnection location. We have not modelled core network assets since we believe that once traffic is aggregated at the core network level the additional traffic generated by USO subscribers would be relatively insignificant in comparison to the existing core network traffic of the designated USP(s) and other sources of growth in core network traffic.

4.1.3 Take-up

The approach to modelling considers either the number of premises passed or the number of premises likely to be connected as a key parameter in dimensioning the network. Some assets are likely only to be deployed when a subscriber takes up the service. Other assets, however, must be dimensioned in order to serve all possible eligible subscriber premises, since the geographical dispersion of take-up is unknown and assets cannot be deployed only to serve specific known subscriber premises.

The base case assumes a long-run take-up of 80% of eligible subscribers in line with the approximate current level of take-up of broadband services in the UK.[74] However, we also test as a sensitivity the impact of long-run take-up only reaching 55% for Scenarios 1, 2 and 3 and 30% for the Superfast scenario.[75]

For modelling purposes, we assume that the take-up rate is even across the country.

4.1.4 Committed information rates

In Section 1.4 we set out the CIRs required in order to meet the service specifications defined by Ofcom for each scenario. In Figure 4.2 below we recap the required CIR for each scenario as well as the values that are to be tested as sensitivities to the base case.

Figure 4.2: CIR scenarios considered [Source: Analysys Mason, 2016]

Scenario	Base/sensitivity	Download sync (Mbit/s)	Access CIR (Mbit/s)	Core CIR (Mbit/s)
Scenario 1	**Base**	**10**	**0.50**	**0.50**
Scenario 2	**Base**	**10**	**1.50**	**1.50**
Scenario 2 – Sensitivity 1	Sensitivity	10	1.50	0.50
Scenario 2 – Sensitivity 2	Sensitivity	10	1.50	1.00
Scenario 3	**Base**	**10**	**1.50**	**1.50**
Scenario 3 – Sensitivity 1	Sensitivity	10	1.50	0.50
Scenario 3 – Sensitivity 2	Sensitivity	10	1.50	1.00
Superfast scenario	**Base**	**30**	**10.00**	**10.00**
Superfast – Sensitivity 1	Sensitivity	30	10.00	5.00
Superfast – Sensitivity 2	Sensitivity	30	10.00	7.50

74 Rounded from 78% in Ofcom's Connected Nations 2015 report (paragraph 4.26). http://stakeholders.ofcom.org.uk/binaries/research/infrastructure/2015/downloads/connected_nations2015.pdf

75 Take-up of SFBB rounded from 27% take-up of broadband with a download sync speed of over 30Mbit/s. The 55% for sensitivity testing is a mid-point between 80% and 30%.

4.1.5 Unit costs

Although many local deployments are on a small scale and may struggle to buy equipment or services at the prices available to a major network builder, it is also true that the goodwill, local relationships and strong local enthusiasm for broadband that has enabled the Market Test Pilots (MTPs) and other local network builders may have resulted in advantageous low unit costs in some circumstances (e.g. land owners agreeing to receive compensation in kind, easements from charities).[76] If a large corporate were involved, with explicit funding from the rest of the industry to reach a mandated service level, it is possibly more likely that the market rate would have to be paid.

In the cost assumptions below we have sought to strike a conservative balance between these ranges by selecting unit costs based on international benchmarks as well as data from the BDUK MTP operators and Openreach. This represents a central reference case for costs and we recognise that a real deployment in response to the USO may make different choices with respect to network architecture, deployment speed and style to that represented in this stylised cost model. These choices could vary with geography, market conditions and with the detailed conditions of the USO obligation.

The unit costs presented in Section 4.2 below are in 2016 terms. The model uses these values adjusted to 2018 nominal terms using the nominal cost trend indicated alongside the costs below. The model results are, however, reported in 2016 real terms based on the inflation forecast produced by the Office for Budget Responsibility (OBR).[77]

The capex amount quoted below represents the cost to supply and install each asset. The opex value represents the typical operational costs for these assets including an allowance for wider operations and maintenance overheads. We recognise that these costs may vary according to the type and scale of organisation that is assigned the USO obligation.

4.1.6 Reuse of assets

Our modelling assumes that the USP(s) would choose to make use of existing infrastructure where possible, in order to minimise costs. Since Openreach owns the most extensive passive telecoms infrastructure network in the UK, we have used the availability of Openreach's infrastructure as a guide to the likely level of reuse that the USP(s) could expect. Openreach is also obliged to provide access through its Passive Infrastructure Access (PIA) product that has already been taken up by some CPs although only in selected regions.[78]

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76 See https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/497369/BDUK_Market_Test_Pilots_-_Emerging_Findings_Feb_2016.pdf page 23

77 +2.4% from 2016 to 2017 and +3.2% from 2017 to 2018. See http://budgetresponsibility.org.uk/download/economic-and-fiscal-outlook-charts-and-tables-march-2016/

78 For example Call Flow; see https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/497369/BDUK_Market_Test_Pilots_-_Emerging_Findings_Feb_2016.pdf page 38

We carried out a study, described in Annex D, to determine the likely level of reuse of ducts and poles. This annex described the level of reuse that we believe the USP(s) might plausibly expect. However, this is based on a relatively small sample of exchanges.

We have assumed that the USP(s) would be liable to pay the PIA product reference prices in order to make use of reusable infrastructure. We have also accounted for additional costs that the USP(s) would need to incur to make use of it (e.g. aerial fixing hardware, hauling cable into ducts). We have not accounted for the costs of remediation where ducts or poles require repairs.

4.2 Network dimensioning

4.2.1 FTTP GPON

To estimate the assets required to serve a postcode group with FTTP GPON we take the following approach:

- Distribution fibre[79] needs to be laid down most public roads within the postcode group. We therefore dimension the length of the distribution fibre network required by calculating the road network length within the postcode group. Figure 4.3 below describes which road classes are included in or excluded from the dimensioning of the required distribution fibre. Road classes are fairly broadly defined so we have sought to include or exclude road classes on the expected propensity of the majority of roads in each class to pass premises likely to be included in the USO.[80]

- The postcode area may not be adjacent to the exchange or an existing fibre route and therefore additional fibre feeder[81] is required to connect the distribution fibre within the postcode group to the exchange. We estimate this based on the shortest road route distance from the postcode group centroid in the group that is closest to the parent exchange back to the parent exchange. In reality it may be possible to connect to a fibre feeder (or 'spine' in Openreach's terminology) that is closer to the postcode area than its parent exchange. Approximately 96% of premises are

79 Fibre between the GPON splitter and the subscriber premises.

80 For 1531 postcodes we did not identify any road because no postcode polygon existed in the postcode polygon dataset. Inspection of a sample of postcodes with a large number of eligible premises (e.g. E14 0BN, M1 1BZ, E1 1AE) as well as some with fewer premises (e.g. OX1 4NG, RH12 1EW) appeared to show that these postcodes correspond to premises within private business parks, large MDUs or, in the minority of cases, recently completed housing estates (e.g. HP18 0BN).

In these types of areas we would expect that no civil works would be required and no fibre would need to be deployed since the postcode represents a single building (or private estate) or area within a building. We therefore assume that these premises can be served with only a requirement to install a final drop. Internal risers are likely to be in place in commercial premises and MDUs while new housing developments are likely to be pre-ducted, therefore final drop costs are unlikely to exceed the value assumed for other standard installations.

81 Fibre between the GPON splitter and the parent exchange. The distinction between distribution and feeder is loosely defined in this modelling approach since the GPON splitter locations are not explicitly defined.

believed to be within 2km of a next-generation access (NGA) aggregation node and therefore we apply a 2km cap to the fibre feeder distance.[82]

Figure 4.3: Road classes included in FTTP GPON dimensioning [Source: Analysys Mason, 2016]

Class	Description	Notes
Motorway	Mainland GB motorway	Exclude – not usually faced with premises
A road	Mainland A road	Exclude – not usually faced with premises
B road	Mainland B road	Include
Unclassified	Mainland road mapped by local authorities but not classified	Include – this would include many minor roads in both rural and urban areas
Not classified	Minor private roads and driveways	Exclude – likely only to be relevant to final drops
NI – Motorway	Northern Ireland motorway	Exclude – not usually faced with premises
NI – A class	Northern Ireland equivalent to A road	Include
NI – B class	Northern Ireland equivalent to B road	Include
NI – Dual carriageway	Northern Ireland dual carriageway	Include (for consistency with mainland A roads which would include most dual carriageways)
NI – <4m tarred	Appears to contain very rural NI roads	Exclude – seems unlikely to pass many premises
NI – <4m t over	Only six very short road sections	Exclude – unclear what these represent and minor in extent
NI – CL minor	Appears to be equivalent to mainland unclassified roads	Include
NI – CL m over	Appears to represent overbridges	Exclude – only a very small number
NI – CL_rail	Appears to represent railway line	Exclude

- The fibre route is further subdivided into the deployment types described in Figure 4.4, based on the central case for deployment type described in Annex D on the basis of the duct and pole feasibility survey.

82 See https://www.openreach.co.uk/orpg/home/products/pricing/loadProductPriceDetails.do?data=0WyIM7tTGGgucFf0dXUIWK4XSAplAmgrRZNg5Pk%2B5%2F%2BkRgB7BL4KNYn%2FlKx2YB4Qe6YShZ82RgLO%0AGLsH2e9%2Bmw%3D%3D

Figure 4.4: FTTP route deployment type [Source: Analysys Mason, 2016]

Technology	Geotype	Directly buried	Ducted	PIA ducted	Aerial	PIA aerial
FTTP – distribution	Urban	–	15%	80%	–	5%
	Rural	–	45%	30%	–	25%
FTTP – feeder	Urban	–	20%	80%	–	–
	Rural	–	20%	80%	–	–

- The fibre sheath (distribution and feeder) required is dimensioned based on the route required with a 3% uplift for cable slack and jointing requirements. We assume that fibre sheath costs can be represented by a single 72F cable, rather than explicitly modelling a variety of cable sizes.[83] Our internal benchmarks found that fibre cable material and installation costs do not vary significantly with the number of fibres they contain. Furthermore, we expect that a prudent deployment would provision a larger cable than is required in order to provide spares for future faults or network expansion. This would even be the case where fibre is ducted since the cable diameter varies little with the number of fibres.
- A standard splitter ratio of 1:32[84] and utilisation rate of 85% is assumed, therefore one splitter is deployed for every 27 premises passed. We assume that one ODF port and one OLT port is dimensioned for every splitter deployed.
- Final drops are only deployed where a premises is connected to the network (i.e. eligible premises multiplied by take-up rate), therefore the costs of final drops are calculated only for the portion of premises that are assumed to take up the service.

83 The exact cable size is not a significant driver of the overall costs of deployment.

84 For example, a 1:32 splitter ratio is used by Openreach (https://www.openreach.co.uk/orpg/home/products/super-fastfibreaccess/fibretothepremises/fttp/downloads/GEA_FTTP_2%2063551%2020111108.pdf).

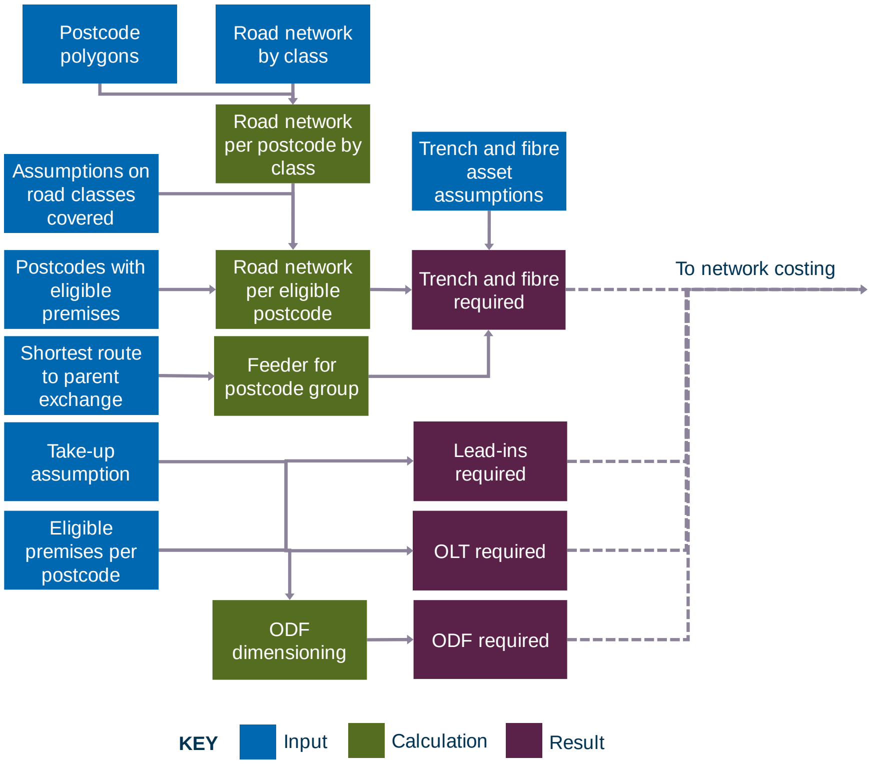


Figure 4.5: Overview of FTTP GPON asset dimensioning [Source: Analysys Mason, 2016]

Figure 4.6 below summarises the unit cost, price trend and lifetime assumptions that are used in the FTTP asset costing calculation. These costs, lifetimes and price trends were developed based on publicly available benchmark models, data provided by BDUK test pilot operators and Openreach in response to our data request and Analysys Mason's experience. This represents a central reference case for costs and we recognise that a real deployment in response to the USO may make different choices with respect to network architecture, deployment speed and style to that represented in this stylised cost model. This is a reasonable approach given that the aim of the stylised cost model is not to capture actual deployment costs.

Figure 4.6: FTTP GPON assets [Source: Analysys Mason, 2016]

Asset description	Unit capex (2016 GBP)	Annual opex (2016 GBP)	Lifetime (years)	Nominal price trend
Trench – feeder, built, ducted (m)	57	2	50	3%
Trench – feeder, built, direct buried (m)	52	2	20	-2%
Trench – feeder, rented, ducted (m)	3	0.5	20	-2%
Trench – distribution, built, ducted (m)	57	2	50	3%
Trench – distribution, built, direct buried (m)	52	2	20	-2%
Trench – distribution, rented, ducted (m)	3	0.6	20	-2%
Aerial route (m)	10	0.2	15	2%
Aerial route – rented (m)	9	0.2	15	2%

Asset description	Unit capex (2016 GBP)	Annual opex (2016 GBP)	Lifetime (years)	Nominal price trend
Fibre cable sheath for ducting – 72F (m)	3	0.1	20	-2%
Fibre cable sheath for direct bury – 72F (m)	3	0.1	20	-2%
Fibre cable sheath for aerial – 72F (m)	2	0.1	20	-2%
ODF port	16	3	20	-4%
OLT port	35	9	5	–
PON splitter, including housing	2600	130	20	–
FTTP final drop (including CSP, ETP and DP)	230	7	20	3%

The trench, duct and aerial route costs quoted above include an allowance for a medium-sized manhole (large enough for two ducts and to house joints for the cables dimensioned in the model) every 500m. [✂✂]

The fibre sheath costs include a splice every 1000m (in addition to those at nodes). [✂✂]

The GPON splitter cost includes the cost to supply and install a GPON splitter in a manhole together with the costs of splicing the assumed 72F cable size fibres.

4.2.2 FTTC VDSL2

The FTTC VDSL2 dimensioning calculation takes into account the existence of potentially reusable infrastructure, and the calculation comprises the following two steps. First, existing cabinet locations (i.e. FTTC deployed at existing passive cabinets or close to existing active cabinets or their feeder) are upgraded. Next, any remaining premises not served by the first step are served by dimensioning new cabinets.

Upgrading existing cabinet locations

We estimate the number of (non-EoL) premises that can be covered by upgrading existing cabinets, either by providing additional capacity where FTTC is already installed or adding FTTC where it is not.

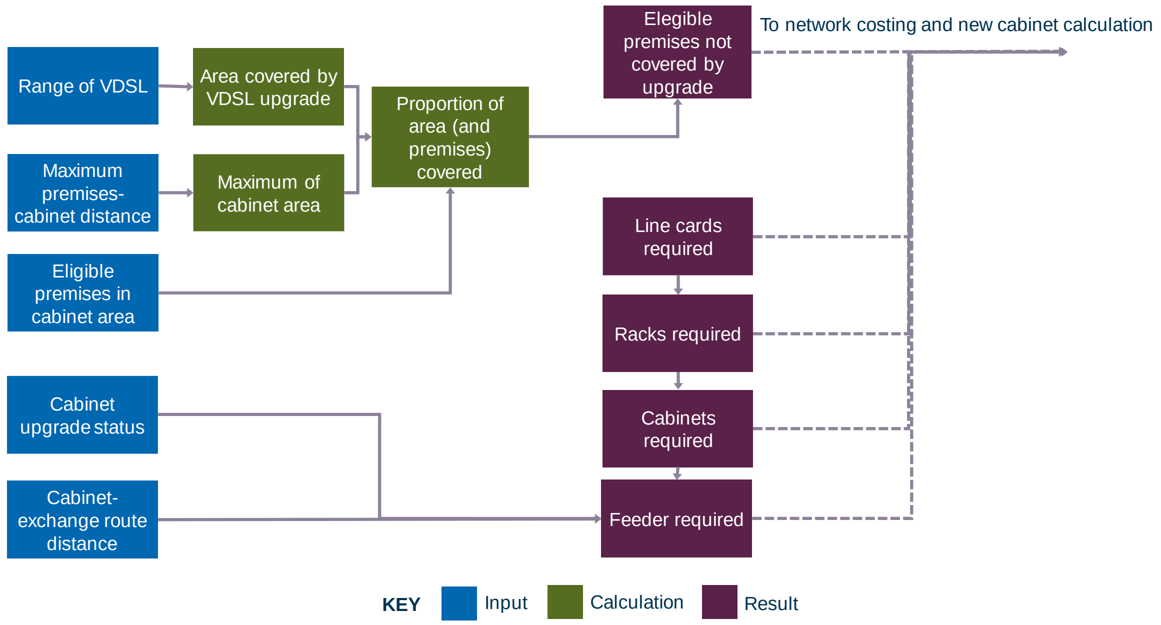
The area served by an existing cabinet is estimated based on the maximum premises–cabinet distance of the USO-eligible postcodes. The proportion of this area that can be served is calculated based on the 'crow fly' range[85] of FTTC VDSL2 at the selected peak sync speed (i.e. maximum

85 This is the technology range in terms of loop length divided by the 'crow fly' ratio of 1.3. This relates the loop distance to a straight-line geographic distance.

premises–cabinet distance divided by technology range).[86] This is the proportion of each postcode served by that cabinet that is assumed to be served in terms of area and in terms of non-EoL premises.

The number of premises served is used to calculate the required line cards, racks and new cabinets. A smaller cabinet is deployed unless sufficient line cards are required to merit the larger cabinet size. Since information on existing cabinet spare capacity is unavailable, we assume that a new cabinet would be co-located rather than an existing one being upgraded.

Figure 4.7: Overview of FTTC cabinet upgrade asset dimensioning [Source: Analysys Mason, 2016]



Where a cabinet is already upgraded to FTTC we assume that the existing fibre feeder can be reused and therefore fibre feeder (based on the road route to the parent exchange) is only dimensioned if the existing cabinet is not already upgraded. The feeder route is assumed to be deployed using the deployment types shown in Figure 4.8, as also discussed in Annex D. Approximately 96% of premises are believed to be within 2km of an NGA aggregation node and therefore we apply a 2km cap to the fibre feeder distance.[87]

Figure 4.8: FTTC feeder route deployment type [Source: Analysys Mason, 2016]

Network layer	Geotype	Directly buried	Ducted	PIA duct	Aerial	PIA aerial
Feeder	Urban	–	20%	80%	–	–
Feeder	Rural	–	20%	80%	–	–

86 The proportion of the cabinet area that is considered to be *covered* is the ratio of the 'crow fly' range of the technology to the maximum premises–cabinet distance of the USO-eligible postcodes served by that cabinet.

87 See https://www.openreach.co.uk/orpg/home/products/pricing/loadProductPriceDetails.do?data=0WyIM7tTGGgucFf0dXUIWK4XSAplAmgrRZNg5Pk%2B5%2F%2BkRgB7BL4KNYn%2FlKx2YB4Qe6YShZ82RgLO%0AGLsH2e9%2Bmw%3D%3D

Where a cabinet is already upgraded to FTTC we also assume that one OLT port and one ODF port is required at the parent exchange.

The costs relating to the assets deployed in each cabinet area are then allocated among all of the postcode groups that are served by the cabinet upgrade.

