Costs for Digital Communications Infrastructures

A Cost Analysis of the UK's Digital Communications Infrastructure options 2017- 2050

Commissioned By

NATIONAL INFRASTRUCTURE COMMISSION

Final Report

This report has been commissioned by the National Infrastructure Commission from Prism Business Consulting Ltd and Tactis, to inform the National Infrastructure Assessment.

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Stefan Stanislawski for draft review and additional comments on the international comparisons

The various Network Operators who participated in the operator engagement stage and the survey.

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1. Executive Summary.

1.1. Background and Purpose.

The National Infrastructure Commission provides the government with impartial, expert advice on major long-term infrastructure challenges. Once a parliament the NIC will publish a National Infrastructure Assessment (NIA) and hold the government to account for delivering it. The NIA will analyse the UK's long-term economic infrastructure needs, outline a strategic vision over the next 30 years and set out recommendations for how identified needs should be met. The first NIA will be published in 2018. One of the areas it covers is digital communications infrastructure.

The NIC has therefore commissioned two projects to analyse the costs and benefits of the various infrastructure options. The outputs and findings will be highly influential in devising the recommendations for the NIA. It should be noted that the cost and benefit analysis overall figures are not directly comparable.

This study, the Cost Analysis, produces design and cost reference models, validated against anonymised 'real life data' from the UK market and referenced against international comparisons to determine the most accurate costs and comparisons for the key technologies available to build this infrastructure. The validated information is then used as the baselines for 'what if' modelling of various technical and commercial options to understand their impact on the economic value of each approach.

1.1.1. Objectives

The objectives of this piece of work were:

- To obtain the most accurate, independent and up to date information on the costs of technology options- through modelling designs in different geographic and demographic circumstances, using reference costs from industry and suppliers.

- To gather evidence that informs the debate surrounding the deployment and operating costs of future, realistic digital infrastructure options in the UK- through validating these designs and costs via an online operator survey of key and influential providers actively delivering infrastructure

- To mitigate the effects of the Technology, Media and Telecoms (TMT) sector being a fast-moving environment- by a focus on the infrastructure components that have a longer life-cycle and undertaking 'what if' analysis on identified trends

- To ensure that equal consideration is given to innovative ways of addressing the issues, including alternative commercial models, re-use and sharing of infrastructure assets, as well as new technologies- by applying use cases to the validated models produced

- To translate appropriate best practice from elsewhere into the UK context to understand what 'world-class' means for the UK- through cross-referencing with relevant international comparisons, benchmarks and other international expertise.

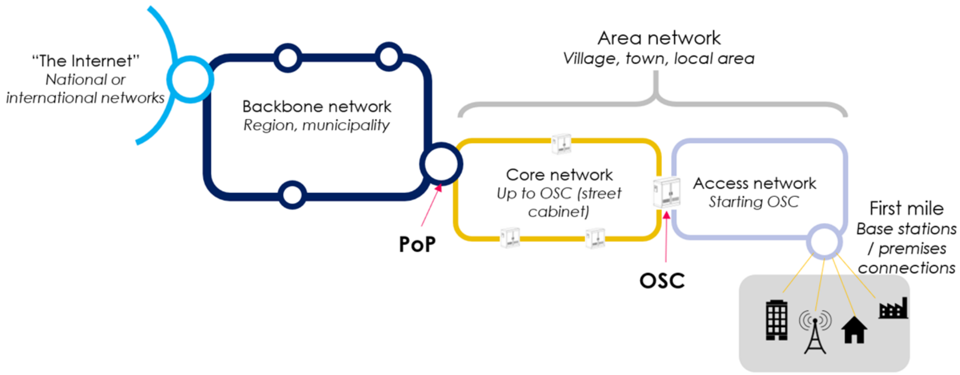
1.2. Scenarios 'fit for the future'

A key consideration of the study was the role that different currently available technologies could play in developing a new digital communications infrastructure fit for the UK's needs through to 2050. The technologies were broadly grouped as follows to define the technology scope of the study:

- Copper in the form of G.Fast delivered over Fibre to the Distribution Point (FTTDp) and DOCSIS 3.1 delivered by cable operators over co-axial cable

- Fibre in the form of Fibre to the Premises (FTTP) with all its variants- e.g. Fibre to the Building-(FTTB), Point to Point fibre connections (PtP), and connections via passive fibre distribution (GPON), etc.

- Wireless in the form of Fixed Wireless Access (FWA) technologies, together with a consideration of the role 5G could play in 'overlaying' local access provision (5G to the lamp-post)



The study scope focused on the role of these technologies in delivering the Area Network; comprising (as shown here) an Access Network to Premises and the local Core Networks to connect them back to the national 'backbone' digital communications infrastructure.
This was considered as the area where the greatest industry debate existed and the development of alternative approaches was focused. The scope of costs considered was therefore limited to those to the right of the Point of Presence (PoP) in the diagram.