Deployment of new cabinets

The number of premises requiring coverage and the area requiring coverage are calculated based on the number of lines (and total area) of the postcode less the number of EoLs (and area) that are served due to the cabinet upgrade step described above.

The number of cabinets required is calculated based on the area of the postcode group requiring coverage and the 'coverage area' of a cabinet at the selected download sync speed limit.[88] The average specification of a cabinet (number of line cards, racks and cabinet size) is calculated based on the number of cabinets required, the total remaining premises requiring coverage and a utilisation factor of 85% for the line cards. These averages are multiplied by the number of cabinets required to calculate the total number of each asset required for the postcode group.

We assume that one OLT port and one ODF port is required at the parent exchange for each cabinet deployed.

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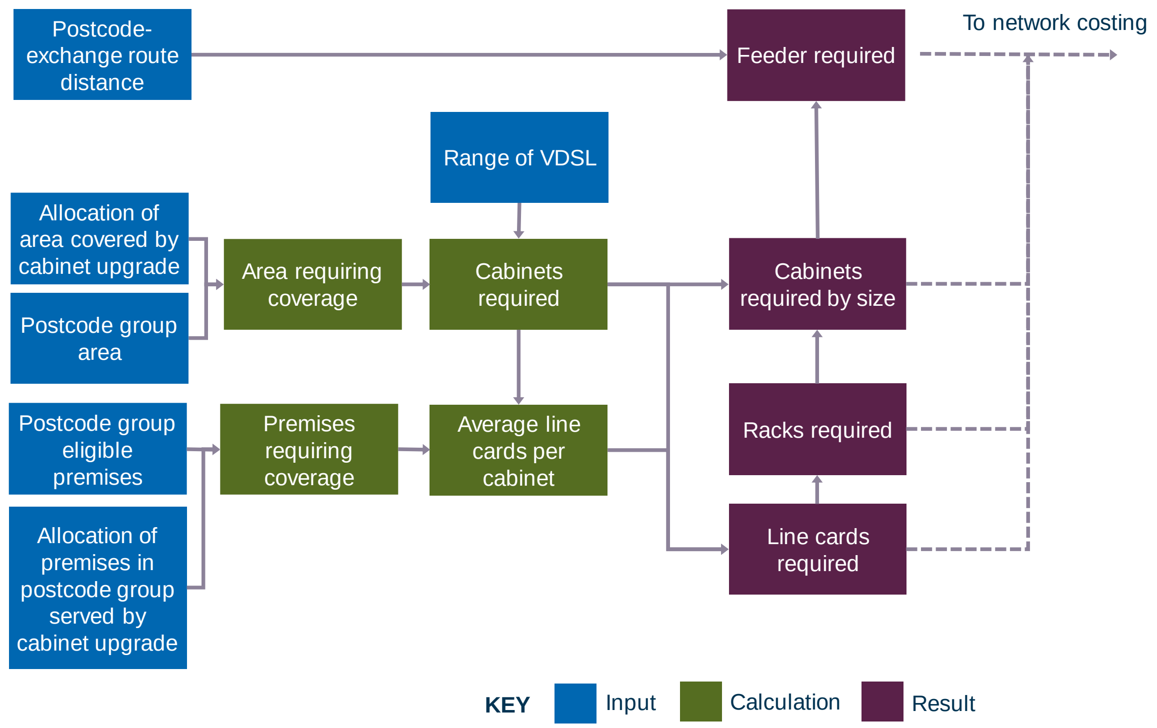
88 The area that a cabinet can serve is calculated as 2.6 × (technology range/'crow fly' ratio)^2 The value of 2.6 is used instead of pi to approximate the cell area as a hexagonal shape which can tessellate. This is a similar approach to that used in our FWA coverage calculation.

Figure 4.9: New cabinet dimensioning calculation [Source: Analysys Mason, 2016]



Estimation of feeder length

Where cabinets are upgraded to FTTC an estimate of the distance of fibre feeder required between the cabinet and its parent exchange is needed.

For all cabinets in the scenario dataset (and all EoL postcodes which may host an FTTC cabinet where one is deployed) we have estimated the road distance to the parent exchange. This was calculated using the Routefinder add-in for MapInfo. Where Routefinder was unable to calculate a suitable link we estimated the road distance with the 'crow fly' distance multiplied by an uplift of 1.4. [✂✂]

Approximately 96% of premises are believed to be within 2km of an NGA aggregation node and therefore we apply a 2km cap to the fibre feeder distance.[89]

We apply a 3% uplift on the fibre cable assets to account for cable slack and jointing requirements.

Figure 4.10 below summarises the unit cost, price trend and lifetime assumptions that are used in the FTTC asset costing calculation. These costs, lifetimes and price trends were developed based on publicly available benchmark models, data provided by BDUK test pilot operators and Openreach in response to our data request, and Analysys Mason's prior experience. This represents a central reference case for

89 See https://www.openreach.co.uk/orpg/home/products/pricing/loadProductPriceDetails.do?data=0WyIM7tTGGgucFf0dXUIWK4XSAplAmgrRZNg5Pk%2B5%2F%2BkRgB7BL4KNYn%2FlKx2YB4Qe6YShZ82RgLO%0AGLsH2e9%2Bmw%3D%3D

costs and we recognise that a real deployment in response to the USO may make different choices with respect to network architecture, deployment speed and style to that represented in this stylised cost model.

Figure 4.10: FTTC assets [Source: Analysys Mason, 2016]

Asset description	Unit capex (2016 GBP)	Annual opex (2016 GBP)	Lifetime (years)	Nominal price trend
Trench – feeder, built, ducted (m)	57	2	50	3%
Trench – feeder, built, direct buried (m)	52	2	20	-2%
Trench – feeder, rented, ducted (m)	3	0.5	20	-2%
Fibre cable sheath for ducting – 72F (m)	3	0.1	20	-2%
Fibre cable sheath for direct bury – 72F (m)	3	0.1	20	-2%
FTTC cabinet (2 rack capacity)	7900	200	15	4%
FTTC cabinet (up to 4 rack capacity)	8500	280	15	4%
VDSL2 DSLAM line card (32 port)	550	60	6	-5%
VDSL2 DSLAM rack (2 line card capacity)	7200	560	6	-5%
LR-VDSL DSLAM line card (32 port)	550	60	6	-5%
LR-VDSL DSLAM rack (2 line card capacity)	7200	560	6	-5%
ODF port	16	3	20	-4%
OLT port	35	9	5	–

The FTTC cabinet cost represented above accounts for the 'passive' components of the cabinet (e.g. housing, foundations, power supply, tie cables to passive cross-connect cabinets), whereas the active electronics is modelled as a set of separate assets (line cards and racks). We note that cabinet costs are subject to significant variation in reality due to factors such as the proximity and capacity of the electricity distribution network.

The trench and duct route costs quoted above include an allowance for a medium-sized manhole (large enough for two ducts and to house joints for the cables dimensioned in the model) every 500m. [✂✂]

4.2.3 FTTC LR-VDSL

FTTC LR-VDSL is modelled in the same way as FTTC VDSL2 but with different range assumptions (as set out in Figure 2.5). The model uses the same unit costs for VDSL2 and LR-VDSL though we note it is possible that, as an emerging technology, the active electronics required for LR-VDSL may be slightly more expensive than for existing VDSL2. We do not expect this to be significantly more expensive.[90]

4.2.4 FWA

Given that the source scenario data assumes that premises are evenly spread through their postcode areas the FWA network dimensioned by the model needs to provide 100% notional area coverage and sufficient capacity to meet the CIR at the assumed level of take-up.

Figure 4.11 summarises the area coverage and site capacity assumptions developed in Section 2.1.6.

Figure 4.11: Summary of coverage and capacity assumptions [Source: Analysys Mason, 2016]

Band	Subscriber throughput	Spectrum	Cell throughput	Max cell radius	Assumed cell area[91]
Low frequency – sub-1GHz	10Mbit/s	2×10MHz FDD	69Mbit/s	10km	260sqkm
Low frequency – sub-1GHz	30Mbit/s	2×10MHz FDD	69Mbit/s	10km	260sqkm
High frequency – 5.8GHz	10Mbit/s	20MHz TDD	103Mbit/s	1km	2.6sqkm
High frequency – 5.8GHz	30Mbit/s	20MHz TDD	103Mbit/s	0.5km	0.65sqkm

Since the radio access network is a shared resource in an FWA network, the cell throughput is shared among the premises covered by a single cell. With a CIR requirement in the access layer of 1.5Mbit/s for Scenarios 2 and 3 (as explained in Section 1.4) and 10Mbit/s for the Superfast scenario, 46 eligible premises can be served by a low-frequency cell in Scenarios 2 and 3, and 68 by a high-frequency cell; while 6 and 10 premises can be served in the Superfast scenario. Scenario 1 does not define a CIR but for modelling purposes we have assumed a CIR of 0.5Mbit/s. This implies that 138 eligible premises can be served by a low-frequency FWA cell and 206 by a high-frequency FWA cell.

90 The difference between VDSL2 and LR-VDSL is in the profile used. We are not aware of any significant differences in the cost of LR-VDSL line cards compared to the cost of VDSL line cards or to a difference in their cost of installation. The fundamental technology underpinning both options is effectively the same.

91 This assumes a 'cell pi' value of 2.6. This reflects that circular cell areas would overlap significantly in order to provide 100% area coverage and therefore cell areas (when calculating coverage site requirements) need to be scaled down accordingly.

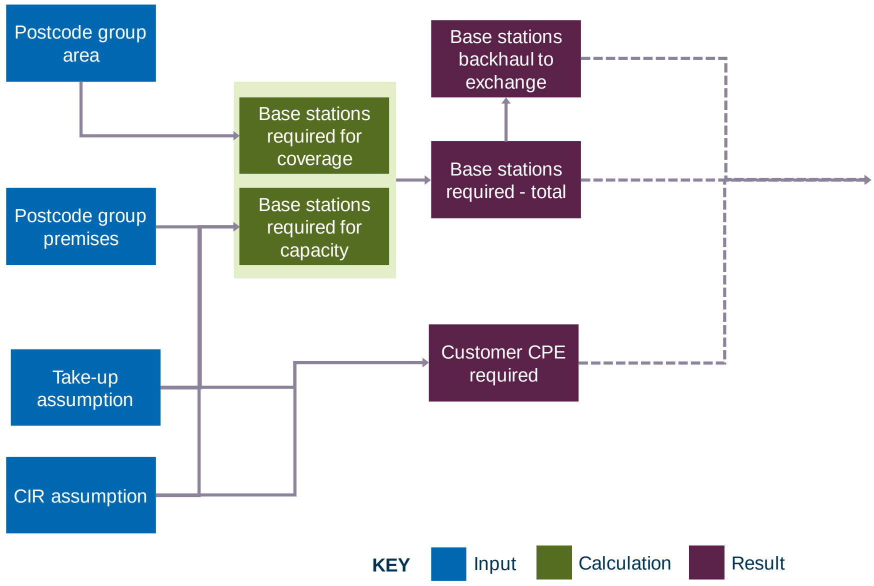


Figure 4.12: Overview of FWA asset dimensioning [Source: Analysys Mason, 2016]

To estimate the assets required to serve a postcode group with FWA we take the following approach:

- We calculate the number of sites required to provide 100% notional area coverage by dividing the postcode group area by the cell area. This value is capped at the number of eligible premises. We also calculate the number of sites needed to support the required throughput for the number of eligible premises by dividing the total throughput required for each postcode group (at the assumed CIR) by the capacity of a cell. The maximum number of sites required for coverage or the number of sites required for capacity is the number of sites deployed.

- We estimate the mix of deployment styles based on information received from **[✂✂]** and summarised in Figure 4.13 below. However, we note that in reality this distribution is likely to vary depending on the availability of sites and the build-vs-buy choices made by the USP(s).

	Proportion
Tower – owned	10%
Tower – rented	20%
Rooftop – rented	70%

Figure 4.13: Proportion of site types in FWA deployment [Source: Analysys Mason, 2016]

- We assume that one microwave hop with throughput of at least 103Mbit/s is required to link back to an exchange or other suitable fibre flexibility point from which point a fibre backhaul service can be used whose cost is estimated as part of the core network (discussed in Section 4.2.5). **[✂✂]**[92]

92 A more refined estimate would require a full radio planning exercise.

- In addition to the above assets we also dimension an external antenna installation (including wiring) such that the FWA service we are dimensioning is equivalent to the wireline technologies modelled in its termination point.

Figure 4.14 below summarises the unit cost, price trend and lifetime assumptions that are used in the FWA asset costing calculation. These costs, lifetime and price trends were developed based on publicly available benchmark models, data provided by BDUK test pilot operators in response to our data request, and on Analysys Mason's prior experience. This represents a central reference case for costs and we recognise that a real deployment in response to the USO may make different choices with respect to network architecture, deployment speed and style to that represented in this stylised cost model.

Figure 4.14: FWA assets [Source: Analysys Mason, 2016]

Asset description	Unit capex (2016 GBP)	Annual opex (2016 GBP)	Lifetime (years)	Nominal price trend
FWA site with mast (including antennae and shelter)	197 000	19 700	14	1%
FWA site – rented	12 000	12 000	14	1%
Rooftop FWA site – rented	12 000	12 000	14	1%
Active equipment at FWA base station	18 000	1800	7	-5%
Microwave backhaul link	18 000	1800	14	-5%
Customer's external FWA antenna	200	6	14	–

Where an FWA site is owned, we assume that savings can be made by reusing the existing USP infrastructure. We assume that 70% of FWA sites that are owned contain infrastructure that can be reused (e.g. land, power supply, shelter, tower) and that this would result in a discount of 80% on the full cost of an FWA site, since a significant proportion of site costs relate to civil works and passive infrastructure.

4.2.5 Core network

There is a requirement for the USP(s) to backhaul the infrastructure dimensioned above to its own core equipment. We have assumed that the price of an EAD (Ethernet Access Direct) link sufficient to serve the capacity required would serve as an upper bound to the cost on the core network even if this service was delivered using another product or combination of products. This service is widely available (i.e. from each of BT's exchanges) and the USP(s) would be likely to self-provide this service only if able to do so more cost-effectively. Some BDUK providers have also indicated that they already use EAD services. Figure 4.15 summarises the cost to set up and lease EAD links of the relevant capacities.

Service	Connection fee (2016 GBP)	Annual rental (2016 GBP)
EAD10 (10Mbit/s)	1950	1800
EAD100 (100Mbit/s)	1950	1800
EAD1000 (1000Mbit/s)	2100	3200

Figure 4.15: EAD pricing [Source: Openreach[93], 2016]

We calculated the capacity required at each exchange based on the core CIR requirement (as described in Section 1.4), eligible premises in that exchange and take-up rate. From this aggregate throughput requirement we calculated the required volume of EAD services.

We have assumed that a single EAD 'hop' would be sufficient for the USP(s) to reach their own core network] since the service allows a maximum route distance of 86km.[94]

The USP(s) might be liable for excess construction charges (ECCs) if Openreach required these charges in order to establish an EAD service. Ofcom has, however, set a GBP2800 exemption limit under which no ECC is payable for the charge control period starting in 2016/17. Openreach stated that 89% of circuits in 2015/16 were within this exemption limit;[95] we therefore assume that no ECC charges are levied.

We also assume that the USP(s) would incur no additional costs for equipment co-location of IP transit costs since the additional throughput per exchange is low (136Mbit/s on average in the base case, with 80% take-up and a 0.5Mbit/s CIR in the core network). We also assume that no additional interconnection costs are required as we assume that the USP(s) would already interconnect at a suitable location.

4.3 Calculating costs

In order to place all of the compared technologies on an even footing, it is necessary to annualise the respective technology costs. Some of the technologies require large capital investments (on long-lived assets) and have relatively low operating costs, while others (notably satellite, assuming that the satellite capacity is rented from a commercial provider) have much higher operating costs. Our modelling therefore outputs both the total deployment cost and an annualised cost.

Once asset counts have been calculated for each postcode group, the model calculates the required capex and opex investment needed to build and operate the incremental network in each postcode group.

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93 See https://www.openreach.co.uk/orpg/home/products/pricing/loadProductPriceDetails.do?data=5uW5cDedIGJkun%2FLo2I67PEgpNm%2BtShF6YESRcCqrDFZ6rNZujnCs99NbIKJZPD9hXYmiijxH6wrCQm97GZMyQ%3D%3D

94 The extended reach version of EAD (priced at the same rate as the standard EAD) allows a maximum radial distance of 45km or route distance of 86km.

95 See https://www.ciz-openreach.co.uk/Business/content/394/Ethernet-price-reductions-2016-17?utm_source=eadlanding&utm_medium=CampaignBanner&utm_campaign=ead+landing+page+gigantic+reductions

In order to arrive at an annualised cost for each technology, the capex costs need to be annualised using a depreciation calculation. A flat annuity would be the simplest approach. This method calculates a constant annualised cost per year that, after discounting, fully recovers the investment and return on capital employed. This implicitly assumes that the replacement cost is not changing over time.

A tilted annuity approach is slightly more sophisticated and accounts for the change in price of the network assets over time. The annualised cost of recovering the investment and the return on capital is tilted with the forecast price of the asset. As such, tilted annuities can be used as a proxy for economic depreciation, particularly where the output of the asset does not change significantly over the period – as in a broadband access network.

Tilted annuity is a standard approach in bottom-up cost modelling of fixed telecoms networks.[96]

We calculate the tilted annuity charge using the following formula:

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

Where GRC is the gross replacement cost, WACC is the weighted average cost of capital (set at 10% in pre-tax nominal terms) and the modern equivalent asset (MEA) price change reflects the long-run price trend for each asset.

The model outputs are reported below in Section 5 in terms of national deployment cost but also in terms of the average cost per premises connected (CPPC), which can be used to compare the relative cost of covering different modelled areas. The model is also able to report costs in terms of the average cost per premises passed (CPPP).

The model operates in 2018 nominal terms. The unit costs are inflated by their nominal cost trends from those values quoted above. The results in Section 5 below are reported in 2016 real terms based on the inflation forecast produced by the OBR.[97]

96 See for example Figure 70 : in the Analysys Mason report for Ofcom entitled ‘Study of approaches to fixed call origination and termination charge controls’, available at https://www.ofcom.org.uk/__data/assets/pdf_file/0036/73989/analysys_mason.pdf

97 +2.4% from 2016 to 2017 and +3.2% from 2017 to 2018. See http://budgetresponsibility.org.uk/download/economic-and-fiscal-outlook-charts-and-tables-march-2016/

5 Cost modelling results

This section summarises the key outputs generated by the stylised cost model for FTTP GPON, FTTC VDSL2, FTTC LR-VDSL and FWA deployments at a national level. This section also presents the results of sensitivity tests carried out to understand the impact of changes to certain key assumptions.

5.1 Access network costs

Figure 5.1 below summarises the total deployment cost for the incremental access network required to serve the predicted USO-eligible premises in each scenario. Core network costs are summarised in Section 5.2. These values represent a conservative estimate of the deployment and operational costs which could be higher or lower depending on the specific technological choices made by the USP(s) and by the extent of reuse and asset sharing actually achieved.

Figure 5.1: Total incremental access network deployment cost and annualised cost [Source: Analysys Mason, 2016]

Technology	Total deployment cost (GBP billion 2016 real terms)				Annualised cost [98] (GBP billion 2016 real terms)			
	Scn1	Scn2	Scn3	SF*	Scn1	Scn2	Scn3	SF*
FWA – sub-1GHz	2.0	3.1	4.8	29.9	1.1	1.7	2.6	17.1
FWA – 5.8GHz	1.9	2.6	4.0	20.8	1.0	1.4	2.1	11.8
FTTC VDSL2	1.7	1.9	2.2	2.8	0.3	0.4	0.5	0.6
FTTC LR-VDSL	1.4	1.5	2.0	2.5	0.3	0.3	0.4	0.5
FTTP	7.2	7.6	8.5	9.6	1.0	1.0	1.2	1.4
Lowest-cost	**1.2**	**1.4**	**1.8**	**2.4**	**0.3**	**0.3**	**0.4**	**0.5**
Lowest-cost (wireline only)	**1.4**	**1.5**	**1.9**	**2.4**	**0.3**	**0.3**	**0.4**	**0.5**

*SF = Superfast scenario

The cost model is conservative in that it does not aim to capture *all* the efficiencies that might be possible from sharing new and existing infrastructure; this is because we do not have sufficient information on existing networks to do so. The cost model also makes conservative estimates on network topology, equipment capacity, utilisation and reuse of existing infrastructure. As such, the costs calculated form a likely upper bound on the cost of deploying a network to serve each scenario. In reality, we would expect any real deployment to be achieved at a lower cost than the figures shown in Figure 5.1.

98 Tilted annuity charge and annual opex combined.

Figure 5.2 summarises the lowest-cost technology mix calculated for each scenario according to either the deployment capex or the annualised cost of deploying and operating the incremental network

Figure 5.2: Lowest-cost technology mix for each scenario [Source: Analysys Mason, 2016]

Technology	By total deployment cost				By annualised cost			
	Scn1	Scn2	Scn3	SF	Scn1	Scn2	Scn3	SF
FWA – sub-1GHz	27%	4%	2%	–	–	–	–	–
FWA – 5.8GHz	15%	6%	3%	–	–	–	–	–
FTTC VDSL2	43%	67%	78%	87%	75%	72%	80%	84%
FTTC LR-VDSL	15%	22%	14%	11%	20%	24%	15%	11%
FTTP	1%	1%	2%	2%	5%	4%	5%	5%

The lowest-cost algorithm sorts in a specific order such that where the cost of two technologies are the same the first is favoured in the mix. In certain circumstances the two types of FWA and two types of FTTC technology can be estimated to have the same costs. The sorting order is: FWA 5.8GHz, FWA sub-1GHz, FTTC VDSL2, FTTC LR-VDSL, FTTP.

The model typically shows FTTC VDSL2 as cheaper than FTTC LR-VDSL when the two are estimated to have the same costs. This occurs in situations where the area to be served is sufficiently small that the additional range of FTTC LR-VDSL does not offer a cost saving over FTTC VDSL2. Where the area to be served is large enough, FTTC LR-VDSL can be cheaper since the additional range it provides reduces the number of additional active cabinets required.

5.1.1 Cumulative deployment cost curves and CPPC curves

Figure 5.3 to Figure 5.10 below show the cumulative deployment cost curves and CPPC curves (from lowest-cost premises to most expensive premises) for each of the technologies modelled, both in the situation where only one technology is deployed in all postcode groups and where the lowest-cost technology is deployed.

These figures illustrate that there is a tail of disproportionately expensive-to-serve premises in the final 10% of the eligible premises in each scenario. These premises, while small in number, are very expensive to serve.

We noted that as the CIR specification increases from Scenario 1 to 3 and then increases significantly in the Superfast scenario, there is a clear increase in the minimum CPPC for the FWA technology options, with even the lowest-cost premises significantly more expensive to serve than with the wireline technologies.

Conversely, FTTP appears more and more attractive in CPPC terms as the CIR specification increases. As the number of eligible premises increases from 1.6 million to 5.5 million, the economies of scale for this wireline overlay technology improves relative to the other technologies.

This can be observed from the point at which the FTTP curve crosses the curves for other technologies at a later point in successive scenarios.

Figure 5.3: Scenario 1 cumulative deployment cost [Source: Analysys Mason, 2016]

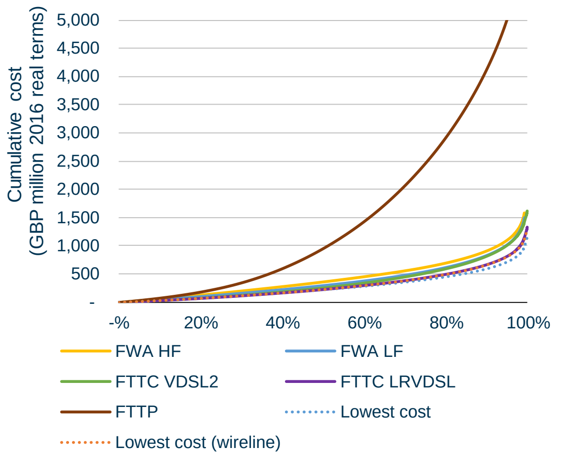


Figure 5.4: Scenario 1 deployment CPPC [Source: Analysys Mason, 2016]

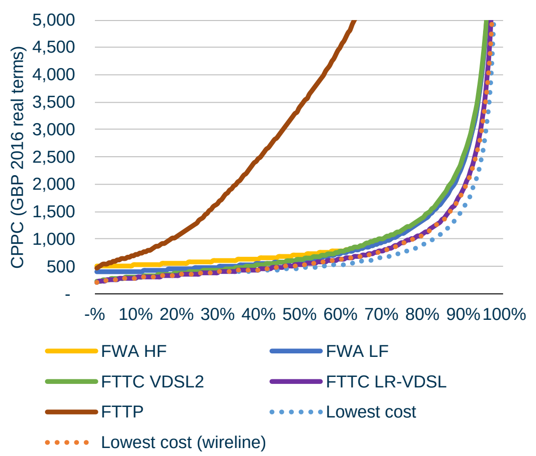


Figure 5.5: Scenario 2 cumulative deployment cost [Source: Analysys Mason, 2016]

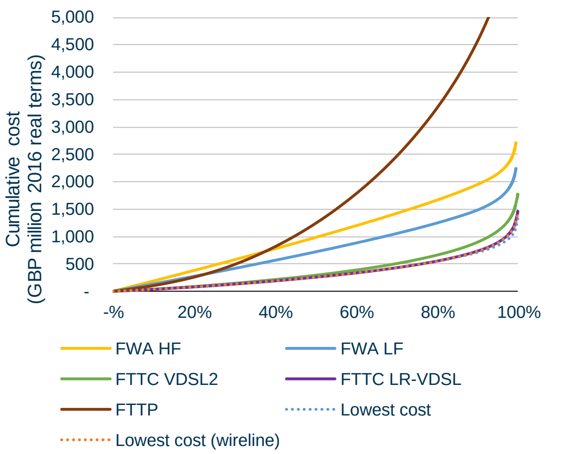


Figure 5.6: Scenario 2 deployment CPPC [Source: Analysys Mason, 2016]

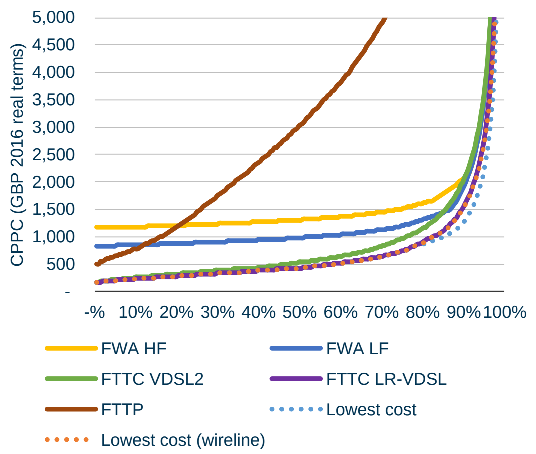


Figure 5.7: Scenario 3 cumulative deployment cost [Source: Analysys Mason, 2016]

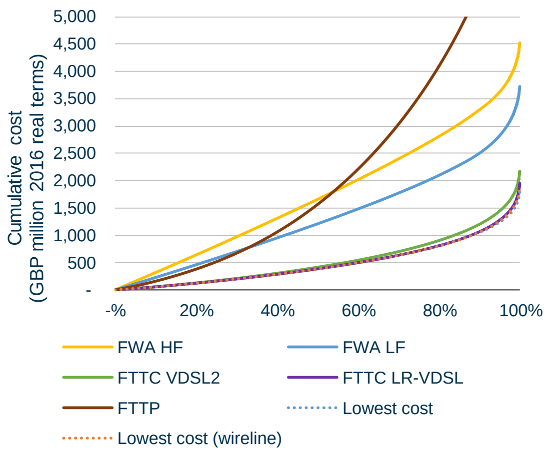


Figure 5.8: Scenario 3 deployment CPPC [Source: Analysys Mason, 2016]

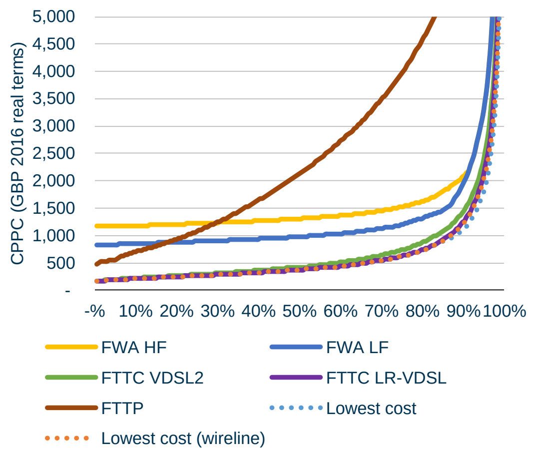


Figure 5.9: Superfast scenario cumulative deployment cost [Source: Analysys Mason, 2016]

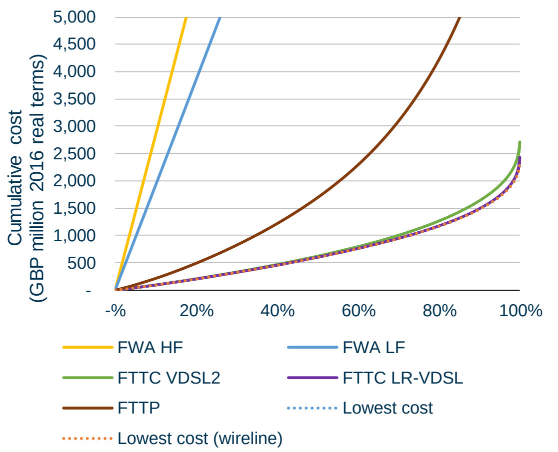
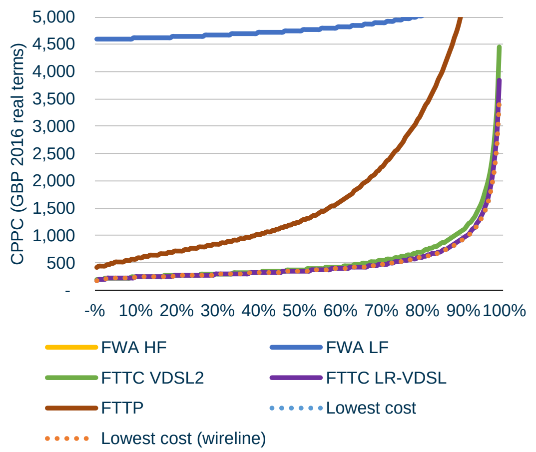


Figure 5.10: Superfast scenario deployment CPPC [Source: Analysys Mason, 2016]



While CIR and sync speed specifications are increased in the course of the various scenarios illustrated above, Figure 5.3 to Figure 5.10 indicate that the FTTP curve does not reach the same cost-effectiveness as the FTTC LR-VDSL and FTTC VDSL2 curves in any of the scenarios presented (which are for the most part lower overall). However, the curves do move closer together. This suggests that while increasing the specification does make FTTP the most economical technology for increasing the number of premises, FTTC variants will continue to play a significant role even if the required technology specification rose towards Superfast scenario levels.

The average deployment and annualised costs in cost per premises connected are summarised below in Figure 5.11. The base case assumption is that 80% of eligible premises are connected.

Figure 5.11: Average incremental access network deployment cost and annualised cost per premises connected [Source: Analysys Mason, 2016]

Technology	Deployment cost per premises passed, CPPC (GBP 2016 real terms)				Annualised cost per premises passed [99] (GBP 2016 real terms)			
	Scn1	Scn2	Scn3	SF*	Scn1	Scn2	Scn3	SF*
FWA – sub-1GHz	1524	1848	1682	6812	826	1014	918	3884
FWA – 5.8GHz	1466	1568	1402	4723	793	852	756	2676
FTTC VDSL2	1346	1126	790	630	261	221	163	133
FTTC LR-VDSL	1090	917	704	562	219	187	149	122
FTTP	5632	4543	3011	2173	746	606	414	307
Lowest-cost	**922**	**814**	**644**	**535**	**206**	**176**	**140**	**115**
Lowest-cost (wireline only)	**1047**	**882**	**674**	**540**	**206**	**176**	**140**	**115**

*SF = Superfast scenario

5.2 Core network costs

In addition to the access network costs described above, the USP(s) would be likely to incur some costs relating to transiting traffic generated by USO subscribers from the exchange (where the access network infrastructure ends in the stylised cost model) to its own core network. We have assumed that this cost can be approximated by the cost of a single EAD link from each exchange to the USP's own core network(s). This uses the conservative assumption that the same CIR is required in this part of the network as in the access network itself.

Scenario	Connection capex (2016 GBP million)	Annual rental (2016 GBP million)	Annualised cost (2016 GBP million)
Scenario 1	46.7	43.2	47.9
Scenario 2	51.7	49.4	54.6
Scenario 3	53.1	54.1	59.4
Superfast scenario	120.8	181.4	193.6

Figure 5.12: Additional core network costs [Source: Analysys Mason, 2016]

Figure 5.12 indicates that the absolute scale of the connection fee and annual rental is very low compared to the costs of deploying and operating the access network itself.

99 Tilted annuity charge and annual opex combined.

5.3 Sensitivity tests

We carried out a number of sensitivity tests to estimate the impact of altering certain key input assumptions, including:

- the take-up rate
- the assumed CIR
- the distribution of route deployment type
- trenching costs
- FWA site ownership
- modelling scale.

5.3.1 The take-up rate

The base case take-up rate is 80% of eligible premises. We tested the impact of reducing this to 55% in Scenarios 1, 2 and 3. We also tested the impact of reducing the take-up in the Superfast scenario to 30%.

Access network

Figure 5.13 below shows the impact of adopting the lowered take-up assumptions described above.

Figure 5.13: Cost for lowest-cost technology mix per premises passed in the base case and with reduced take-up [Source: Analysys Mason, 2016]

	Deployment cost *per premises* (GBP 2016 real terms)		Total deployment cost (GBP billion 2016 real terms)		Total annualised cost (GBP billion 2016 real terms)	
	Base case	Take-up sensitivity	Base case	Take-up sensitivity	Base case	Take-up sensitivity
Scenario 1	922	1282 (+39%)	1.19	1.13 (-4%)	0.27	0.25 (-4%)
Scenario 2	814	1129(+39%)	1.36	1.30 (-5%)	0.30	0.28 (-6%)
Scenario 3	644	880 (+37%)	1.82	1.71 (-6%)	0.40	0.36 (-8%)
Superfast scenario	535	1230 (+130%)	2.35	2.03 (-14%)	0.51	0.41 (-20%)

Figure 5.14 below shows the impact of reducing the take-up assumption by technology for Scenario 1. Reducing the number of premises connected from 80% of those eligible to 55% of those eligible increases the cost per premises connected by approximately 40% in all technologies. However, the overall cost of deployment and the total annualised cost are relatively insensitive to this change. This is because while the take-up reduces, the area coverage required in the stylised cost model for each of the technologies remains the same. This suggests that the overall cost of the obligation is likely to be driven more strongly by the area requiring coverage (or dispersion of potentially eligible premises) than the absolute number of subscribers taking up the service.

Unless the location of premises taking up the service is clustered in some way (this model assumes a uniform distribution in the postcodes predicted to contain USO-eligible premises), the 100% notional area coverage assumption would be required for dimensioning the network for each technology and the overall cost of deployment is likely to remain relatively unchanged.

Figure 5.14: Cost for lowest-cost technology mix per premises passed in Scenario 1 base case and with reduced take-up [Source: Analysys Mason, 2016]

	Deployment cost *per premises* (GBP 2016 real terms)		Total deployment cost (GBP billion 2016 real terms)		Total annualised cost (GBP billion 2016 real terms)	
	Base case	Take-up sensitivity	Base case	Take-up sensitivity	Base case	Take-up sensitivity
FWA – sub-1GHz	1524	2139 (+40%)	1.96	1.89 (-3%)	1.06	1.05 (-2%)
FWA – 5.8GHz	1466	2055 (+40%)	1.88	1.82 (-4%)	1.02	1.00 (-2%)
FTTC VDSL2	1346	1920 (+43%)	1.73	1.70 (-2%)	0.34	0.33 (-3%)
FTTC LR-VDSL	1090	1541 (+41%)	1.40	1.36 (-3%)	0.28	0.27 (-4%)
FTTP	5632	8070 (+43%)	7.24	7.13 (-1%)	0.96	0.94 (-2%)
Lowest-cost	922	1282 (+39%)	1.19	1.13 (-4%)	0.27	0.25 (-4%)
Lowest-cost (wireline)	1047	1479 (+41%)	1.35	1.31 (-3%)	0.27	0.25 (-4%)

Impact on core network

The impact of a change in take-up from 80% to 55% for Scenarios 1, 2 and 3 is relatively modest in absolute terms because the overall core network costs are small compared to those for the access network. In relative terms, however, the impact is significant.

The CIR for the Superfast scenario is 10Mbit/s in the core. Therefore when take-up is reduced from the base case of 80% to a more pessimistic 30% (corresponding to the present day take-up of SFBB services), the annualised cost is reduced to one-third of the base case value.

Scenario	Base case (real 2016 GBP million)	Reduced take-up (real 2016 GBP million)
Scenario 1	47.9	26.9 (-44%)
Scenario 2	54.6	27.2 (-51%)
Scenario 3	59.4	30.5 (-49%)
Superfast scenario	193.6	54.6 (-72%)

Figure 5.15: Core network annualised cost [Source: Analysys Mason, 2016]

5.3.2 The assumed CIR

A change in the CIR has no impact on the cost to deliver FTTP or FTTC in the stylised cost model since these technologies use dedicated resources for each subscriber (i.e. dedicated wavelengths in a fibre, dedicated copper sub-loop). However, since FWA makes use of a shared radio access layer, we have tested the impact of reducing the CIR required in the access network in Scenarios 2 and 3, and the Superfast scenario. Scenario 1 does not specify a minimum CIR for the access layer.

There is also an impact on the core network regardless of access network technology since core network resources are shared between subscribers. This is also described below.

Impact on FWA

As the results in Figure 5.16 show, reducing the CIR has a larger impact on the sub-1GHz technology option since these sites have a smaller overall capacity than the 5.8GHz sites as a result of their smaller available downlink spectrum. Since the CIR is the same in both Scenarios 2 and 3, the difference between the two scenarios is largely down to variations in the distribution of subscribers between postcode groups.

Figure 5.16: Total deployment cost with reduced CIR (2016 GBP billion) [Source: Analysys Mason, 2016]

Scenario	Total deployment costs			Annualised costs		
	Base case 1.5Mbit/s	Sensitivity 1 0.5Mbit/s	Sensitivity 2 1Mbit/s	Base case 1.5Mbit/s	Sensitivity 1 0.5Mbit/s	Sensitivity 2 1Mbit/s
Scenario 2 – sub-1GHz	3.10	2.20 (-29%)	2.63 (-15%)	1.70	1.18 (-30%)	1.43 (-16%)
Scenario 2 – 5.8GHz	2.63	2.08 (-21%)	2.33 (-11%)	1.43	1.11 (-22%)	1.26 (-12%)
Scenario 3 – sub-1GHz	4.77	3.26 (-32%)	3.97 (-17%)	2.60	1.73 (-34%)	2.14 (-18%)
Scenario 3 – 5.8GHz	3.97	3.06 (-23%)	3.48 (-12%)	2.14	1.62 (-25%)	1.86 (-13%)

As can be seen in Figure 5.17, which presents total deployment cost with reduced CIR in the Superfast scenario, both the 5.8GHz option and sub-1GHz option are capacity constrained to a greater degree than in Scenarios 2 and 3. Reducing the CIR from the base case to one-third or two-thirds of its value therefore has a larger impact.

Figure 5.17: Total deployment cost with reduced CIR (2016 GBP billion) [Source: Analysys Mason, 2016]

Scenario	Total deployment costs			Annualised costs		
	Base case 1.5Mbit/s	Sensitivity 1 0.5Mbit/s	Sensitivity 2 1Mbit/s	Base case 1.5Mbit/s	Sensitivity 1 0.5Mbit/s	Sensitivity 2 1Mbit/s
Superfast scenario – sub-1GHz	29.94	16.17 (-46%)	23.05 (-23%)	11.07	9.11 (-47%)	13.08 (-23%)
Superfast scenario – 5.8GHz	20.76	11.61 (-44%)	16.18 (-22%)	11.76	6.47 (-45%)	9.11 (-23%)

Impact on core network

The impact of changing the CIR on the costs of connecting to the USP's existing core network(s) are modest overall compared to the scale of the change made to the CIR. This is because the EAD core network service needs to be purchased in multiples of 10Mbit/s, 100Mbit/s or 1000Mbit/s. The impact on the Superfast scenario (see Figure 5.19) is relatively larger than for Scenarios 2 and 3 (see Figure 5.18) as the absolute CIR per subscriber is much larger.