The capability of the technologies was then considered to produce 5 potential scenarios:

1) 100% FTTP premises coverage with no re-use of existing infrastructure (the 'theoretical case' for baseline costing)

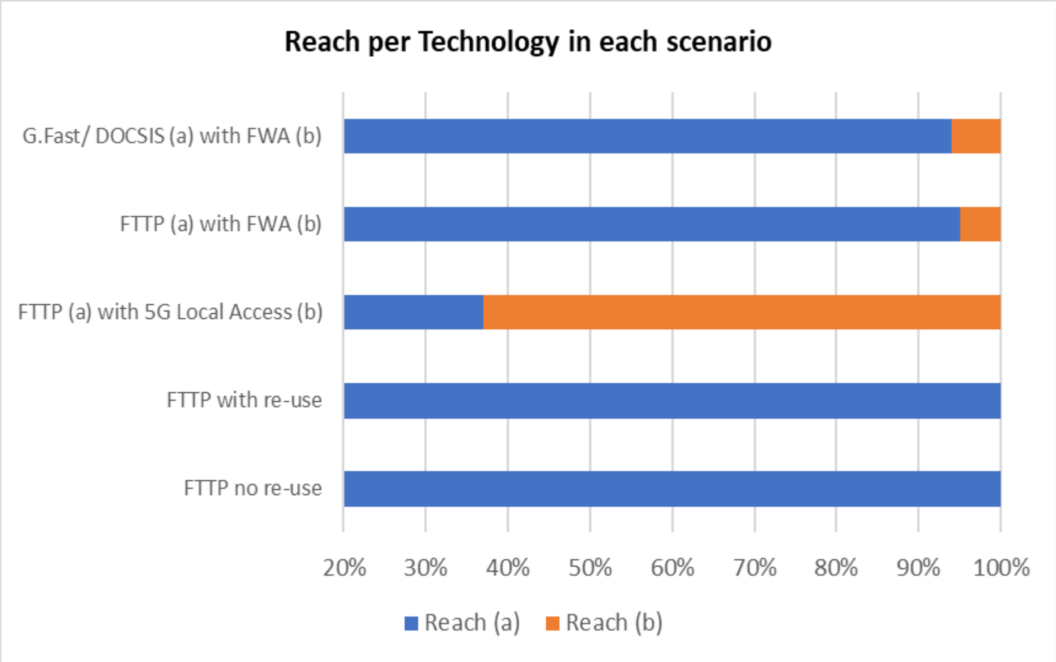
2) 100% FTTP premises coverage with re-use of physical infrastructure

3) Fibre to 5G premises access nodes- e.g. on lamp-posts (the adoption of 'disruptive' technology)

4) FTTP with FWA/ Long-Range VDSL in rural areas (consideraton of economic constraints on FTTP)

5) Mixed Technology Deployment (to upgrade the UK's existing infrastructure), such as G.Fast over FTTDp and DOCSIS 3.1 over co-axial cable.

Based on modelling these scenarios and using test designs (as described below), the costs for reaching 100% of premises was produced, using various technologies in each scenario as shown below:



(NB: the reach percentages for scenario 3- Fibre to 5G local premises access nodes- assumes that all premises in dense and semi-urban areas are served through 5G access; FTTP is deployed to the remaining premises)

Using the design and performance assumptions defined in Appendix A, the performance received by premises under each scenario from the technologies would be:

- In scenarios 1 and 2, 100% of premises are reached with FTTP and could receive 1GBps and beyond.
- In scenario 3, the 63% of premises with 5G access could receive up to 500Mbps and possibly more, depending on contention and transit capacity. The 37% with FTTP could receive 1GBps and beyond.
- In scenario 4 the 95% reached by FTTP could receive 1GBps and beyond. The remaining 5% of FWA premises could receive up to 100MBps at the costs and designs modelled, with the capability to expand with improvements in FWA to 'match' 5G capability.
- In scenario 5, the design maximum for the 94% (plus) of G.Fast and DOCSIS premises assumes up to 300Mbps download. The remaining 6% of FWA premises have the same characteristics and future capability as described for scenario 4 above.

Following analysis of these scenarios, three variants were then considered:

- The introduction of a Universal Service Obligation (USO) that requires premises to have a minimum download capability of 100MBps
- The difference on the cost of scenario 3 if a 5G core infrastructure was already in place for other services, making 5G costs for premises access 'incremental'

- The possibility and impact of subsequently moving to an FTTP infrastructure following on from G.Fast/ FTTDp and DOCSIS3.1 in scenario 5.

These were assessed at high level in the 'What If' section of the report, with a summary below.

1.2.1. Approach of the Study.

1.2.2. Modelling the UK

The study used design, modelling and costing tools for digital communications infrastructure that have already been used extensively elsewhere with great success; most notably in France, where the same approach has underpinned the national development of new infrastructure; and more recently in many parts of sub-Saharan Africa.

This modelling approach varied from techniques used by similar previous studies. These adopted segmentations into geotypes by line length, amongst other technical criteria. However, this does not reflect the rollout approach that would be adopted by an operator; an area would be chosen, consisting generally of a technical 'centre' or hub, from which service would radiate. Areas would be prioritised and selected based more on premises density than line length.

An alternative standard techno-economic analysis of broadband infrastructure was adopted, where the team modelled a 10% sample of all UK premises (3.1 million properties) across 40 Local Authority Districts with varied geographic and demographic conditions. These were structured around 6 key geotypes, ranging from 'extreme rural' to 'dense conurbations', using the 6 regional classifications of Local Authority Districts defined by the UK Government Department of the Environment, Food and Rural Affairs (DEFRA).