Scenario	Base case – 1.5Mbit/s (real 2016 GBP million)	Sensitivity 1 – 0.5Mbit/s (real 2016 GBP million)	Sensitivity 2 – 1Mbit/s (real 2016 GBP million)
Scenario 2	54.6	44.8 (-18%)	48.8 (-11%)
Scenario 3	59.4	46.3 (-22%)	55.2 (-7%)

Figure 5.18: Core network annualised cost [Source: Analysys Mason, 2016]

Scenario	Base case – 10Mbit/s (real 2016 GBP million)	Sensitivity 1 – 5Mbit/s (real 2016 GBP million)	Sensitivity 2 – 7.5Mbit/s (real 2016 GBP million)
Superfast scenario	193.6	109.8 (-43%)	150.1 (-22%)

Figure 5.19: Core network annualised cost [Source: Analysys Mason, 2016]

5.3.3 The distribution of route deployment type

The distribution of route types in the base case is summarised in Figure 5.20 below.

Figure 5.20: Base case route type distribution [Source: Analysys Mason, 2016]

Technology	Geotype	Directly buried	Ducted	PIA ducted	Aerial	PIA aerial
FTTC – feeder	Urban	–	20%	80%	–	–
	Rural	–	20%	80%	–	–
FTTP – distribution	Urban	–	15%	80%	–	5%
	Rural	–	45%	30%	–	25%
FTTP – feeder	Urban	–	20%	80%	–	–
	Rural	–	20%	80%	–	–

We tested the impact of two possible changes from the base case distribution of route deployment type. We tested the impact of assuming that *all* route was built as a fully ducted network with no reuse of passive infrastructure and no new aerial infrastructure. We also tested the impact of assuming that all new route was deployed as aerial with reuse of existing assets remaining unchanged, as shown in Figure 5.21.

Figure 5.21: Distribution of route type with new aerial build [Source: Analysys Mason, 2016]

Technology	Geotype	Directly buried	Ducted	PIA ducted	Aerial	PIA aerial
FTTC – feeder	Urban	–	–	80%	20%	–
	Rural	–	–	80%	20%	–
FTTP – distribution	Urban	–	–	80%	15%	5%
	Rural	–	–	30%	45%	25%
FTTP – feeder	Urban	–	–	80%	20%	–
	Rural	–	–	80%	20%	–

Figure 5.22 shows that building entirely new ducted infrastructure significantly raises the cost per premises connected.

Figure 5.22: Impact on total deployment cost of revised route type assumptions (Scenario 1, GBP billion 2016 real terms) [Source: Analysys Mason, 2016]

	Base case	Impact of building only new duct	Impact of allowing some new aerial build
FTTC VDSL2	1.73	3.65 (+111%)	1.30 (-25%)
FTTC LR-VDSL	1.40	2.74 (+95%)	1.10 (-21%)
FTTP	7.24	16.29 (+125%)	3.68 (-50%)

Figure 5.22 shows that if reusable infrastructure is unavailable, the USP(s) would incur costs of

around double those calculated in the base case. On the other hand, complementing the reusable infrastructure assumptions with relatively low-cost new aerial infrastructure could provide a significant overall deployment cost saving for the wireline technologies.

5.3.4 Trenching costs

There is considerable uncertainty around the average trenching costs that would be achieved in the context of the USP(s) deploying new ducts and cables to serve a broadband USO. This is discussed in more detail in Annex F.

We therefore tested the impact of raising the base case trenching unit costs by 50%. We also tested the impact of the USP(s) achieving the very lowest trenching rates that might be reached in ideal conditions with the most innovative trenching techniques.

Figure 5.23: Trenching costs sensitivity test capex inputs [Source: Analysys Mason, 2016]

Trenching technique	Base case[100] (2016 GBP/metre)	Increased trenching rates (2016 GBP/metre)	Lowest possible trenching rates (2016 GBP/metre)
Ducted	56	84 (+50%)	15 (-73%)
Directly buried	51	77 (+50%)	10 (-80%)
Rented	2	2	2

Figure 5.24 shows that in Scenario 1, wireline technologies are impacted significantly by this change despite the relatively high proportion of duct reuse assumed in the network. FTTP requires relatively more fibre to be laid than FTTC (as FTTC reuses the copper sub loop while FTTP overlays this part of the network with fibre) and therefore its deployment costs are impacted more strongly in this test.

	Base case	Increased trenching rates (+50%)	Lowest possible trenching rates
FWA – sub-1GHz	1.96	1.96 (-%)	1.96 (-%)
FWA – 5.8GHz	1.88	1.88 (-%)	1.88 (-%)
FTTC VDSL2	1.73	2.04 (+18%)	1.37 (-21%)
FTTC LR-VDSL	1.40	1.62 (+15%)	1.15 (-18%)
FTTP	7.24	9.99 (+38%)	3.60 (-50%)
Lowest-cost	**1.19**	**1.38 (+17%)**	**1.06 (-11%)**
Lowest-cost (wireline)	**1.35**	**1.57 (+16%)**	**1.08 (-20%)**

Figure 5.24: Total deployment cost for Scenario 1 with increased trenching costs (GBP billion 2016 real terms) [Source: Analysys Mason, 2016]

[100] Excluding manhole costs.

5.3.5 FWA site ownership

The base case assumptions are that 10% of the FWA sites required are built by the USP(s) as traditional tower sites, 20% of the FWA sites required lease space at an existing tower site, and the remainder are leased rooftop antenna sites. We tested the impact of a worst-case scenario where all sites need to be built as a traditional tower site by the USP(s).

Figure 5.25 demonstrates the significant impact that the FWA site ownership assumptions have on deployment costs in each scenario.

Scenario	Base case		All sites are towers built by USP	
	Sub-1GHz	5.8GHz	Sub-1GHz	5.8GHz
Scenario 1	1.96	1.88	5.29 (+170%)	5.07 (+170%)
Scenario 2	3.10	2.63	8.47 (+173%)	7.10 (+170%)
Scenario 3	4.77	3.97	12.96 (+172%)	10.65 (+168%)
Superfast scenario	29.94	20.76	85.86 (+187%)	59.09 (+185%)

Figure 5.25: Impact on total deployment cost of the USP(s) building all sites as towers (GBP billion 2016 real terms) [Source: Analysys Mason, 2016]

5.3.6 Modelling scale

As discussed in Section 3.1.2 and Annex C, we have also tested the impact of modelling on a common scale instead of at a cabinet area level. The methodology is explained in Annex C.

Figure 5.26 below shows that modelling at the 2×2km scale and 4×4km scale instead of at the cabinet area inflates the overall deployment cost estimated by the stylised cost model. This effect is more pronounced at the 2×2km scale than at the 4×4km scale. The stylised cost model deploys at least one FWA site, one FTTC cabinet or one FTTP GPON splitter per modelled entity (cabinet area or grid square) and therefore in constraining the size of modelled entities (according to the grid square size) the model constrains the area or number of premises that each asset could serve according to its technical capabilities. As more assets are dimensioned at the 2×2km and 4×4km grid square scales compared to the cabinet area modelling scale, the network costs will be higher.

	Base case (cabinet areas)	2×2km scale	4×4km scale
FWA – sub-1GHz	1.96	3.20 (+63%)	2.03 (+4%)
FWA – 5.8GHz	1.88	4.35 (+131%)	3.73 (+98%)
FTTC VDSL2	1.73	4.18 (+142%)	3.68 (+113%)
FTTC LR-VDSL	1.40	3.19 (+128%)	2.45 (+75%)
FTTP	7.24	8.53 (+18%)	8.10 (+12%)

Figure 5.26: Total deployment cost when modelled at common scales (GBP 2016 real terms) [Source: Analysys Mason, 2016]

However, modelling at a common scale is useful to confirm the technology mix estimated as the lowest cost by the model at the cabinet area scale, as indicated in Figure 5.27.

	Base case (cabinet areas)	2×2km scale	4×4km scale
FWA – sub-1GHz	-%	4%	8%
FWA – 5.8GHz	-%	-%	-%
FTTC VDSL2	75%	79%	78%
FTTC LR-VDSL	20%	4%	2%
FTTP	5%	13%	12%

Figure 5.27: Lowest annualised cost technology mix when modelled at common scales [Source: Analysys Mason, 2016]

Figure 5.28 below shows the lowest deployment cost technology mix for a sample region when modelled with the cabinet area as the geographic modelling unit. Figure 5.29 shows the equivalent but with the cabinet areas split and regrouped to approximate a 4×4km grid as closely as possible.

This shows that in modelling smaller geographic units the grid approach is able to more closely approximate a hybrid deployment with more discernible pockets where wireline technologies have the lowest cost surrounded by more areas of fixed wireless. While the overall technology mix (shown in Figure 5.27 above) does diverge, the overall balance (primarily FTTC with some FTTP and FWA making up the difference) does seem to be broadly supported by the results of the 2×2km and 4×4km grid scale results. More detailed premise-by-premise modelling is likely to be able to capture the potential efficiencies of a hybrid wireless/wireline deployment than our area approach.

Figure 5.28: Scenario 1 lowest deployment cost mix in North East Scotland – cabinet areas [Source: Analysys Mason, 2016]

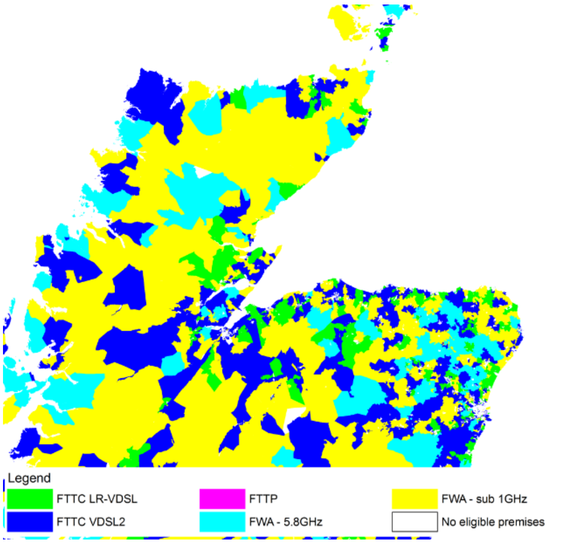
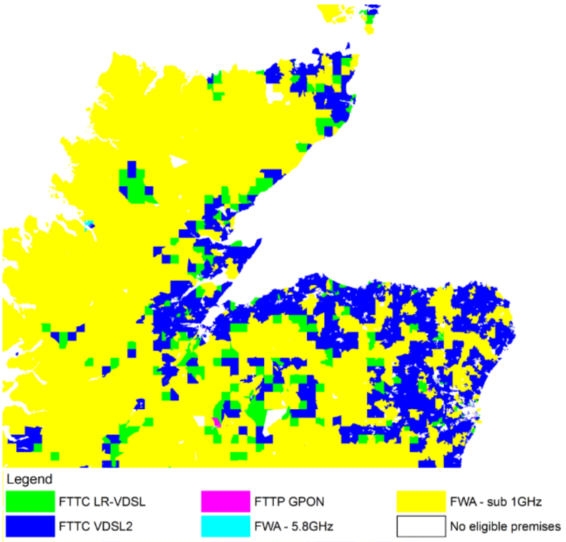


Figure 5.29: Scenario 1 lowest deployment cost mix in North East Scotland – 4×4km grid [Source: Analysys Mason, 2016]



5.4 Technologies not directly modelled

5.4.1 FTTP PTP

In many respects an FTTP PTP deployment would resemble an FTTP GPON deployment. It would require new fibre from the exchange to each subscribers' premises. The key difference between GPON and PTP is that the latter requires a dedicated fibre for the entire route. Therefore FTTP PTP is likely to be slightly more expensive than FTTP GPON as it would require larger fibre cable sizes to be deployed throughout the network. This would also mean that larger ducts would need to be installed and may reduce the proportion of existing passive infrastructure that can be reused. While passive optical splitters would not be required in an FTTP PTP deployment, there would still be a requirement for regular jointing in the network.

FTTP PTP is therefore likely to be more expensive to deploy than FTTP GPON. In previous work carried out by Analysys Mason, we concluded that FTTP PTP was approximately 20% more expensive to deploy than FTTP GPON.[101]

5.4.2 FTTdp G.fast

An FTTdp G.fast deployment, in cost terms, is likely to resemble a compromise between FTTP GPON and FTTC VDSL2. It would require fibre to be deployed to distribution points close to subscriber premises. This is likely to be co-located with the existing copper distribution point which

[101] See Figure 1/6 in http://www.analysysmason.com/PageFiles/5766/Analysys-Mason-final-report-for-BSG-(Sept2008).pdf

is typically within 60m of the subscriber premises and would therefore make use of the existing copper final drop.

G.fast can be reverse powered (i.e. powered by the subscriber's own power supply), thus avoiding the costly connection of each distribution point to the electricity network.

While FTTdp G.fast would require less new fibre to be deployed than FTTP GPON, it would also require new active equipment to be deployed at distribution points. In combination we therefore expect that the overall cost of deployment would be only slightly lower than the overall cost of deployment for FTTP GPON.

5.4.3 HFC

As would be the case with deploying new FTTP GPON, FTTP PTP and FTTdp G.fast, deploying HFC would require extensive civil works in order to deploy coaxial cable past all premises to be covered as well as ensuring the deployment of sufficient amplifiers.

Where an area containing eligible postcodes is adjacent to an area covered by HFC and the relevant coaxial bus has spare capacity, it may be reasonably cost-effective to extend the coaxial bus by a small amount to provide coverage. If the area to be covered is large, then a significant amount of new HFC cable and trench may need to be deployed. If there is limited capacity on the nearest coaxial bus then a feeder link to a distribution node or headend may also be required.

Greenfield HFC deployment (i.e. not extending or infilling an existing HFC deployment) requires extensive civil works and active equipment, and is therefore likely to be nearly as expensive as FTTP GPON or FTTdp G.fast deployment. However, for 'infill' adjacent to covered areas, HFC deployment may be cost-effective as making use of the existing coaxial bus could lead to potential savings.

5.4.4 Satellite

The role that satellite technology can play in serving a potential USO is limited by the capacity available on existing satellites. There are existing commercial services that can meet the specifications for the scenarios modelled in this report, with the exception of latency. Existing satellites provide near-complete coverage of the UK – rare exceptions are due to a limited view of the sky in a small number of locations in the UK.

The incremental cost of serving a premise is therefore primarily driven by the fixed cost of installing a satellite dish and CPE. In its response to Ofcom's CFI, Satellite Internet stated that only a fixed cost of GBP400–600 per premises including VAT (i.e. GBP333–500 excluding VAT) would be the required investment at the subscriber premises.

As discussed in Section 2.1.7, the overall satellite capacity available before 2020 is unlikely to be sufficient for extensive use of satellite to serve the broadband USO in this timeframe. The launch of high-capacity satellites such as ViaSat-3 in the early 2020s with over 1Tbit/s available throughput (shared over the entire transponder footprint, which extends beyond the UK)[102] could extend the viability of satellite as a solution in the medium term. However, satellite seems likely to only play a small part in the overall technology mix required to deliver the broadband USO, due to the CIRs envisaged in Ofcom's specifications.

Given the limitations of overall capacity and latency, it is possible that satellite technology could be suitable for consideration where the cost of deploying terrestrial infrastructure would be uneconomic. This is likely to apply in the most sparsely populated areas and perhaps as an infill technology at particularly hard-to-reach locations in slightly less sparsely populated areas (e.g. where line-of-site problems prevent a small number of premises from being served in an area that might otherwise be economic for FWA).

5.5 Conclusions

Figure 5.30 summarises the incremental cost to deploy and operate the incremental network required to serve the specification for eligible premises in each of the four scenarios. This represents a relatively high-cost deployment style with conservative estimates on network topology, equipment capacity and utilisation and the reuse of existing infrastructure.

Figure 5.30: Total deployment cost and annualised cost [Source: Analysys Mason, 2016]

Technology	Total deployment cost (GBP billion 2016 real terms)				Annualised cost [103] (GBP billion 2016 real terms)			
	Scn1	Scn2	Scn3	SF	Scn1	Scn2	Scn3	SF
FWA – sub-1GHz	2.0	3.1	4.8	29.9	1.1	1.7	2.6	17.1
FWA – 5.8GHz	1.9	2.6	4.0	20.8	1.0	1.4	2.1	11.8
FTTC VDSL2	1.7	1.9	2.2	2.8	0.3	0.4	0.5	0.6
FTTC LR-VDSL	1.4	1.5	2.0	2.5	0.3	0.3	0.4	0.5
FTTP	7.2	7.6	8.5	9.6	1.0	1.0	1.2	1.4
Lowest-cost (access network only)	**1.2**	**1.4**	**1.8**	**2.4**	**0.3**	**0.3**	**0.4**	**0.5**
Lowest-cost (including core network)	**1.2**	**1.4**	**1.9**	**2.5**	**0.3**	**0.4**	**0.5**	**0.7**

We made the following findings:

- The stylised cost model results suggest that FTTC[104] is likely to be a major part of the lowest-cost technology mix in all scenarios, including the Superfast scenario because these formed the

[102] See ViaSat's response to Ofcom's CFI at http://stakeholders.ofcom.org.uk/binaries/consultations/broadband-USO-CFI/responses/ViaSat.pdf

[103] Tilted annuity charge and annual opex combined.

[104] This is likely to include both LR-VDSL (if commercialised) and VDSL2.

most significant part of the modelled lowest-cost technology mix. Interestingly, FTTP could play a small role in the lowest-cost technology mix, in areas where eligible premises are relatively closely clustered. Similarly, FWA could play a small role, although in annualised terms it is very rarely the lowest-cost technology in a cabinet-serving area.[105] In practice this may mean that FWA is only seldom considered by the USP(s) for individual hard-to-reach premises.

- We did not directly model FTTP PTP, HFC or FTTdp. These technologies could potentially play a limited part in the USP network(s) but are unlikely to introduce significant cost savings compared to the modelled technologies. FTTdp in particular is likely to be similar in cost to FTTP GPON due to the requirement to build fibre almost to the distribution point close to the subscriber premises. However, it could be used to reduce the costs in some of the areas identified as lowest cost for FTTP GPON. Since the overall proportion of FTTP GPON is expected to be a small part of the lowest-cost technology mix this is unlikely to have a significant impact on the total cost of the USO.

- For all three USO scenarios and the Superfast scenario there is a tail of very expensive-to-serve premises. Specifically, the cost of the final 10% of eligible premises (covering c. 160 000 premises in Scenario 1 to c. 550 000 premises in the Superfast scenario) rises very significantly. Satellite may be able to address some of these premises, though it has only a limited overall capacity in the context of the CIR in the specifications that we have modelled and in the timeframe envisaged for the USO. The commercial satellite services that we have examined are unlikely to be able to meet the higher proposed latency specifications.

- The wireline technology costs are very sensitive to the level of reusable infrastructure and trenching costs, both of which are key areas of uncertainty in the modelling. Deploying new fibre aerially offers scope for cost savings and this may be more acceptable in very rural areas than it is in urban environments.

- Core network costs are relatively small compared to the overall incremental access network costs. The additional traffic in the core network carried as a result of serving the subscribers that take-up the modelled service (80% in the base case) is relatively small compared to the traffic already being carried in the core network.

- FWA is sensitive to the CIR specification. There is relatively little spectrum available in the sub-1GHz range, which constrains the capacity that individual sites could provide. In the 5.8GHz band, limited propagation distance limits the area that each site can cover. In both cases this means a large number of sites is required to serve all eligible premises, resulting in high deployment and operational costs, particularly in the Superfast scenario which requires a 10Mbit/s CIR per subscriber.

105 We also note that spectrum licence costs have not been considered in the cost model. These costs could be considerable (whether opportunity or actual costs).

- Reducing the take-up rate assumption only reduces total deployment costs by a relatively small proportion as a network must still be built to pass all premises that may potentially request the service. For example, lowering take-up from 80% of eligible premises to 55% in Scenario 1 results in a reduction in deployment costs and annualised costs of only 4%.
- Wireline technologies benefit from economies of scale as the number of eligible premises increases. They are also largely invariant to the CIR specified hence the CPPC reduces between Scenario 1 and the Superfast scenario. However, FWA becomes increasingly more expensive per premises as the specification is raised due to the limited capacity that each FWA site can serve and the shared nature of the radio access layer. The poor scalability of FWA does not pass through to the lowest-cost technology deployment since it makes up only a very small part of the mix.

5.6 Limitations and areas for further study

The stylised cost model described above is sufficient to provide a preliminary estimate of the likely range of costs that would be incurred in deploying a network to serve a broadband USO, the key drivers of costs and the way in which they influence the overall total. However, the accuracy of the conclusions could be improved by conducting a more detailed cost modelling exercise based on actual premises data and a better understanding of certain key parameters. Below we outline some key areas for further study that would enable the above estimates to be refined if a more detailed analysis was required at a later stage.

Ideally our modelling could be carried out on a premise-by-premise level. This would allow for the highest degree of optimisation but would be highly computationally intensive. Premise-level data was not available at the time this modelling work was carried out, therefore the stylised cost model uses a simplified assumption that premises are evenly distributed across their postcode area.[106]

The location and reusable capacity of existing infrastructure is an area of significant complexity and uncertainty. The stylised cost model estimates the proportion of premises that could be served by upgrading existing cabinets and it uses estimates of the proportion of reusable duct, poles and FWA sites to calculate a cost for deploying each technology. A better understanding of both the proportion of each type of infrastructure that could be reused and its location relative to USO-eligible premises would enable the accuracy of the cost estimate to be refined.

FTTP GPON

The overall cost of deploying FTTP GPON infrastructure is driven primarily by the costs of civil works. Therefore the proportion of reusable duct or pole infrastructure is a significant driver of the overall cost of deployment. The cost of deploying new duct or poles is also a significant driver which is subject to significant variation in terms of geography and deployment style. The cost model

106 One limitation of this is that the modelled network needs to be designed to provide 100% notional area coverage which would tend to overestimate the real costs.

assumes that no new aerial routes are used. If new aerial routes could be used in the FTTP GPON distribution network this could further reduce the costs currently estimated by the model.

The stylised cost model assumes that the new FTTP GPON distribution network requires a new fibre feeder cable to the parent exchange. In reality there may be a suitable fibre 'spine' passing closer to each deployment area than to the exchange, and this spine could be reused.[107] Knowledge of the location and capacity of Openreach's fibre spines and other operators' suitable infrastructure could therefore be employed to usefully develop an estimate of the possible efficiencies that could be exploited to reduce FTTP deployment costs.

Data on USO-eligible premise locations would enable an optimised distribution network to be designed (the stylised cost model makes assumptions about which roads need to be covered to pass all premises). This optimised distribution network could take into account the dispersion of premises and therefore the most appropriate network routeing and splitter strategies (e.g. two-way split, splitter close to exchange, or splitter close to subscriber).

FTTP VDSL2 and FTTC LR-VDSL

Many of the key drivers of costs and improvements to modelling applicable to FTTP GPON are also applicable to FTTC. There is one exception, namely that since FTTC reuses existing copper sub-loop only the parameters relevant to the fibre feeder apply to FTTC.

The overall costs of deploying FTTC are also driven primarily by the number and location of FTTC cabinets containing active equipment. In our simplified cost modelling approach, a large number of cabinets would need to be deployed serving only a small number of premises each. The large number of cabinets is primarily driven by the large majority of postcode groups containing fewer premises than would occupy a single line card (assumed to have a capacity of 32 lines).

The cost of deploying cabinets is relatively well understood for the most part, with the exception of the cost required to connect new cabinets to a power supply. The closest power supply with available capacity and the cost to deploy a power cable to a new cabinet is a relatively unknown variable.

Knowledge of the exact location of premises would allow for the number of cabinets required to be optimised based on possible opportunities to share coverage between postcode groups or to reduce coverage from a 100% notional postcode group area (as the cost model assumes) to only the area required by the actual location of premises.

A significant driver of the cost of deploying FTTC is also the cost of deploying fibre feeder in ducts between each new cabinet and its parent exchange. We assumed that a significant proportion of the required fibre feeder could reuse existing ducts. However, the amount of new infrastructure

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107 For this reason we applied a 2km cap to the length of new fibre feeder built in the FTTP and FTTC models based on the statement that 96% of premises are within 2km of the nearest NGA aggregation node. However, there are cases where substantially more feeder is required. For example, see http://www.btplc.com/Thegroup/BTUKandWorldwide/BTRegions/England/InTouch/YorkshireandHumber/Summer2016/BroadbandEastRiding/index.htm

calculated to be required could be reduced if nearby fibre spines with spare capacity could be identified and connected to.

The stylised cost model used assumptions on the range and capabilities of LR-VDSL based on information available in the public domain. However, it should be noted that LR-VDSL is a technology that is still under development and therefore its precise specifications and performance are yet to be determined.

FWA

The stylised cost model uses relatively simple capacity and coverage calculations to estimate the number of sites required based on a generic link budget for each band. A full radio planning exercise could refine the estimates made by the cost model, particularly in relation to the longer-range sub-1GHz case, to better take into account terrain, clutter and interference. This could also allow for a better understanding of required site type (e.g. tower, rooftop) and the availability of suitable locations. This may also show that there are certain locations where FWA may be a more economically viable solution than our simple model suggests. In other areas the opposite may be true. However, we would note that a full radio planning exercise on the scale of all premises in the broadband USO would be a significant undertaking.

The FWA cost calculations in the stylised cost model also do not account for the cost of acquiring and holding the requisite spectrum licences.

Hybrid deployments

A cost model that represents the most efficient possible deployment would consider the ability for various technologies to overlap in coverage and share infrastructure. Our postcode-group-based approach does approach this in one way by modelling relatively small, cabinet serving areas and by testing the effect of modelling areas of a common, small, grid scale. However, this approach is not able to fully capture the way in which certain parts of the network can be shared (most notably the fibre feeder for FTTP and FTTC). It also does not capture the possibility of introducing further efficiency by allowing different technology areas to overlap – this could only be addressed by using a premise-by-premise approach.

Annex A Provisioned throughput calculation

For some technologies (e.g. FTTP PTP) most or all of the access network is dedicated to each subscriber, while for other technologies resources are shared and these therefore need to be dimensioned in a way that provides sufficient throughput per subscriber to match the estimated distribution of speeds that could be expected for current 10Mbit/s broadband connections.

We have carried out a statistical analysis based on queuing theory to estimate the guaranteed throughput per subscriber that needs to be provided in order to meet or exceed the speed distribution estimated by Ofcom for Scenarios 2 and 3.

Our model calculates the equivalent curve for the probability that there is an available 2Mbit/s channel given the distribution of other users being served by the available channels and the duration of their use. We assume that each channel of video takes 2Mbit/s to deliver, and that demand for video is Erlang B distributed (i.e. call duration is negative exponential and call start times random – making the inter-arrival distribution poisson).

The model requires a number of input assumptions as these are unknown:

- Rate of video demand ("hours per hour" = Erlangs)
- Number of users served by the node with the capacity constraint of interest
- Capacity constraint in channels (we assume 2Mbit per channel) ("k")
- Average duration of the video (assumed to be 1.5 hours, but this is not always the case as a television programme might consist one or more episodes at 45–60 minutes).

This is modelled as an M/M/k queue. The properties of the steady state M/M/k queue with a set number of users are used to calculate the probabilities of the system having (instantaneously) 0,1,2,3,4,5 units of spare capacity at any one time. (i.e. the servers (or channels) are currently working on k,k-1,k-2,k-3 etc. jobs, so another 0,1,2,3 etc. can start immediately).

We assume:

- 25 users – which corresponds to the approximate number of subscribers an FWA cell might cover, though it would vary depending on the total spectrum bandwidth being used and hence the capacity of the cell.
- 20–25% rate of each user using 2Mbit/s video (hours per hour) – i.e. average roughly 4–5 hours per day in total average video duration of 1.5 hours. This corresponds approximately to the level of usage that Ofcom expected would make up a 10Mbit/s connection in its Connected Nations 2015 report.[108]

[108] This included 6Mbit/s for a HD video stream, 2Mbit/s for an SD video stream, 1.5Mbit/s for video calls and browsing and 0.5Mbit/s for a separate browsing session.

In order to approximate the measured probability curve in the >85% probability part of the curve, a total of 18 channels was required at the 20% rate of usage (slightly undershooting) and 21 channels at the 25% rate of usage (slightly overprovisioning). These correspond to 1.44Mbit/s per subscriber and 1.68Mbit/s per subscriber respectively.

- 1.68Mbit/s for 25% of the time would equate to an average throughput (across the day) of 420kbit/s, which is not very much higher than the ~380kbit/s that Analysys Mason's Research division forecasted for average continuous Internet throughput per connection for the UK in 2015.
- 1.44Mbit/s for 20% of the time would equate to an average throughput (across the day) of 288kbit/s, which is significantly lower than the ~380kbit/s forecast.

Some of the assumptions used in our model may result in a slightly conservative estimate of the throughput required (e.g. the use of a small pool of 25 subscribers) for some technologies. In addition, the measured probability may contain some biases (e.g. the methodology used only samples when the line is not busy, which may result in the busy hour being under-sampled, therefore suggesting that higher speeds are more likely than they are in reality). In combination, therefore, we believe that this analysis supports the use of a minimum guaranteed throughput of 1.5Mbit/s as representative of an estimated 10Mbit/s broadband connection.

Given that there is some uncertainty, this value should be sensitivity tested in order to understand the degree to which it influences the cost-modelling results.

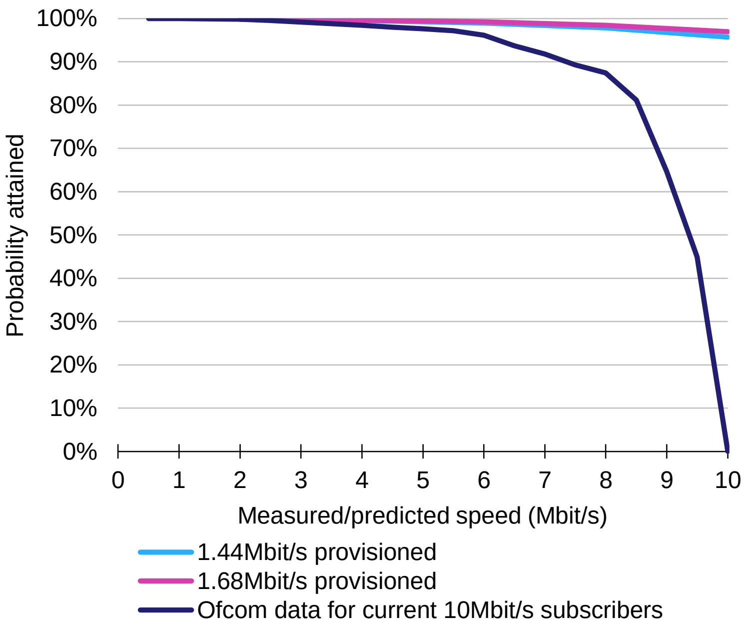


Figure A.1: Estimated speed distribution for a typical fixed 10Mbit/s broadband connection compared to estimate for 1.5Mbit/s provisioned [Source: Ofcom, Analysys Mason, 2016]

Annex B Input data

This Annex contains further information relating to the geographical approach to modelling that is described in Section 3. It should be read in conjunction with that section.

B.1 Introduction

Ofcom has provided Analysys Mason with input datasets for each of the three broadband USO specification scenarios as well as for a Superfast scenario. Data was provided separately for the KCOM area around Hull since this was calculated on a different basis to the main UK and Northern Ireland datasets.

Each of these input datasets contains the list of postcodes that are predicted to contain USO-eligible premises under each scenario. The datasets also contain a number of statistics for each postcode, the most important of which are explained in Figure B.1:[109]

Figure B.1: Summary of scenario data provided by Ofcom [Source: Ofcom, 2016]

Category	Description
Postcode unit	E.g. 'AB10 1QS'
Postcode co-ordinates	The x and y co-ordinates (using a British National Grid co-ordinate system) of the postcode unit's centroid, as of June 2015 for GB postcodes and as of November 2015 for NI postcodes
Postcode area	The area of the postcode unit, in sqm, as of June 2015 for GB postcodes and as of November 2015 for NI postcodes
Total number of premises	Total number of premises in each postcode unit as of April 2015
Total number of EoLs	Total number of EoLs served by Openreach/KCOM as of June 2016
Number of USO-eligible lines	Number of premises in the postcode unit which are predicted to be eligible for the USO (or Superfast scenario)
Number of exchange only eligible lines	Number of EoLs in the postcode unit which are eligible for the USO (or Superfast scenario) in the given scenario
Cabinet ID	Cabinet ID code for the cabinet which serves this postcode unit's premises, as of June 2016
Cabinet co-ordinates	The x and y co-ordinates (using a British National Grid co-ordinate system) of the cabinet, as of June 2016
Exchange ID	Exchange ID code for the exchange which serves this postcode unit's premises, as of June 2016

109 Figure B.1 only shows the key data provided by Ofcom which was used in our modelling. The following information was also included: proportion of premises meeting the specified download speed, presence of Virgin Media, households, rurality classification, demographic information, elevation data, cabinet upgrade status in relation to FTTC, postcode co-ordinates and area, household number and density, and nation.

Category	Description
Exchange co-ordinates	The x and y co-ordinates (using a British National Grid co-ordinate system) of the exchange, as of June 2016
Average distance from cabinet to eligible premises	The average ‘crow fly’ distance, in metres, from the USO-eligible premises in the postcode unit, to the nearest cabinet serving the postcode unit
Average distance from exchange to eligible premises	The average ‘crow fly’ distance, in metres, from the USO-eligible premises in the postcode unit, to the nearest exchange serving the postcode unit

In both the KCOM and BT datasets, the postcodes in Scenario 1 are a subset of the postcodes in Scenario 2, and the postcodes in Scenario 2 are a subset of the postcodes in Scenario 3. However, the Superfast scenario (which contains the most postcodes) does not contain all of the postcodes in Scenario 3, as the data was derived using a different methodology.[110]

In addition to the scenario data, Ofcom also provided Analysys Mason with a number of supporting files which contained information on the postcodes in a different format to that used in the main scenario datasets. Ofcom also provided the Ordnance Survey Code Point polygons that it used in its calculations (under the terms of a PSMA sub-licence and LPS sub-licence) which has allowed us to use a consistent set of polygons in our grouping work.

B.2 Data processing

Due to inconsistencies in the underlying datasets used to produce the scenario data there were a number of omissions and potential incompatibilities that it was necessary to account for before feeding the data into the grouping and modelling processes. These are summarised below in the following two tables for the Openreach and KCOM coverage areas respectively.

Area and distance information are required for modelling calculations that consider coverage or range limitations (e.g. maximum cell areas for FWA or maximum line lengths for FTTC). Co-ordinates are required for the grouping process and to calculate missing distance information.

Figure B.2: Potential omissions and inconsistencies with scenario data provided for UK, excluding Hull [Source: Analysys Mason, 2016]

	Scenario 1	Scenario 2	Scenario 3	Superfast
Postcode/cabinet combinations (i.e. rows)	246 515	291 812	422 719	578 836
Missing postcode co-ordinates	21 500	22 741	28 447	41 510
Missing area	1	1	2	3

110 The postcodes in the Superfast scenario were derived using a different set of thresholds: postcodes where there is less than 100% coverage of SFBB or where the average upload speed for SFBB lines is less than 6Mbit/s. As a result of this approach, some postcodes which have 100% SFBB coverage but did not have an average SFBB upload speed (for example, where there was no active SFBB lines) have been excluded.

	Scenario 1	Scenario 2	Scenario 3	Superfast
No cabinet ID and EoL<100%	1754	1886	2981	5890
Cabinet co-ordinates missing	212	209	228	249
Has a cabinet, but no cabinet distance[111]	18 048	18 680	20 229	31 479
Missing exchange	104	106	129	152
Missing exchange distance[111]	202 851	243 400	363 863	490 320

Figure B.3: Summary of scenario data provided for Hull area [Source: Analysys Mason, 2016]

	Scenario 1	Scenario 2	Scenario 3	Superfast
Postcode/cabinet combinations (i.e. rows)	5975	5995	7337	7975
Missing postcode co-ordinates	24	28	56	61
Missing area	–	–	–	–
Missing exchange	187	187	125	194
Missing exchange distance[111]	93	97	188	130

Below we describe how we have accounted for these omissions and inconsistencies, as well as explaining our geotyping of the postcodes into ‘urban’ and ‘rural’ classifications.

Postcode co-ordinates

We added the missing postcode co-ordinates based on the following sources in decreasing order of precedence:

- Great Britain and Northern Ireland CodePoint data (supplied by Ofcom under the OS PMSA and LPS sub-licence agreements)
- http://www.gridreferencefinder.com/postcodeBatchConverter/
- https://www.doogal.co.uk/PostcodeDownloads.php

Postcodes with no area data

Across all scenarios, there were three postcodes that did not have an area value attributed to them: NE1 7XR, PO2 8QN and SW19 2PE. These appeared to correspond to either an MDU or a private area containing only commercial premises (commercial premises are likely to be connected to a

[111] Distance information either due to missing co-ordinate information or because distance exceeds a ‘reasonable’ distance cap of 10km.

centralised site-wide distribution frame). Since we have been unable to define an area based on OS mapping data, we have assumed a notional area of 1000sqm.

Records with no cabinet ID but less than 100% EoLs

There were a number of records in each scenario which suggested that certain areas contained lines served by cabinets but did not provide a cabinet ID. Since the number of premises affected was small, these records were updated to assume that all lines are EoLs.[112]

The fields in the scenario datasets that were updated to account for these changed assumptions were: ‘pct_eol’, ‘eligible_eol’ and ‘eligible_non_eol’.

Cabinets with no co-ordinates

Across the scenarios there were 54 unique cabinets with no co-ordinates. These correspond to 228 and 249 cabinet/postcode entries in Scenario 3 and the Superfast scenario (which contain the superset of all cabinets), respectively.

We assumed that the co-ordinates of the postcode considered to be served by each cabinet would be representative of its location. We used the base cabinet data files from Ofcom (‘cabinets_full_scen3.csv’ and ‘cabinets_full_scen4.csv’) to look up this information.

Records with no serving exchange information

There were 152 records with no serving exchange information in the data pertaining to Openreach’s coverage area. None of these records were marked as served by cabinets (i.e. all lines are served directly from the exchange). We located the postcode centroids for each of these records and compared them to an exchange boundary map in order to establish the exchange that serves them. The exchange ID and co-ordinates fields were updated based on this matching process.

For records relating to the KCOM coverage area around Hull, we identified the approximate extent of the areas served by each exchange (where known) by plotting a thematic map of postcodes by serving exchange, as shown in Figure B.4 below. We manually identified the exchange area that would likely serve each remaining postcode.

[✂]

Figure B.4: KCOM postcodes by serving exchange [Source: Analysys Mason based on data provided by Ofcom, 2016]

[112] In Scenario 1 this affected approximately 200 postcodes and resulted in an overestimate of approximately 1650 lines out of a total of 1.6 million.

Records with no cabinet or exchange distances

Where cabinet or exchange distances were missing we used the Euclidean distance (i.e. calculated using Pythagoras' theorem) between the centroids to estimate the remaining missing distances.

Some records suggested that the average distance from premises to cabinet or exchange was very high (e.g. some records indicated that certain postcodes were served by exchanges up to 800km away). To account for this we established an average distance cap of 10km (for both cabinet and exchange distance, in both the Openreach and KCOM areas).

Geotypes

The scenario data used a different geotyping classification system for postcodes according to the recording system used in each home nation. In order to have a consistent approach across all four nations for modelling purposes, we have mapped all postcodes to one of two geotypes: urban and rural. The distinction is used in the model to set certain parameters (e.g. proportion of aerial route).

Figure B.5: Geotype classification [Source: Analysys Mason, 2016]

England and Wales			Scotland			Northern Ireland		
Classification		Geotype	Classification		Geotype	Classification		Geotype
A1	Urban major conurbation	Urban	1	Large urban areas	Urban	A	Belfast metropolitan urban area	Urban
B1	Urban minor conurbation	Urban	2	Other urban areas	Urban	B	Derry urban area	Urban
C1	Urban city and town	Urban	3	Accessible small towns	Urban	C	Large town	Urban
C2	Urban city and town (sparse)	Urban	4	Remote small towns	Urban	D	Medium town	Urban
–	–	–	–	–	–	E	Small town	Urban
D1	Rural town and fringe	Rural	5	Very remote small towns	Rural	F	Intermediate settlement	Rural
D2	Rural town and fringe (sparse)	Rural	6	Accessible rural	Rural	G	Village	Rural
E1	Rural village	Rural	7	Remote rural	Rural	H	Small village, hamlet and open countryside	Rural
E2	Rural village (sparse)	Rural	8	Very remote rural	Rural	–	–	–
F1	Rural hamlet and isolated dwellings	Rural	–	–	–	–	–	–
F2	Rural hamlet and isolated dwellings (sparse)	Rural	–	–	–	–	–	–

Where no classification data was provided we assumed that the postcode was rural. This assumption was primarily required for postcodes in Northern Ireland.

Annex C Approach to grouping postcode areas to a common scale

As described in Section 3 in addition to modelling on a cabinet area basis we have tested the impact of modelling on a common length scale. This Annex explains how the common scales were selected and the way in which we developed areas to match those scales.