It is important to note that this segmentation of geotypes means that urban and rural locations are mixed; albeit in every case, premises were 'clustered' by density (as described in section 2.3.1 below). An example of this is Bristol, which is included in the sample areas under geotype 4 due to the mix of urban and rural locations in the area. The impact of this is that various cost profiles in each geotype do not follow the same patterns as seen in other analyses. Nonetheless, this approach provides an effective simulation of how infrastructure would be developed and rolled out, enabling a good estimation of costs to be determined.

Further, the study has concentrated on developing 'pure costs'. This means that all externalities have been deemed out of scope, such as (but not limited) to:

- Regulatory considerations
- The attractiveness of one technology over another in investment terms
- Planning regulations and procedures
- Wayleaves and other consents
- Opex and support overheads accounting principles within operators' overall business structures
- Market conditions

It is recognised that whilst these aspects of the overall deployment are not considered, some may be significant; however, the net effect of many of these factors will be the same across all the scenarios described above (with the exception of investment attractiveness). This means that the cost estimates provided are capable of comparison as pure technology costs.

1.2.3. Cost analysis by Scenario in each Geotype

Cost models were then produced and run for the 3.1 million sample residential and SME premises across the 6 geotypes for each of the 5 scenarios. Total cost profiles were developed using input cost data, validated against actual data from UK and international projects and component vendors. Capital and operating expenditure was included. Total cost of ownership was calculated using Opex based on a 30 year 'minimum life expectation' of the physical infrastructure assets and an 8 year expectation for active equipment components. A Weighted Average Cost of Capital (WACC) was applied to all Opex, through applying a discount rate of 9.3%. This is in line with Ofcom's current approach, as shown in Appendix E and also at section 3. As such, the WACC applied to the analysis can be deemed as 'nominal'.

The output figures were then tested, prior to aggregating them and applying suitable weightings to produce realistic cost projections for 31 million UK premises being reached under each of the 5 scenarios.

One other additional consideration should be taken into account when looking at the 'pure costs' of each scenario and the 'comparative positions' between them. Scenarios 1 to 4 are based primarily on new networks deployed in some (or none in the case of scenario 1) of existing UK infrastructure. This means they could be deployed by various operators. Scenario 5 however, relies heavily on the use of both infrastructure and network technologies that already exist and are deployed. As such, they are very likely to be much more relevant to principal existing operators, such as Openreach or Virgin Media. This has no material impact on Capex- but does on Opex, as support and maintenance costs will likely be distributed across both 'old' and 'new' platforms.

As it is outside of the scope of this study to comment or hypothesise over how operators might identify and treat such Opex elements in their accounting principles, 'pure' Opex costs have been considered that relate directly to the support of the 'new' technologies under consideration. However, the analysis recognises the existence of the current copper networks that would be utilised in this scenario and is based on the assumption that the copper network remains (i.e. there is no 'copper cutover'); hence the related support costs are currently separately accounted for. Therefore only 'pure costs' relating to the incremental support of a G.Fast solution over FTTDp have then been applied entirely to the infrastructure described in scenario 5 - and may therefore represent a portion of the operating costs allocations of operators, particularly incumbents.

1.2.4. **Review against 'Real-Life' Experience**

An online survey was developed to validate the cost model findings and gain feedback from a focus group of key operators and interested related parties with valuable knowledge and 'real life experience' of the digital communications infrastructures as defined or key components within it.

The survey was also used to gather their views and opinions on alternative and 'disruptive' deployment techniques, 5G rollout and other 'key issues' known to be considered as contributing factors to infrastructure cost analysis.

Feedback was also invited from Ofcom, the Infrastructure Projects Authority and operators who had not participated in the survey.

All feedback received was reviewed and following validation, incorporated into the analysis.

1.2.5. What If analysis

Various factors that were believed to have a potentially disruptive impact on the cost model or approach were reviewed and where possible, the quantum of impact was assessed.

1.2.6. Reference to International Comparisons

Relevant international benchmarks and comparisons were then sought to provide a further reference point for the cost model outputs.