C.1 Choice of scale

The approximate scales relevant to each technology scenario that we are modelling are as follows:

- FTTP GPON
  - no practical scale limits within the context of an access network
- FTTC
  - VDSL2 – this technology has an estimated range of up to 1.9km at 10Mbit/s and up to 1.3km at 30Mbit/s. We estimate this to correspond to a 'crow fly' distance[113] of up to 1.5km and 1.0km respectively
  - LR-VDSL – this technology has an estimated range of 3.5km at 10Mbit/s and 2.8km at 30Mbit/s. We estimate this to correspond to a 'crow fly' distance of around 2.7km and 1.4km respectively
- FWA
  - low frequency – up to 10km cell radius
  - high frequency – 1km cell radius at 10Mbit/s and 0.5km at 30Mbit/s.

The different technologies therefore give a spread of scales (radii) ranging from 0.5km to 10km. In choosing an appropriate modelling scale, the following considerations are also relevant:

- **Technologies of most interest** – FTTC VDSL2 and LR-VDSL are of interest since the former is already deployed and the latter is being actively trialled by Openreach. In contrast, the availability of spectrum for widespread FWA deployment is less clear. FTTP has no practical range limitation and we understand that KCOM is planning to significantly expand its FTTP footprint, although this is only relevant to the Hull area[114] With that in mind technology scales around the range of FTTC deployments are likely to be the most relevant.

113 This is based on converting to a 'crow fly' distance using a ratio of 1.3. [✂✂]

114 See https://www.kcomhome.com/products/broadband/lightstream-rollout/

- **Distribution of cabinet USO areas**[115] – as shown in Figure 3.1 below, 80% of USO cabinet areas are less than 3sqkm and over 90% are under 10sqkm, suggesting it is appropriate to have a focus towards the lower end of the range.

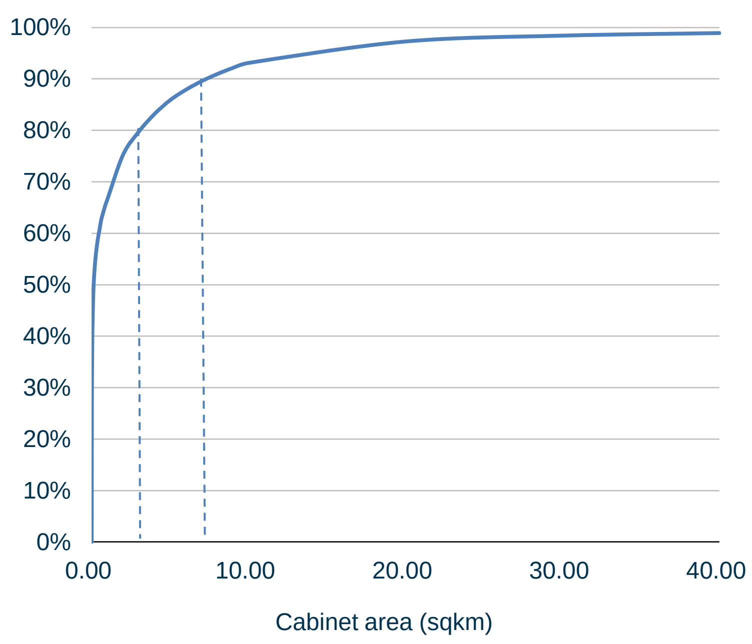


Figure 5.6: Cumulative distribution of cabinet USO areas for Scenario 3 [Source: Analysys Mason, 2016]

- **Simple numbers** – scales that are multiples of each other are helpful both for computational purposes and ease of comparison.
- **Computational difficulty** – the smaller the scale chosen, the larger the number of postcode groups produced, and therefore the more the computational complexity of dimensioning assets and calculating costs. There is therefore a balance to be struck between the detail that smaller scales usually allow and a scale that can be modelled in a straightforward manner.

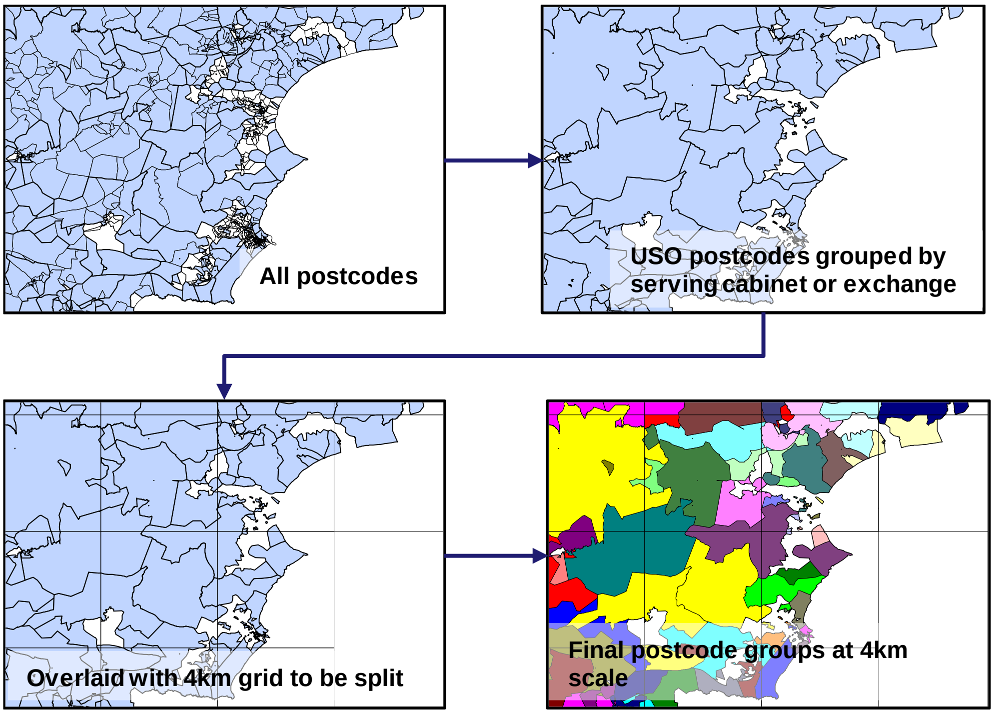
In an effort to balance the considerations above we have decided to test at scales of 2×2km and 4×4km.

C.2 Grouping methodology

The following section provides a detailed description of the approach taken to combine/split postcodes into postcode groups of the required scale for modelling. As described above, grouping scales of 2×2km and 4×4km were chosen. These are referred to below as the ‘scale areas’. The process described below was repeated separately for each of the scale areas.

115 ‘Cabinet USO area’ has been calculated by summing all postcode areas which contain USO-eligible premises and are served by a given cabinet (or a given exchange in the case of EoL).

Figure C.1: Overview of grouping methodology at 4x4km scale [Source: Analysys Mason,2016]



C.2.1 Step 1. Allocate each postcode to a unique cabinet

The first stage of the process was to allocate each postcode to a unique cabinet. As described in Section 3.2, Ofcom has provided details of the serving cabinets associated with each postcode. In cases where a postcode does not have a serving cabinet (i.e. its premises are all EoLs), it is assigned a 'notional cabinet' at the MDF.

There was a small number of postcodes with no associated polygon area.[116]

C.2.2 Step 2. Where postcodes are served by multiple cabinets, use a Voronoi construction to split them up

In some instances a single postcode is served by multiple cabinets (16% of the postcodes that occur across all four scenarios). In order to retain the direct relationship between postcodes and cabinets in the modelling process, we have developed a methodology which keeps the cabinet information of postcodes served by multiple cabinets. This allows for further analysis to be carried out on our cost modelling results on a postcode-by-postcode basis.

In these cases, a Voronoi construction[117] is used to split the postcode up into pieces. Each piece is then assigned to the relevant cabinet. This process is illustrated in Figure C.2 below for a postcode which is

116 Out of a total of 583 097 postcodes occurring across all four scenarios 2.5% have no corresponding shape.

117 A Voronoi construction of a set of points is a tiling in which each tile contains exactly one point, and each tile consists of the region which is closer to the enclosed point than to any other point.

served by five different cabinets. Where postcodes are served by multiple cabinets the number of serving cabinets tends to be low, but we observed cases where nearly 30 cabinets serve a postcode.

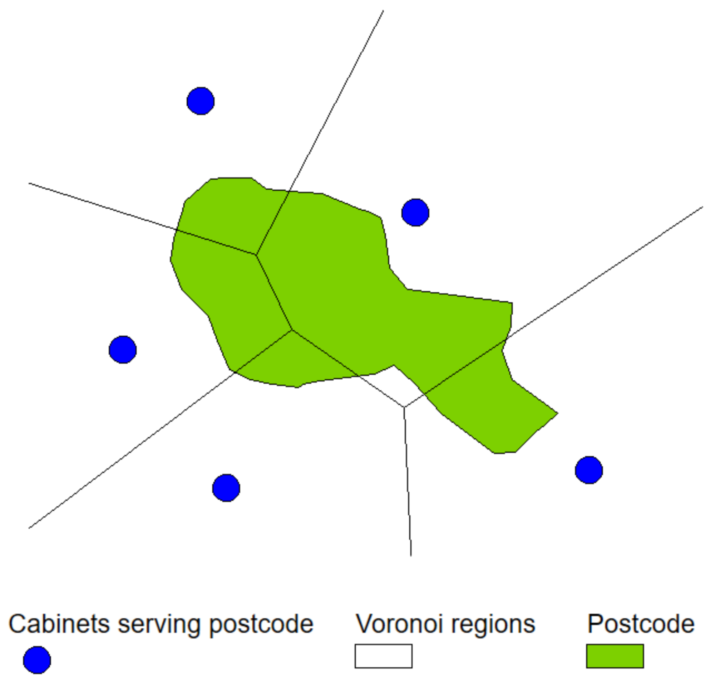


Figure C.2: Schematic of the Voronoi process [Source: Analysys Mason, 2016]

C.2.3 Step 3. Combine postcode pieces by their cabinet ID

All the postcodes and postcode pieces with the same cabinet ID are combined into a single object (the 'cabinet shape'). The areas of the cabinet shapes are then calculated, and shall be referred to as *cab_area_actual*. It should be noted that these objects are not necessarily contiguous shapes, as illustrated in Figure C.3 below. The white space between the coloured cabinet areas indicates postcode areas that do not contain USO-eligible premises.

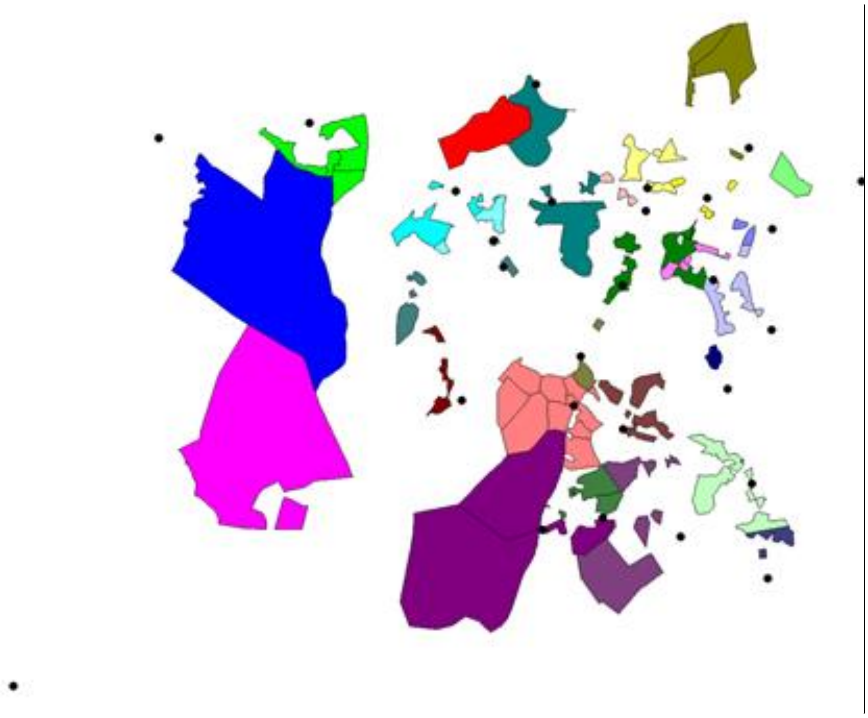


Figure C.3: Sample of postcodes from LS19 and LS20 post sectors coloured by cabinet ID. Objects of the same colour are combined to produce cabinet areas [Source: Analysys Mason, 2016]

Serving cabinets are indicated with a black point.

C.2.4 Step 4. Enclose the combined shape with a 'convex hull' and calculate the convex area

Where a cabinet shape is smaller than the scale area it is used as its own group in Step 5. In order to check whether a cabinet shape is smaller than the scale area, we calculate its convex area.

The cabinet shapes are enclosed with a 'convex hull'.[118] In two dimensions, the convex hull can intuitively be thought of as the shape which is formed by wrapping an elastic band around the object. The convex hulling process is illustrated in Figure C.4 below.

118 The convex hull of a shape is the smallest convex region which bounds the object. A convex shape is a region such that, for every pair of points within the region, every point on the straight line between the two points is also within the region.

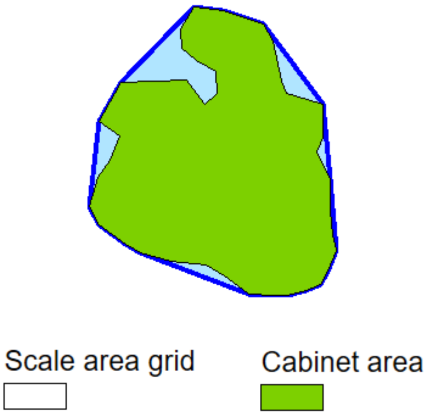


Figure C.4: Schematic of the convex hull process [Source: Analysys Mason, 2016]

The areas of the cabinet shapes' convex hulls are then calculated, and shall be referred to as *cab_area_convex*. The relationship between *cab_area_convex* and the scale area determines the next step in the process.

C.2.5 Step 5: Compare group area to scale area

Step 5a. If cab_area_convex < scale area

If the convex hull of the cabinet shape is *smaller* than the scale area, then the cabinet shape is used as the group. This is illustrated in Figure C.5 below.

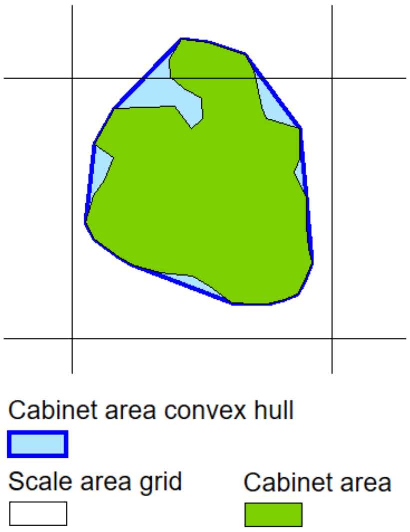


Figure C.5: Schematic – case in which the convex hull of the cabinet shape is smaller than the scale area [Source: Analysys Mason, 2016]

Step 5b. If cab_area_convex > scale area

If the convex hull of the cabinet shape is *larger* than the scale area, we first consider if *cab_area_actual* < scale area. If so, and if the cabinet shape is a single contiguous object, then the cabinet shape is used as the group. This is illustrated in Figure C.6 below.

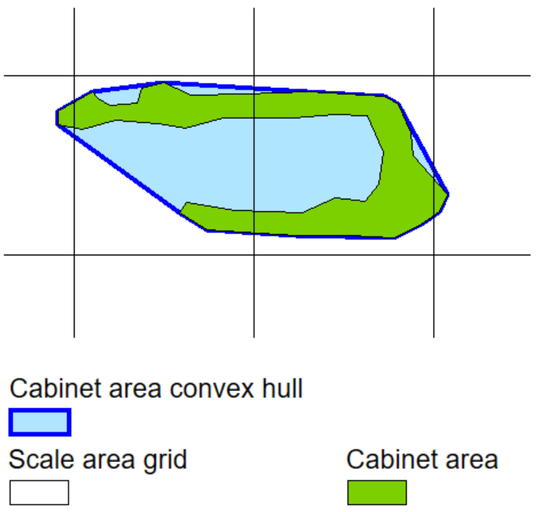


Figure C.6: Schematic – case in which the convex hull is larger than the scale area, but the actual area is contiguous and smaller than the scale area [Source: Analysys Mason, 2016]

For all other situations, the cabinet shapes are subdivided using square tiles of the correct area scale. If a square tile overlaps a cabinet shape by more than half, then the overlap area is designated to be its own group. Where the overlap area covers less than half of the tile, this piece is reallocated to the adjacent tile which has the largest overlap with the cabinet shape. This is illustrated in the figures below.

Figure C.7 shows a cabinet shape overlaid by square tiles of the scale area. In this case, the convex hull of the cabinet shape is clearly larger than a single tile. Figure C.8 highlights the nine tiles (outlined in blue) which overlap with the cabinet shape by more than half. These nine pieces of cabinet area become their own groups.

Figure C.7: Cabinet shape and scale area grid squares [Source: Analysys Mason, 2016]

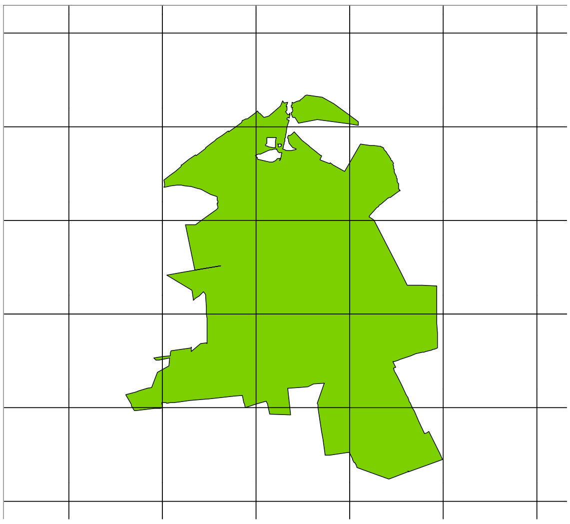


Figure C.8: Grid squares which overlap the cabinet shape by more than half have been highlighted [Source: Analysys Mason, 2016]

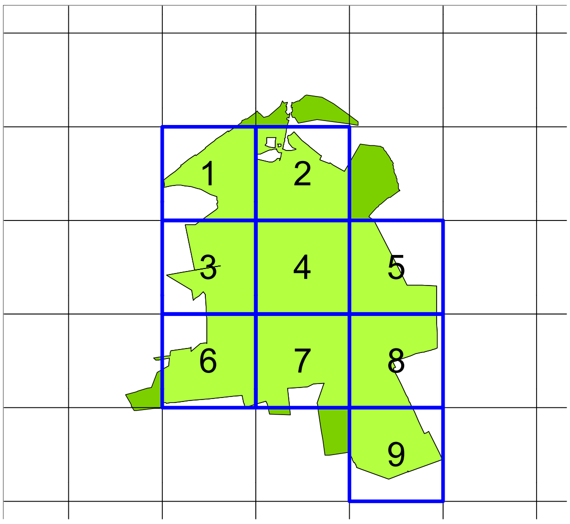
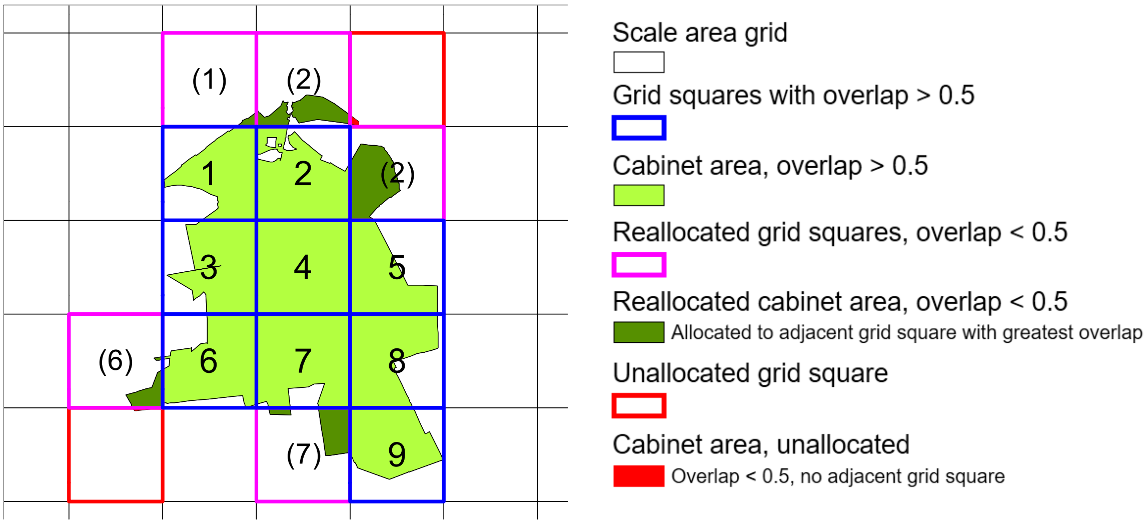


Figure C.9 highlights the five tiles (outlined in pink) which overlap with the cabinet shape by less than half. As shown, these tiles are reallocated to the adjacent tile which has the largest overlap with the cabinet shape. The adjacent tile which they have been reallocated to is indicated by the number in brackets.