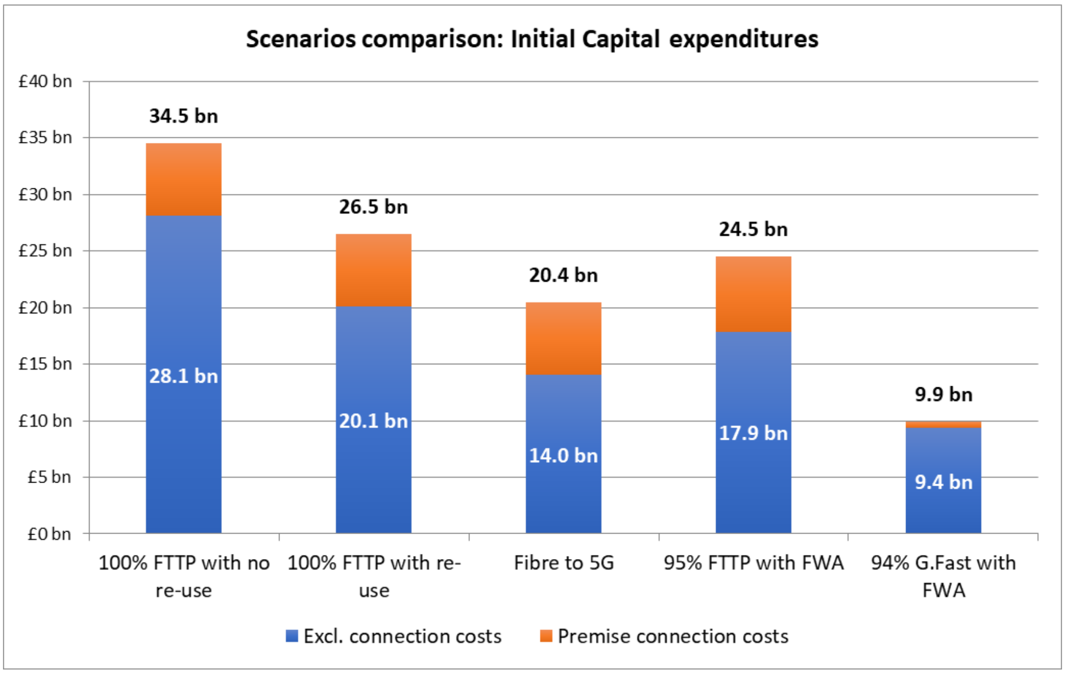
1.3. Results of the Analysis

Details of the results can be found in section 3.

Regarding 5G as described in scenario 3, given the current development stage of the strategy for 5G and the associated technology development (modulation choices, synchronisation issues, spectrum, etc) we would like to draw the attention to the fact that the assumptions on which the analysis is based are still preliminary. Regarding the other scenarios, the costs are much more certain since the technologies have reached a higher level of maturity.

1.3.1. Total UK Cost of each Scenario: Capital

A summary of the capital costs associated with each scenario is shown below.

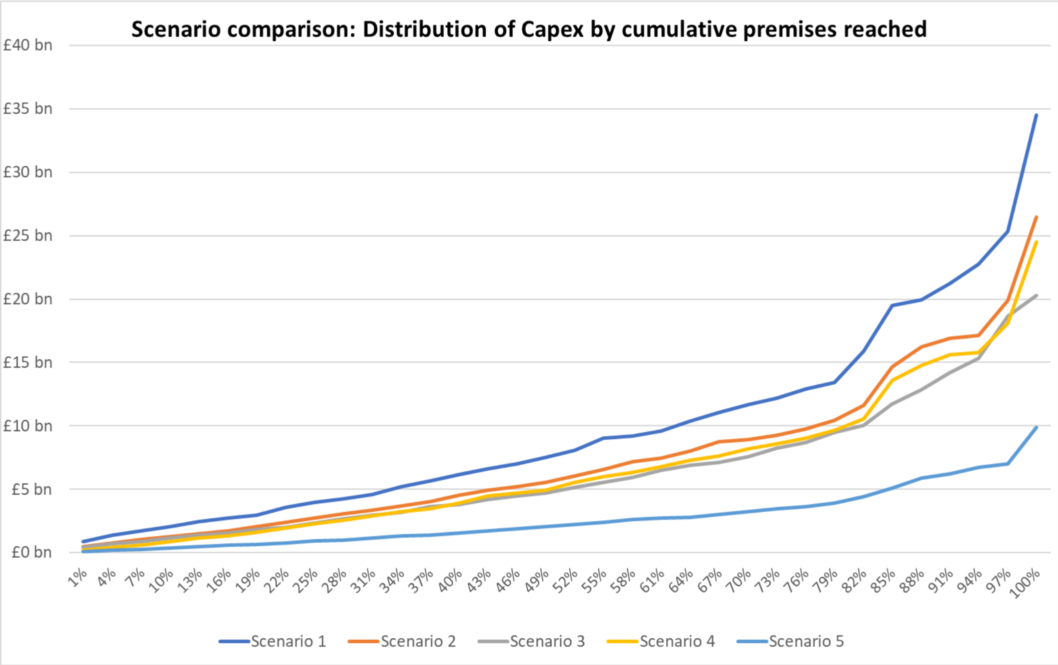


This graph breaks down the capital for local core network and access infrastructure (blue)- which would be borne by the network operator- and typical premises connections costs (orange)- which would typically be borne by the service provider.

The analysis indicates capital costs for the infrastructure (excluding premises connection costs) of £20.1bn for 100% premises reach using FTTP and assuming utilisation where possible of existing infrastructure, compared with £9.4bn by using G.Fast over fibre extended to the 'green cabinet' Primary Cross Connection Points and beyond them to the Distribution Points (FTTDp).

Clearly, a solution using existing copper as well as existing physical infrastructure will require much lower capital costs (£9.9bn to reach 94% of premises) compared with one both completely replacing copper with fibre and providing new infrastructure (£34.5bn to reach 100%).

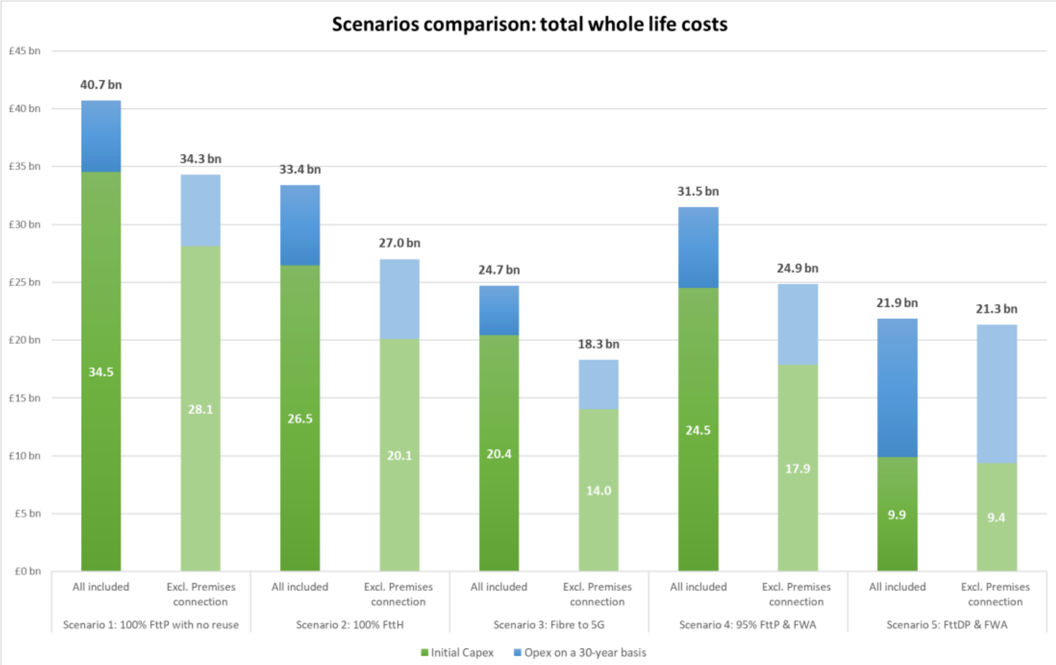
In all scenarios, the capital costs rise significantly with the number of premises reached, as would be expected. The graph below shows that this is broadly consistent across all technologies, in proportion with the total capital spend:



In line with trends identified in the deployment of previous technologies, there are marked changes in the gradient of cost at around 78% and again at 97% premises reach.

1.3.2. Total UK Cost of each Scenario: Whole Life Costs

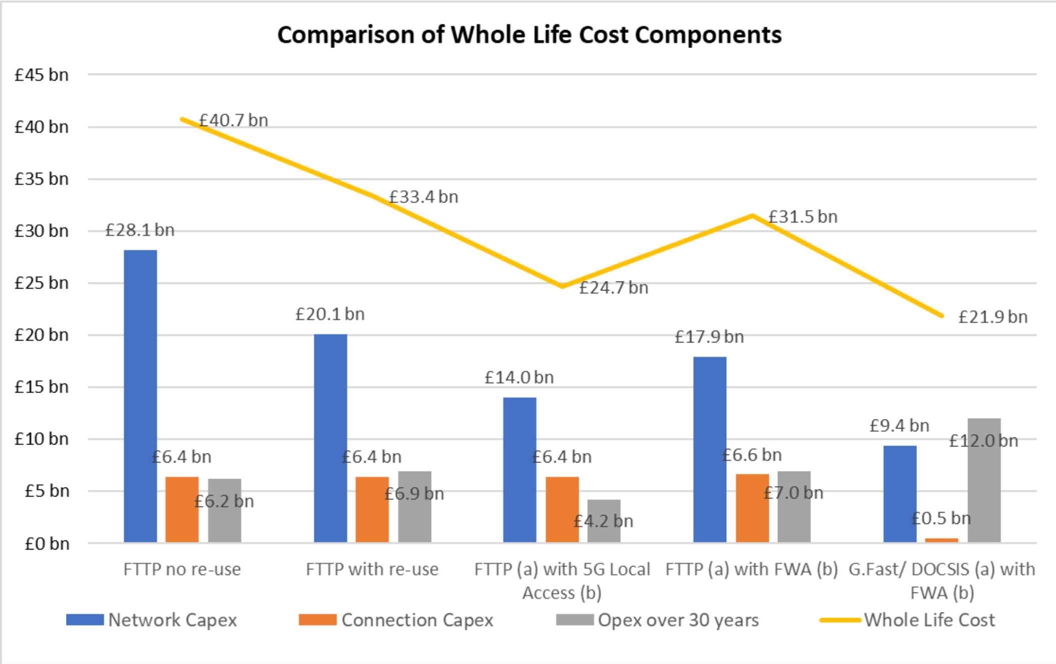
Inclusion of operating expenditure for the 30-year projection of the study provides a whole life cost for each scenario. Comparison of these results indicates significantly less variance between the scenarios with just the Capex detailed above:



The operating cost (Opex) implications of supporting a copper infrastructure for another 30 years is significantly higher than fibre. There are also significant Opex implications relating to FWA; these arise from higher levels of maintenance and licensing. There would also be high rental costs to FWA operators for backhaul provision to base stations; however to maintain consistency between the scenarios for comparison, these have not been included. Instead, provision has been made in the associated Capex of these scenarios for the deployment of fibre to base stations.