It can also be seen from Figure C.9 that this process leaves two tiles containing cabinet shapes unallocated (since they cannot be reallocated to an adjacent tile). These tiles have been outlined in red. Such areas will be lost in the grouping process, however this is a relatively insignificant effect.

Figure C.9: Grid squares which overlap the cabinet shape by less than half have been additionally highlighted [Source: Analysys Mason, 2016]



This process will sometimes omit small non-contiguous cabinet areas. A schematic illustration of such a cabinet area is shown in Figure C.10 below.

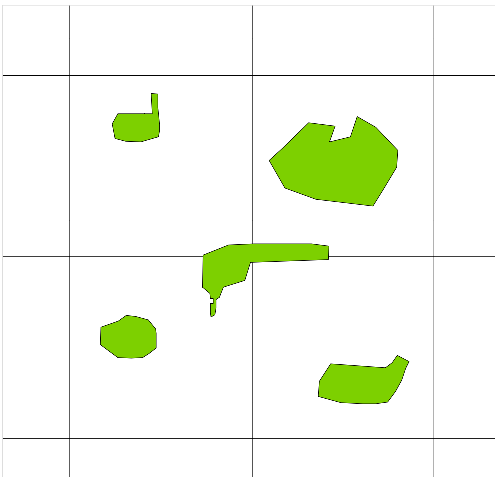


Figure C.10: Schematic illustration of cabinet area which will not be split up or reallocated [Source: Analysys Mason, 2016]

Such cases are accounted for by mapping the original postcodes (or split postcode pieces) to the square tile with which they have the greatest overlap.

Annex D Duct and pole feasibility study

The proportion of reusable duct and pole infrastructure that a USO provider is able to make use of when deploying new wireline infrastructure has a potentially significant impact on the overall cost of deployment. Reusing duct or pole infrastructure could allow for significant savings in capex when deploying the network, but additional rental opex is also incurred over the lifetime of the infrastructure.

This desktop study sought to check the fraction of feeder (E-side) and distribution (D-side) links for which reusable civil infrastructure would be available to the USP(s). This Annex outlines the sample exchanges selected to examine existing duct/pole infrastructure, the data sources and methodology used to establish the coverage of existing infrastructure, and the parameters chosen for use in the model.

D.1 Sample selection

A small sample of exchanges was selected in order to examine the status of the existing duct/pole infrastructure. In consultation with Ofcom, we selected sample exchanges representative of the range in USO premise density,[119] urban/rural geotype and the home nation. Sample exchanges were selected using the following approach:

- For each exchange in the Scenario 3 dataset, total area and average USO premise density was calculated for postcodes containing USO-eligible lines. All the USO postcodes in Scenarios 1 and 2 are also contained within Scenario 3. Since the Superfast scenario is likely to be of less interest and is derived in a different way to the first three scenarios, this was not included in the range of postcodes from which the sample was drawn.
- The following areas were excluded from further analysis:
  - KCOM areas – only Openreach data was available for use in this task
  - areas with USO premises density in USO postcodes of less than 20 premises per sqkm; these areas are unlikely to be viable for wireline technology deployment
  - areas where the USO postcode area was under 4sqkm or over 25sqkm – this ensures that the sample area would have, in terms of further analysis, a significant but manageable size
- The remaining 1463 exchanges were sorted by USO premise density and split into 8 segments. The midpoint exchange was selected for each of the segments.

One rural exchange in the eighth least dense segment was replaced with a rural exchange from Northern Ireland to ensure there was coverage of Northern Ireland. A ninth, rural, exchange in

[119] Total USO-eligible premises within the exchange divided by total area of postcodes containing USO-eligible premises. Note that the denominator is not the total exchange area.

Scotland was also added to the sample, in order to ensure that at least one rural exchange from Scotland was included. The resulting exchange sample is presented in Figure D.1 below.

Figure D.1: Details of sample exchanges [Source: Analysys Mason, 2016]

Segment	Exchange area (sqkm)	USO postcode area (sqkm)	Eligible premises	Eligible premises density in USO areas (per sqkm)	Cabinets	Geotype	Nation	Description
1	19.3	8	1744	231	31	Urban	England	Killingworth, North East
2	25.5	11	1640	144	46	Urban	Scotland	Johnstone, Scotland
3	4.4	17	1907	114	47	Urban	England	Ardwick, North West
4	35.5	24	2257	93	20	Urban	England	Holmewood, East Midlands
5	13.2	12	941	79	3	Rural	England	Roydon, East
6	41.9	23	1569	69	43	Urban[120]	Wales	Bargoed, Wales
7	19.4	12	732	63	11	Rural	England	Yapton, South East
Manual	25.9	24	670	28	1	Rural	Northern Ireland	Dunloy, Northern Ireland
Manual	14.4	12	721	59	5	Rural	Scotland	Fairlie, Scotland

D.2 Methodology and data sources

Having defined the sample exchanges, we next sought to find the percentage of Openreach's network (both feeder and distribution) which could be reused by the USP(s) within those exchanges. This entailed finding the following values, for both the feeder and distribution sides of the network:

- the fraction of a USP network that would be covered by Openreach duct (duct 'coverage')
- the fraction of a USP network that would be covered by Openreach pole[121] (pole 'coverage'[122])
- the fraction of Openreach ducts which are available for reuse by the USP(s) (duct 'usability')
- the fraction of Openreach poles that are available for reuse by the USP(s) (pole 'usability').

[120] This exchange should be classified as rural since inspection of maps of the exchange area show the majority of the exchange area is rural with only a small urban area at the centre (Bargoed village).

[121] Openreach connects every distribution point to the exchange by either using duct or aerial cabling ('pole'), or a combination of both. Duct coverage and pole coverage should therefore add up to 100%.

[122] Duct/pole coverage refers to duct/pole only up to the distribution point.

Coverage values have been established with a desktop inspection of Openreach’s infrastructure records. Duct and pole usability have been approximated using data from two surveys conducted by Analysys Mason for Ofcom in 2009 and 2010.[123] These values are used in the model to establish what proportion of the route required for an incremental wireline deployment (i.e. FTTP GPON, FTTC VDSL2 or VDL LR-VDSL) by the USP(s) could be reused and what proportion could be rented through Openreach’s Passive Infrastructure Access (PIA) product.[124]

In the case of an FTTC deployment, only the feeder side of Openreach’s network is relevant, since it is likely that a USP would make use of Openreach’s existing copper sub-loop network. We would expect the USP(s) to first deploy active FTTC cabinets close to Openreach’s existing passive cross-connect cabinets (i.e. those not upgraded to FTTC). Therefore a reasonable approximation of the proportion of feeder that could reuse existing infrastructure can be estimated by identifying the proportion of routes to existing cabinets that align with existing duct or pole infrastructure.

In each sample exchange, we used MapInfo/Routefinder software to estimate the shortest possible road route from cabinets to their parent exchanges. These routes are referred to below as the Routefinder feeder links.

[✂✂]

Infrastructure records from Openreach were then used to establish what percentage of the Routefinder feeder links are covered by ducts, and what percentage are covered by poles.

In the case of FTTP GPON deployment our modelling uses the simple assumption that in order to pass every premise, fibre would need to be laid down every public road in a postcode area containing USO premises. Therefore the proportion of infrastructure that could be reused in the distribution part of the FTTP GPON network (i.e. beyond the aggregation node) can be approximated with the proportion of public road network that is covered by Openreach’s distribution duct or pole infrastructure.

We were able to inspect Openreach’s infrastructure and estimate coverage using the following three data sources:

- Openreach ‘Infrastructure Discovery’ tool
- Openreach ‘Maps by email’ tool
- extract from Openreach pole catalogue.[125]

[123] *Telecoms infrastructure access – sample survey of duct access*, published March 2009. This was a survey of E-side infrastructure undertaken by Analysys Mason for Ofcom. Eleven different UK cities/towns were selected to represent the diversity of Openreach’s national infrastructure network. Overall, 31 contiguous routes were surveyed, including 817 chambers, 18 206 duct-ends, and 76 street cabinets over a total route distance of 143km. See http://stakeholders.ofcom.org.uk/binaries/telecoms/policy/ductreport.pdf

Sample survey of ducts and poles in the UK access network, published January 2010. This was a survey of D-side infrastructure undertaken by Analysys Mason for Ofcom. 552 chambers and 320 poles in 7 different locations in the UK were examined. See http://stakeholders.ofcom.org.uk/binaries/consultations/wla/annexes/duct_pole.pdf

[124] In reality other infrastructure providers are available but are more relevant to national trunk routes and not to the access network. Therefore this study has focused on Openreach’s infrastructure only.

[125] We also used Google Street View to confirm the level of coverage indicated by the pole catalogue and to establish the existence of any potentially reusable alternative pole infrastructure (e.g. electricity distribution poles).

D.3 Results

D.3.1 Duct coverage

Using Openreach's 'Infrastructure Discovery' and 'Maps by email' tools, we found that almost all of the Routefinder feeder links in the areas that we examined (in both urban and rural exchanges) were covered by existing duct. In a small number of instances there was no duct coverage, however in such cases a nearby route of similar length was identified, which would be able to provide a fully ducted feeder link back to the exchange.[126]

On the distribution side, we found that almost all public roads (>90%) were covered by Openreach duct in urban areas while duct coverage seemed to be closer to 40–50% in rural areas. We note that this is estimated from a relatively small sample and inferred from the presence of route with underground infrastructure in place.

D.3.2 Pole coverage

Aerial cable is most commonly used for distribution in the least dense parts of rural exchanges (and separately for the final drop in some urban and rural areas).

The Openreach pole catalogue provided the most useful data regarding pole coverage. Figure D.2 below shows the percentage of roads covered by existing pole infrastructure. We found that exchanges of an urban geotype typically have a lower coverage (5–10%), while rural exchanges typically have a higher coverage (30–50%). Our cross-check using Google Street View broadly corroborated these values. We did not identify a significant volume of other reusable infrastructure (e.g. electricity distribution) in the areas we sampled.

Figure D.2: Reusable aerial infrastructure by sample exchange [Source: Analysys Mason, Openreach Pole Catalogue, 2016]

Sample exchange	Geotype	Eligible premises density in USO areas (per sqkm)	% of roads in exchange covered by existing aerial infrastructure
NEKI	Urban	231	5%
WSJOH	Urban	144	6%
MRARD	Urban	114	6%
SLHWD	Urban	93	41%
Typical range	**Urban**	**–**	**5–10%**
EARDN	Rural	79	29%
SWQJA	Rural [127]	69	53%

126 This indicates that Openreach's copper and fibre feeder network seems to be fully ducted but that the Routefinder process identified some shorter routes than those currently used by Openreach's networks.

127 The SWQJA exchange in Bargoed, Wales has been reclassified as rural. Although technically urban, it has an eligible premise density more similar to that of the other rural sample exchanges and only a small proportion of the area of the exchange is built up.

Sample exchange	Geotype	Eligible premises density in USO areas (per sqkm)	% of roads in exchange covered by existing aerial infrastructure
SDYPTN	Rural	63	50%
NIDL	Rural	28	50%
WSFAI	Rural	59	8%
Typical range	**Rural**	**–**	**30–50%**

The rural exchange WSFAI has a much lower pole coverage (8%) than the other rural exchanges, though in this case most of the premises seem to be clustered in a single village, rather than being dispersed throughout the exchange area. However, the urban exchange SLHWD remains an exception, with a much higher pole coverage (41%) than the other urban exchanges. This illustrates that the small duct and pole feasibility study being discussed here allows us only to draw general conclusions.

D.3.3 Duct usability

The existence of duct/pole infrastructure does not guarantee that it will be available to USPs through Openreach's PIA product,[128] since it may already be occupied with BT or third-party equipment.

Previous work by Analysys Mason undertaken for Ofcom in 2009 surveyed duct access in Openreach's network.[129] This survey found that, overall, 78% of duct-ends had sufficient unoccupied space to be able to accommodate at least one further 25mm sub-duct or cable.

Unoccupied duct-end space does not necessarily directly translate into *useable* duct space for USPs wishing to use BT's PIA product. This is because:

- a duct might have collapsed or silted up in the middle of a section
- the cable arrangement far into the duct may be such that existing cable cross-over may prevent any further cables being inserted in the duct
- engineering rules may prevent unoccupied space being used (e.g. to limit disruption with other cables in the duct).

These obstacles can be remedied (e.g. through jetting of silted ducts), and therefore the extent to which they would further limit usable space is not known.

128 This is the Openreach product which enables CPs to deploy NGA cables/fibres by sharing BT's ducts/poles. See https://www.openreach.co.uk/orpg/home/products/ductandpolesharing/ductandpolesharing.do

129 See http://stakeholders.ofcom.org.uk/binaries/telecoms/policy/ductreport.pdf

D.3.4 Pole usability

With regards to spare capacity on poles, a 2010 survey by Analysys Mason for Ofcom[130] found that 85% of the poles surveyed could accommodate at least one additional dropwire,[131] and 63% could accommodate double the amount of wires currently installed.

The report also noted that the most critical factor in the ability of existing poles to support new fibre deployment is the loading characteristics of the new fibre, e.g. the diameter, weight and breaking load of fibre cables.[132] This will depend on the specific type of fibre deployed by the USP(s).

D.3.5 Summary

Based on the results above, we have developed a plausible 'typical' case for the overall proportion of a USP's new route that could reuse existing infrastructure. This is estimated as approximately the product of the duct/pole coverage and the duct/pole usability.

Based on inspection of the Openreach maps, we are of the opinion that a USP's feeder network would be likely to be close to fully covered by duct (in both rural and urban geotypes). In a few cases, duct was not present along the calculated Routefinder feeder links, however in such cases a nearby ducted route could be used instead. We consider that such routes, though not optimally efficient (in terms of distance) would introduce insignificant additional rental costs. Ducting was typically present along 90–100% of public roads in urban exchanges and in 40–50% of rural exchanges that we sampled.

As described in Section D.3.3, around 80% of ducted distribution routes in Openreach's network were found to have additional capacity. This therefore seems to be a reasonable central case for the proportion of available duct that could be reused by the USP(s) whose requirements would be low in terms of the number of cables or sub-ducts needing to be accommodated. As described in Section D.3.4, about 60% of poles were found to be able to accommodate double the amount of wires currently installed.[133]

Typical values of duct/pole coverage and usability by geotype and network layer that could be used to inform our cost modelling work are summarised in Figure D.3 below. These form a plausible central case for each geotype which in practice would vary between areas.

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130 See http://stakeholders.ofcom.org.uk/binaries/consultations/wla/annexes/duct_pole.pdf

131 These results were calculated using BT's engineering rules for pole loading. See Section 3.4.4 of the report for details.

132 See paragraph 183.

133 See Section 3.4.4 of the 2010 survey report for a discussion of loading requirements.

Figure D.3: Typical duct/pole coverage and usability factors [Source: Analysys Mason, 2016]

Category	Urban feeder	Urban distribution	Rural feeder	Rural distribution
Duct coverage *(% of route that is ducted by Openreach)*	~100%	90–100%	~100%	40–50%
Duct usability *(% of duct that a CP could use)*	80%	80%	80%	80%
Proportion of route where duct can be reused	**~80%**	**~80%**	**~80%**	**~30%**
Aerial coverage *(% of route that is covered by aerial infrastructure)*	Not applicable	5–10%	Not applicable	30–50%
Aerial usability *(% of aerial that a CP could use)*	Not applicable	60%	Not applicable	60%
Proportion of route where aerial can be reused	**Not applicable**	**~5%**	**Not applicable**	**~25%**

These values for duct reuse are broadly in line with industry consensus as described in Analysys Mason's report for the Broadband Stakeholders Group in 2008.[134] This report accepted that reuse factors of approximately 80% of feeder and 30% of distribution were representative reference values.

[✂✂]

Based on the results and considerations outlined above, in our model base case we have estimated the reusage parameters outlined in Figure D.4 below as 'PIA ducted' and 'PIA aerial'. These are rounded values within the ranges outlined above in Figure D.3.

Figure D.4: Distribution of new route by deployment type used as central case [Source: Analysys Mason, 2016]

Technology	Geotype	Directly buried	Ducted	PIA ducted	Aerial	PIA aerial
FTTC – feeder	Urban	–	20%	80%	–	–
	Rural	–	20%	80%	–	–
FTTP – distribution	Urban	–	15%	80%	–	5%
	Rural	–	45%	30%	–	25%
FTTP – feeder	Urban	–	20%	80%	–	–
	Rural	–	20%	80%	–	–

With respect to FTTC, we have assumed that USPs would be likely to favour a fully ducted feeder network. Therefore we assume that they would make use of existing duct infrastructure where available (as estimated in Figure D.3) and build the rest of their required route as ducted.

134 See Figure 4.20; http://www.analysysmason.com/PageFiles/5766/Analysys-Mason-final-report-for-BSG-(Sept2008).pdf

With respect to FTTP, we assume that in the feeder part of the network the USPs would make similar design choices for the rationale explained above.

Similarly, we assume that USPs would rent existing aerial duct or aerial route where possible (as estimated in Figure D.3) and would use ducted trench for the remainder of the required route. [✂✂]

Annex E Data request

As part of this study, Analysys Mason consulted a number of operators in the UK who have recent experience of fixed broadband network deployments using a variety of technologies. We contacted Openreach as the largest fixed infrastructure owner in the UK. We also contacted the operators involved with BDUK's Phase 3 MTPs where we had a suitable contact.

We asked these operators to provide information on their network architectures and costs. Most operators responded positively and shared information to the extent they were able to do so, subject to confidentiality and time constraints. Figure E.1 below lists the type of information received from operators.

We note that some information was supplied under non-disclosure agreements and therefore no further details are recorded in this document.

Figure E.1: Summary of data received [Source: Analysys Mason, 2016]

Operator	Type of information
Call Flow	• Description of a combined FTTP, FTTC and FWA deployment to a large rural area (1500 premises) including network architecture and some cost metrics • A copy of the Commercial Model Call Flow supplied to DCMS as part of its BDUK MTP application
Cybermoor	• A bill of materials for a sample project • Various supporting documents describing the network roll-out and funding process
Gigaclear	• A bill of materials for a sample project • Information on network architecture and drivers of deployment costs and provided further explanation by conference call
Openreach	• Passive infrastructure data for a sample of exchanges (related to the duct and pole feasibility study described in Annex D) • Wholesale pricing information as published on the Openreach website • Information on network architecture and FTTC asset costs
Quickline	• Information on network architecture, spectrum bands, cell capacity, site types and site ownership
Satellite Internet	• A copy of their Feasibility Update report to BDUK

Annex F Trenching costs

Trench costs are affected by a number of factors, such as soil type, number of ducts, trench size and trenching technology. This Annex provides a brief explanation of the most important factors, and outlines the typical range of values that per m trench/ducting costs can take. This Annex also explains the choice of unit costs for trenching used in our model.

F.1 Factors which drive cost

F.1.1 Direct buried

In some cases ducts are not used and cables are directly buried in the ground. Where this is the case, specific armoured cable is used. This method of deployment can be significantly less expensive than full duct deployment, as it usually only requires a narrow, shallow trench to be excavated in which to install the cable. Alternatively, some cables or flexible ducts can be ploughed.

[✂✂]

F.1.2 Duct size and number

Ducting is the primary method of underground cable installation and, once deployed, it allows for the subsequent installation and removal of cables by a variety of techniques. In the UK, the vast majority of access network nodes and chambers are connected with ducts.

Larger ducts are more expensive. In the UK, ducts are deployed in standard sizes: E-side ducts are usually 90mm in diameter while D-side ducts comprise a mixture of 90mm diameter (close to the cabinet) and 50mm diameter (close to the subscriber premises).

In some cases, sub-ducts (around 25mm diameter in the UK) are deployed inside the main ducts to facilitate the insertion or extraction of cables. Small diameter 'microducts' can also be installed, through which fibre can be blown at a later date.

As the number and size of ducts increases, the trench needs to be either deeper or wider. This increases the cost of excavation and the cost of reinstating of the overlying surface.