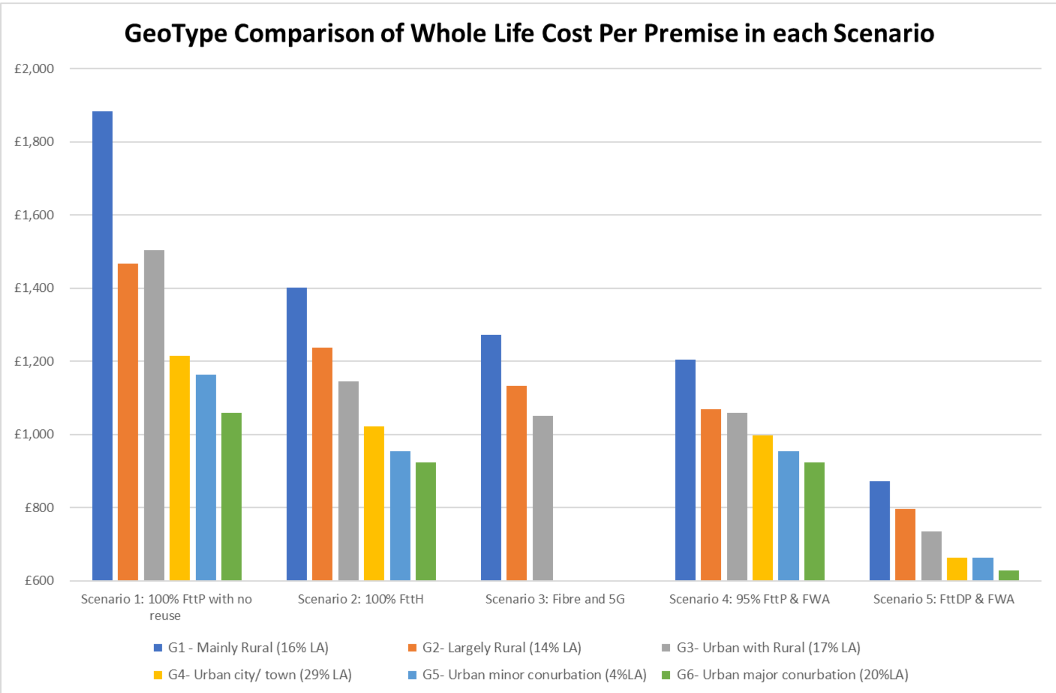
Over the entire time horizon of the report, the whole life cost of scenario 5- using G.Fast over FTTDp with FWA for the final 6% of the population - is £21.9 bn compared with scenario 2 - delivering 100% FTTP using existing infrastructure- at £33.4 bn. These costs represent the initial Capex, 30 years of discounted Opex, together with Capex for active technology refresh- across both the infrastructure and the connection to all premises within reach.

The breakdown of these cost components is compared in the alternative depiction below:

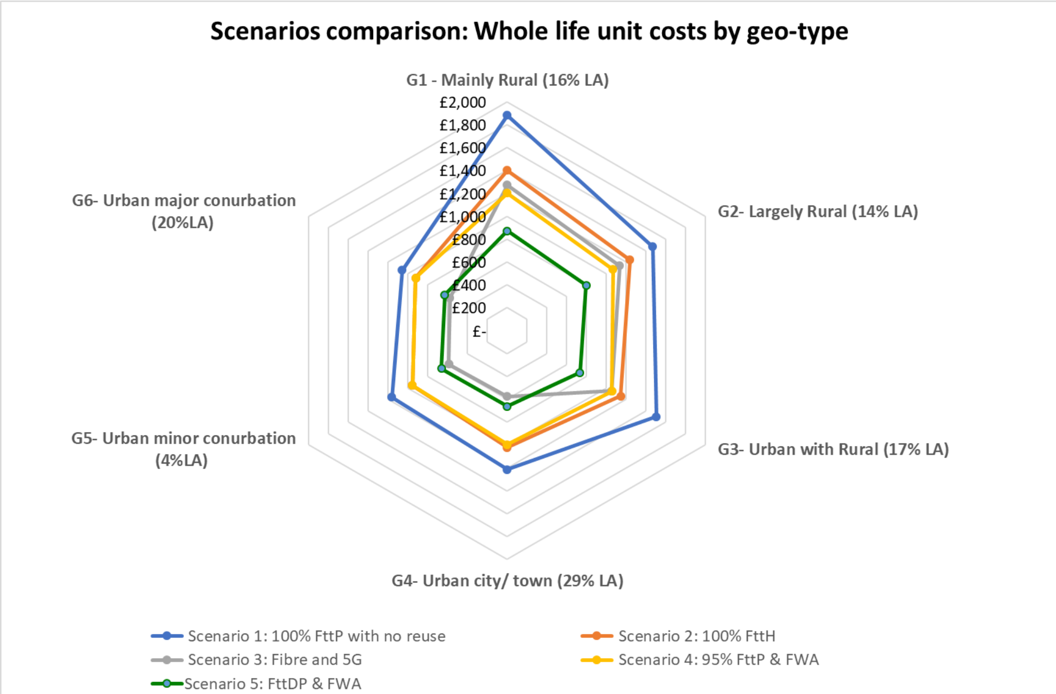


1.3.3. Variation in Premises Costs

Analysis of the whole life cost per premises highlights the significant variation between geotypes, ranging from £1,882 in scenario 1 for geotype 1 to £628 in scenario 5 for geotype 6:



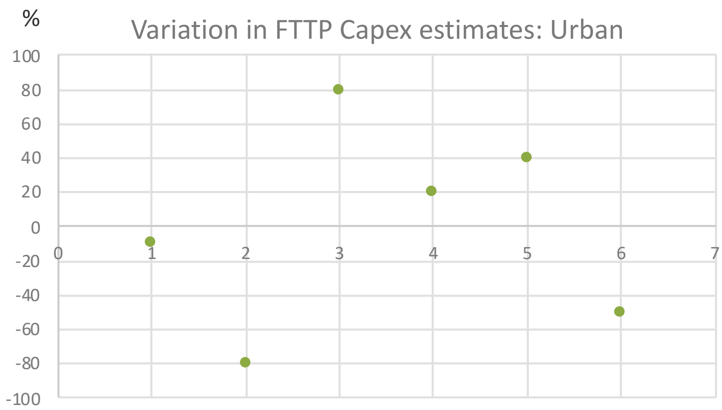
This is clearly driven primarily by premises density, as shown on the geotype 'radar' diagram below. This indicates the heavy cost burden of reaching the final 4-8% of premises with any digital communications infrastructure capable of supporting speeds exceeding 100Mbps, using any fixed technology.



1.3.4. Feedback and Review

- The results of the online survey broadly validated the cost model data, within reasonable levels of tolerance (generally 10-20%). The biggest variance revolved around the capital costs of FTTP provision, as shown below:

Six survey respondents believed there would be a difference from the FTTP Capex costs modelled for an urban infrastructure. The graph shows the percentage (on the y-axis) by which they considered them to be over (+) or under (-) estimated.
The average of their responses is a 0% variation on the modelled costs



This variance was due to the FTTP reference information provided for the survey being the sample test designs produced for the baseline modelling around scenario 1; most operator experience involved re-using infrastructure in some form and hence gave feedback more in line with Scenario 2.

Respondents also commented on the significant reductions in capital that can be achieved through re-use or sharing of physical infrastructure, whether Openreach or others.

Full results of the survey, along with charts showing the variance of responses, can be found at Appendix F of the Report.

Further feedback was also received on the drafts of the report from Arqiva, BT, the Infrastructure Projects Authority and Ofcom. Along with the operator responses, these were all used to review the logic and input data to the models and refine the outputs.

In particular, this feedback helped refine input costs and assumptions regarding:

- Capacity and dimensioning assumptions in the architecture
- Minor Capex input cost adjustments
- Some Opex costs from further 'real life' data relating to 5G, FWA and G.Fast; this includes Openreach experience with FTTP support.
- Deployment of construction and installation crews and the impact on rollout times

1.3.5. Comparison of the Options

The key financial indicators were then compared between scenarios. This can be found in Section 4.1. Broadly, the comparisons identified that:

- G.Fast over FTTDp can provide access to 94% of premises of the other scenarios for much lower capital; however, based on the performance assumptions used in the modelling, it cannot reach the final c.6%, which would require an alternative technology. It also assumes the operator has access to the existing copper or co-axial infrastructure to achieve the costs profiled.

- The whole life costs of 100% FTTP infrastructure deployment are approximately a third greater than G.Fast- especially in scenario 2 with physical infrastructure re-use or sharing, where the overall whole life cost is £33.4bn, comprising Capex of £26.5bn and Opex of £6.9bn. This is £11.5bn greater than FTTDp where the overall whole life cost is £21.9bn, comprising Capex of £9.9bn and Opex of £12bn.

- Capex rises significantly as premises reach increases. The last 5% of premises have Capex costs on average 4 times higher than the premises around the median.

- Comparisons of modelled rollout durations were also made. Re-using infrastructure reduced FTTP rollout by at least 20%, from 15 to 12 years. G.Fast was modelled at taking 7.5 years to reach 95% of premises, which corroborated Openreach's own stated figures for 10m premises by 2020.

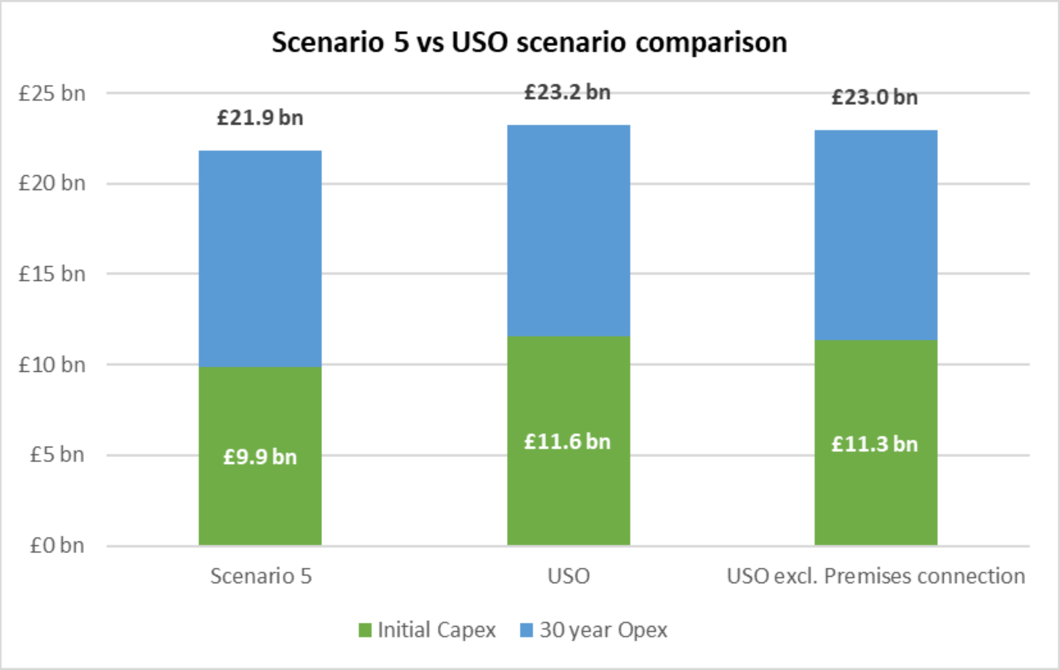
- 5G Access offers a credible option for areas with high premises density and allows a 're-allocation' of Capex to less dense areas. Scenario 3 demonstrates this with £20.3bn of Capex for 63% reach of UK premises with 5G access and FTTP for the remaining 37%. Whole Life Costs of £24.5bn also make it highly credible against the other scenarios. The challenge will be that availability of a commercial rollout is likely to be significantly beyond the timescales quoted above.