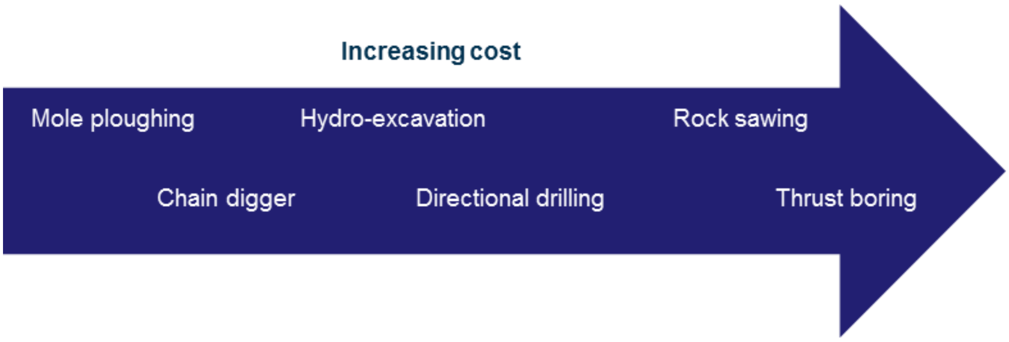
F.1.3 Trenching technology

There are a number of different techniques which can be used to dig trench, including: mole ploughing, chain digging, thrusting, rock sawing, directional drilling and hydro-excavation.[135] Different techniques have different associated costs, and are more or less appropriate for different

135 See the Beca report: *FPP Corridor Cost Analysis – Response to Submissions, Report 4 (Final)* for a fuller description of different trenching techniques. The report was prepared for the Commerce Commission (New Zealand's regulator) and published in December 2015. See https://www.comcom.govt.nz/dmsdocument/13937

trench sizes, soil types and locations. Figure F.1 below shows some of the most common trenching techniques, and their relative cost.

Figure F.1: Trenching techniques by cost [Source: Analysys Mason, 2016]



The range of available trenching technology is strongly driven by the soil/ground type to be excavated as well as the overlying surface and the presence of obstacles (e.g. other utilities, tree routes, foundations). For instance the cost of digging a trench in a tarmacked urban geotype with shallow soil will be greater than the cost of ploughing through a continuous loose grass verge or field.

F.1.4 Other

Other costs to consider include:

- Design and project management costs
  - these may increase where the network architecture is complex
- Wayleaves
  - these may be required when deploying in privately owned land
  - costs may be arise from both wayleave payments and potential delays in obtaining wayleaves
- Planning consent
  - planning requirements vary between local authorities and may be greater if USPs do not have code powers
- Traffic management
  - this varies significantly between different road types and is significantly greater when junctions must be crossed
  - unforeseen circumstances may require a change in deployment strategy
- Presence of other utilities
  - there may be an additional cost associated with avoiding and protecting existing utilities in the vicinity of a new duct or cable.

F.2 Typical per m cost

We have referred to publicly available fixed access LRIC cost models to benchmark typical national average trench/ducting costs:

- Denmark[136] – CATV and fibre access model built by Analysys Mason for the Danish regulator (DBA) in 2010/2011
- New Zealand[137] – copper and fibre access model built by TERA for the New Zealand regulator (ComCom) in 2014/2015
- Norway[138] – copper and fibre access draft model built by Analysys Mason for the Norwegian regulator (Nkom) in 2012
- Belgium[139] – copper and fibre model built by Analysys Mason for the Belgian regulator (BIPT) in 2012.

These models have been chosen as a *starting point* for establishing unit costs, since they are all publicly available sources of nationally averaged costs in comparable counties (both geographically and in terms of labour costs).

These costs can vary significantly between deployment projects due to variations in the technology choice, and due to variation in the other factors discussed above. Figure F.2 shows the variation in the unit cost of trenching for the hardest and softest soil types quoted as well as the separate urban rate (assuming two ducts per trench) in New Zealand which gives an indication of the range that might be expected in the UK.

Figure F.2: Trenching costs for different soil types, assuming two ducts per trench, GBP per metre (nominal 2016 terms) [Source: BECA[140], 2015]

Duct diameter	Trenching technique	Softest soil (GBP/metre)	Hardest soil (GBP/metre)	Urban (GBP/metre)
40–50mm	Mole ploughing	17	–	–
	Chain digger	19	–	–
	Open trench 400 wide	28	–	46
	Directional drilling	26	–	34
	Rock saw	–	70	87
	Thrust boring – impact mole	–	–	70
	Hydro-excavation	–	–	53
110mm	Mole ploughing	25	–	–

136 See https://erhvervsstyrelsen.dk/sites/default/files/media/ed_documentation_pdf.pdf

137 See http://www.teraconsultants.fr/en/issues/TSLRIC-price-review-determination-for-the-Unbundled-Copper-Local-Loop-and-Unbundled-Bitstream-Access-services-in-New-Zealand and http://www.teraconsultants.fr/medias/uploads/TERA-s-report-International-Comparators-2015.PDF

138 See http://www.nkom.no/marked/markedsregulering-smp/kostnadsmodeller/lric-fastnett-aksess/_attachment/3956?_download=true&_ts=13a88566f83

139 See http://bipt.be/en/operators/telecommunication/Markets/price-and-cost-monitoring/ngn-nga-cost-model

140 As part of the development of the New Zealand access model, ComCom commissioned engineering consultancy BECA to produce a report on unit duct/trenching costs See https://www.comcom.govt.nz/dmsdocument/13937 Source data was given in NZD per m, as of November 2015. Data has been inflated with a cost trend of +3.3% (the duct/trenching cost trend used in TERA's model) to 2016, and converted to GBP using a forex of 0.48118 NZD per GBP (average rate extracted from oanda.com on 26 July 2016). All rates are the national average and allow for excavation, duct install, backfill, surface reinstatement, consenting and traffic management. GST is excluded.

Duct diameter	Trenching technique	Softest soil (GBP/metre)	Hardest soil (GBP/metre)	Urban (GBP/metre)
	Chain digger	25	–	–
	Open trench 400 wide	30	–	51
	Directional drilling	38	–	68
	Rock saw	–	74	91
	Thrust boring – impact mole	–	–	99
	Hydro-excavation	–	–	84

As can be seen, for two ducts per trench, costs typically lie within a range of GBP20 per m to GBP70 per m, depending on the duct size and trenching technique. However, the cost increases significantly in urban environments, reaching close to GBP100 per m in the most expensive case.

[✂✂]

The assumptions used in Analysys Mason's study for the Broadband Stakeholder's Group (BSG) in 2008[141] resulted in a national average cost of GBP48/m for duct installation for FTTP and GBP57/m for FTTC. This model represented a national deployment which is likely to be more urban in nature than a USO deployment would be.

F.3 Values used in model

Due to the difficulty in identifying the mix of soil and surface types that would be encountered by the USP(s) we have opted to model a central reference case cost based on an average of: the benchmark values that we have collected from publicly available fixed access network LRIC models for comparable countries to the UK; and values provided by infrastructure owners who responded to our data request.[142] This corresponds broadly to the range of nominal values assumed in Analysys Mason's 2008 BSG report, which could be considered to represent an approximate industry view at the time for a full nationwide deployment.

We have assumed that where ducts are reused they are rented at the price set by Openreach's regulated PIA product. However we also assume that a small cost is incurred in setting up the PIA service and installing cabling over and above that incurred when installing cabling in the USP duct(s).

To account for the uncertainty in the costs of trenching, carried out sensitivity tests:

- A high case representing a 50% increase in unit trenching costs (except where duct space is leased). This is close to the upper end of the range of costs shown in Figure F.2.
- A low case representing an optimistic level of trenching costs. [✂✂]

141 See Figure A.8 http://www.analysysmason.com/PageFiles/5766/Analysys-Mason-final-report-for-BSG-(Sept2008).pdf

142 See Annex E.

Figure F.1: Terrestrial route capex unit cost inputs GBP per metre [Source: Analysys Mason, 2016]

Trenching technique	Low case (2016 GBP/m)	Base case (2016 GBP/m)	High case (2016 GBP/m)
Ducted	15	56	84
Directly buried	10	51	77
Rented	2	2	2

The costs above represent the national average cost for installing two ducts and reinstating the surface as well as the installation of a medium-sized manhole every 500m (to allow for jointing and future maintenance). The same rate is assumed in both the feeder and distribution parts of the terrestrial networks being dimensioned.

Addendum to 'Estimating the cost of a broadband Universal Service Obligation'

6 December 2016 • 2007855-502

1 Introduction

In November 2016, Ofcom received data that enabled it to produce revised estimates for the number of premises that may be eligible for a potential Universal Service Obligation (USO). Since there has been a significant change in the number and distribution of premises in comparison to the coverage data that Analysys Mason used in the original modelling work (documented in our report *Estimating the cost of a broadband Universal Service Obligation*, ref: 2007855-481), Ofcom has asked Analysys Mason to reproduce our analysis for three revised scenarios.

This document should be read in conjunction with that report, which describes in detail the model methodology, its capabilities and its limitations.

It should be noted that in order to carry out this work in a compressed timeframe, we made additional simplifications to input data preparation, and hence the results should be treated as indicative.

Figure 1 below summarises the specification of the re-stated scenarios that Ofcom asked Analysys Mason to run. Scenario 2 from the original modelling work has not been included because this is no longer being investigated by Ofcom.

Figure 1: Scenarios for broadband USO technical specification [Source: Ofcom, 2016]

	Scenario 1	Scenario 3	Superfast scenario
Download sync speed[1]	Sync speed 10Mbit/s – best efforts	Achieving at least a similar distribution of actual speeds as a current fixed service with 10Mbit/s predicted speed	Sync speed 30Mbit/s
Upload sync speed	None defined	1Mbit/s	6Mbit/s[2]
Latency	None defined	Medium Response Time	Fast Response Time
Contention ratio/ committed information rate (CIR)	None defined	50:1	10Mbit/s
Eligible premises in previous version	*1.6 million*	*3.5 million*	*5.5 million*
Eligible premises in current version	*1.4 million*	*2.6 million*	*3.5 million*

1 Sync speed is the maximum speed that the line between a subscriber's router and its parent exchange is capable of sustaining in the absence of any other traffic or traffic management policies.

2 This is the median for all superfast broadband (SFBB) lines, including Virgin Media.

2 Data processing

We processed the revised scenario data so that it could be fed into the stylised cost model in a similar way to the original scenarios (as described in Annex B of our main report).

It is important to note that as part of our data processing for these re-stated scenarios we restricted the new model runs to just those postcodes which already existed in the original datasets. This was in order to avoid carrying out further time-consuming geoanalysis work. This does reduce the accuracy of the stylised cost model results.

Below, the key features of the restated scenarios are compared to the previous versions of these scenarios.

2.1 Scenario 1

As before, we infilled some mostly minor gaps in the dataset, relying on data from the previous version of the Superfast scenario,[3] including:

- Infilled missing exchange data: 54
- Infilled missing cabinet coordinates: 5
- Infilled missing postcode coordinates: 135
- Where there was no cabinet ID but <100% exchange-only lines (EoLs), we updated the EoL eligible lines and non-EoL eligible lines to assume that all lines were EoLs: 514
- Missing cabinet distances infilled using straight-line distance (capped at 10km): 937
- Missing exchange distances infilled using straight-line distance (capped at 10km): 181 637, although we note that these are not directly used in the model.

Figure 2 below shows that the number of lines in Scenario 1 has reduced to 1.4 million, from 1.6 million in the previous version. Restricting the modelling to only those geographical areas for which we had already carried out the required geoanalysis means that 1% of records are discarded, corresponding to 2% of postcodes and 1% of lines. The results post-processing process scales the total deployment costs up, to account for these records being discarded.

	Old Scn1	New Scn1
Total records	252 490	224 058
Total records (after discard)	252 490 (100%)	221 033 (99%)
Total unique postcodes	210 233	190 619
Total unique postcodes (after discard)	210 233 (100%)	186 259 (98%)
Total unique lines	1 607 237	1 368 077
Total unique lines (after discard and grouping)	1 606 754 (100%)	1 351 333 (99%)

Figure 2: Key scenario input statistics – revised Scenario 1 [Source: Analysys Mason, 2016]

3 Also, infilling from old Scenario 3 data would capture a further 5284 unique postcodes, representing 16 222 lines. Given this low number, Scenario 3 data was not used to infill the input data for this analysis.

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2.2 Scenario 3

As before, we infilled some mostly minor gaps in the dataset, relying on data from the previous version of the SFBB scenario,[4] including:

- Infilled missing exchange data: 94
- Infilled missing cabinet coordinates: 97
- Infilled missing postcode coordinates: 623
- Where there was no cabinet ID but <100% EoLs, we updated the EoL eligible lines and non-EoL eligible lines to assume that all lines were EoL: 63 493
- Missing cabinet distances infilled using straight-line distance (capped at 10km): 1339
- Missing exchange distances infilled using straight-line distance (capped at 10km): 262 032, although we note that these are not directly used in the model.

Figure 3 below shows that the number of lines in Scenario 3 has reduced to 2.6 million from 3.5 million in the previous version. Restricting the modelling to only those geographical areas for which we had already carried out the required geoanalysis means that 6% of records are discarded, corresponding to 12% of postcodes and 3% of lines. The results post-processing process scales the total deployment costs up, to account for these records being discarded.

	Old Scn3	New Scn3
Total records	430 056	360 735
Total records (after discard)	460 056 (100%)	340 440 (94%)
Total unique postcodes	371 586	309 005
Total unique postcodes (after discard)	371 586 (100%)	292 021 (88%)
Total unique lines	3 542 695	2 609 736
Total unique lines (after discard and grouping)	3 542 022 (100%)	2 544 306 (97%)

Figure 3: Key scenario input statistics – revised Scenario 3 [Source: Analysys Mason, 2016]

2.3 Superfast scenario

As before, we infilled some mostly minor gaps in the dataset, relying on data from the previous version of the Superfast scenario, including:

- Infilled missing exchange data: 119
- Infilled missing cabinet coordinates: 35
- Infilled missing postcode coordinates: 2488
- Where there was no cabinet ID but <100% EoL, we updated the EoL eligible lines and non-EoL eligible lines to assume that all lines were EoL: 726
- Missing cabinet distances infilled using straight-line distance (capped at 10km): 1332

[4] Also, infilling from old Scenario 3 data would capture a further 5284 unique postcodes, representing 16 222 lines. Given this low number, Scenario 3 data was not used to infill the input data for this analysis.

- Missing exchange distances infilled using straight-line distance (capped at 10km): 425 078, although we note these are not directly used in the model.

Figure 4 below shows that the number of lines in the Superfast scenario has reduced to 3.4 million from 5.5 million in the previous version. Restricting the modelling to only those geographical areas for which we had already carried out the required geoanalysis means that 12% of records are discarded, corresponding to 12% of postcodes and 4% of lines. The results post-processing process scales the total deployment costs up to account for these records being discarded.

	Old SF	New SF
Total records	586 811	524 988
Total records (after discard)	586 811 (100%)	462 777 (88%)
Total unique postcodes	493 786	444 803
Total unique postcodes (after discard)	493 786 (100%)	393 560 (88%)
Total unique lines	5 494 597	3 528 594
Total unique lines (after discard and grouping)	5 494 362 (100%)	3 389 090 (96%)

Figure 4: Key scenario input statistics – revised Superfast scenario [Source: Analysys Mason, 2016]

3 Results

Figure 5 below summarises the total deployment costs estimated by the stylised cost model for the restated scenarios, compared to those calculated by the previous model. This suggests that the restated set of eligible premises in Scenario 1, Scenario 3 and the Superfast scenario are cheaper to serve for all technologies compared to the eligible premises in the original version of the model.

Figure 5: Total deployment cost (GBP billion, 2016 real terms) [Source: Analysys Mason, 2016]

Technology	Old Scn1	New Scn1	Old Scn3	New Scn3	Old SF	New SF
FWA – sub-1GHz	2.0	1.7 (-13%)	4.8	3.8 (-21%)	29.9	19.6 (-34%)
FWA – 5.8GHz	1.9	1.6 (-13%)	4.0	3.2 (-20%)	20.7	13.7 (-34%)
FTTC VDSL2	1.7	1.6 (-10%)	2.2	2.0 (-10%)	2.8	2.3 (-18%)
FTTC LR-VDSL	1.4	1.2 (-12%)	2.0	1.8 (-10%)	2.5	2.0 (-17%)
FTTP	7.2	7.2 (-1%)	8.5	8.0 (-7%)	9.6	8.8 (-8%)
Lowest-cost (access network only)	**1.2**	**1.0 (-12%)**	**1.8**	**1.6 (-12%)**	**2.4**	**1.9 (-18%)**

Technology	Old Scn1	New Scn1	Old Scn3	New Scn3	Old SF	New SF
Lowest-cost (including core network)	**1.2**	**1.1 (-12%)**	**1.9**	**1.6 (-12%)**	**2.5**	**2.0 (-20%)**
Number of eligible premises (million)	*1.6*	*1.4 (-15%)*	*3.5*	*2.6 (-15%)*	*5.5*	*3.5 (-36%)*
Number of eligible postcodes (000s)	*210*	*191 (-9%)*	*372*	*309 (-17%)*	*494*	*444 (-10%)*

Figure 6 shows that the deployment cost per premises passed increases in each of the three scenarios. This is because the number of eligible premises in each restated scenario has fallen more significantly than the area requiring coverage (e.g. as expressed in terms of number of postcodes containing eligible premises). This means that the network assets have not reduced between the old and restated scenarios in the same proportion as the number of eligible premises.

Figure 6: Deployment cost per premises connected (GBP, 2016 real terms) [Source: Analysys Mason, 2016]

Technology	Old Scn1	New Scn1	Old Scn3	New Scn3	Old SF	New SF
FWA – sub-1GHz	1524	1562	1682	1807	6812	6958
FWA – 5.8GHz	1466	1506	1402	1530	4723	4878
FTTC VDSL2	1346	1426	790	964	630	804
FTTC LR-VDSL	1090	1127	704	856	562	723
FTTP	5632	6536	3011	3793	2173	3119
Lowest cost (access network only)	922	950 (+3%)	644	768 (+19%)	535	680 (+27%)

Figure 7 summarises the annualised cost of deploying and operating the network for each technology and for the lowest-cost technology mix.

Figure 7: Annualised cost (GBP million, 2016 real terms) [Source: Analysys Mason, 2016]

Technology	Old Scn1	New Scn1	Old Scn3	New Scn3	Old SF	New SF
FWA – sub-1GHz	1063	929	2601	2067	17 071	11 200
FWA – 5.8GHz	1019	893	2143	1733	11 763	7807
FTTC VDSL2	336	301	462	405	586	470
FTTC LR-VDSL	281	246	422	368	537	432
FTTP	959	936	1173	1069	1348	1209
Lowest cost (access network only)	**265**	**233 (-12%)**	**396**	**340 (-14%)**	**507**	**403 (-21%)**
Lowest cost (incl. core network)	**313**	**273 (-13%)**	**455**	**385 (-15%)**	**701**	**512 (-27%)**

3.1 Lowest-cost technology mix

Figure 8 summarises the proportion of premises covered by each technology if the lowest-cost technology (as measured in annualised cost terms) is deployed in each modelled area. FWA continues to be the highest-cost technology in annualised terms in each modelled area and so does not form part of the lowest-cost technology mix.

Figure 8: Lowest-cost technology mix by scenario (according to annualised cost) [Source: Analysys Mason, 2016]

	Old Scn1	New Scn1	Old Scn3	New Scn3	Old SF	New SF
FWA – 5.8GHz	–	–	–	–	–	–
FWA – sub-1GHz	–	–	–	–	–	–
FTTC VDSL2	75%	74%	80%	80%	84%	83%
FTTC LR-VDSL	20%	21%	15%	11%	11%	10%
FTTP GPON	5%	4%	5%	9%	5%	7%

3.2 Core network costs

Figure 9 shows the national costs calculated for the core network for both the original and restated premises datasets.

Figure 9: Core network costs (GBP million, 2016 real terms) [Source: Analysys Mason, 2016]

	Old Scn1	New Scn1	Old Scn3	New Scn3	Old SF	New SF
Connection capex	46.7	38.7 (-17%)	53.1	41.7 (-21%)	120.8	68.9 (-43%)
Annual rental	43.2	35.8 (-17%)	54.1	41.3 (-24%)	181.4	102.4 (-43%)
Annualised cost	47.9	40.0 (-16%)	59.4	45.6 (-23%)	193.6	109.4 (-43%)

The core network costs (connection, annual rental and the annualised cost) behave intuitively: the decrease in each scenario reflects the smaller total number of subscribers in each exchange.

The savings are larger in Scenario 3 and the Superfast scenario, reflecting the relatively larger number of premises and larger CIR requirement.[5] This means that a larger portion of the overall core network costs for each exchange are variable and hence more savings are available when the number of subscribers is decreased.

5 CIR in the core is 0.5Mbit/s for Scenario 1, 1Mbit/s for Scenario 3 and 10Mbit/s for the Superfast scenario.

4 Conclusions

The magnitude of the costs estimated by the stylised cost model is different from those in the original modelling work, reflecting the updated scenario data. However, the restated results do not lead us to conclude that any updates are required to the key findings of our original report.