- FWA provides a more immediate solution using wireless; however, high Opex makes it a less attractive long-term proposition, with average annual Opex costs per premise of £64, nearly double that of FTTDp/ G.Fast at an average of £37 and three times higher than that of FTTP, with an average of £18.

1.4. Further analysis.

1.4.1. Changing the Universal Service Obligation (USO) Threshold

The current government plans to introduce a USO of 10Mbps download speed for 100% of UK premises (where the provision cost is under £3k per premises). This is achievable using a mix of all the currently available technologies. If the USO is set at 100 Mbps, then around an additional £1.3bn would be required to provide the connectivity to the last 6% of the population using FTTP, as shown below:



1.4.2. 5G Development

The Fibre to 5G scenario described an alternative to fixed access for dense urban premises based on the following principles:

1) 5G would be used principally for connecting premises to a local radio distribution point in a point-to-multipoint configuration; thus providing a faster access deployment than premises connection using fibre and rising column distribution points.
2) Small cell networks would be deployed with very low distribution radii, with significant channel re-use. These would typically be on street furniture such as lamp-posts to avoid a 'substitutional cost' of local poles.
3) Fibre would be provided to each 'lamp-post', as high speed, high capacity, low-latency transit would be an essential component of the network.
4) Also, this transit network architecture should be designed as a 'ring topology' network between Optical Sub-loop Connections (OSC) and possibly each small cell distribution point. This would be to ensure in-built resilience for high capacity and low-latency IP traffic, as well as providing 'self-healing' capability.
5) Fibre break-out wcould be provided at each small cell location, enabling connection of further small cells for other purposes.

The cost impact of this approach is a reduction in Initial Capex vs. a full FTTP scenario (assuming re-use), to £20.4bn from £26.5bn, representing the difference in cost between fibre as far as the lamppost rather than to the premises.
The whole life cost is the second lowest, slightly higher than FTTDp.

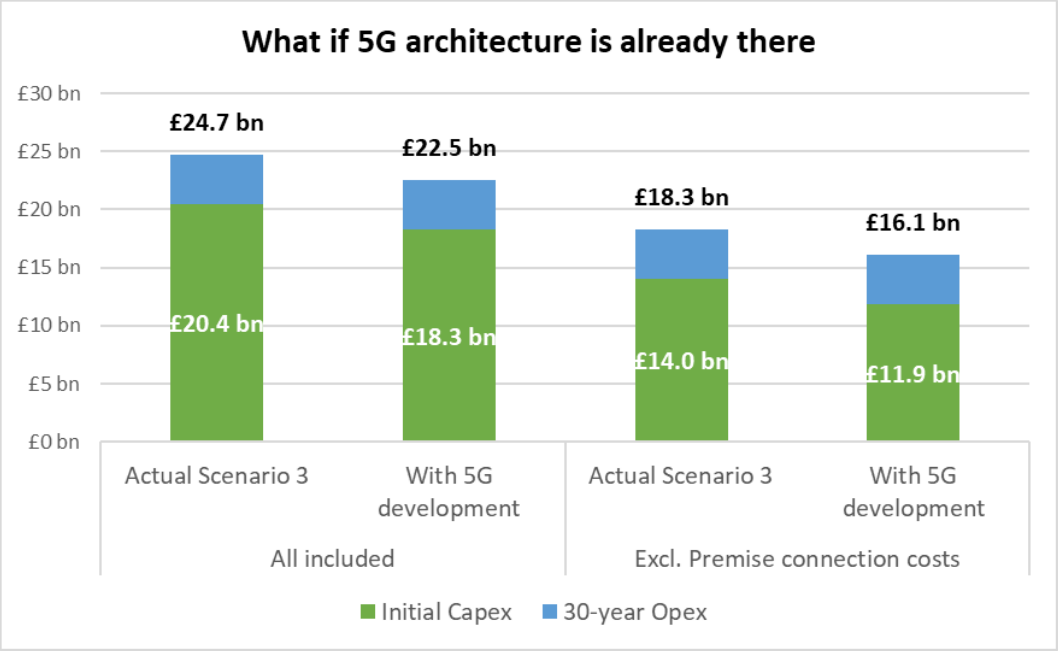
The key challenge of 5G technology is that it is still in development. It also has a Capex requirement double that of G.Fast.

However, this assumes all deployment costs of the 5G architecture are attributed to this one 'use case' for 5G. Whilst this approach is necessary to determine a 'pure' comparative cost against other scenarios it is also highly improbable, as the business cases for the other services and capabilities available through a 5G infrastructure are likely to be more compelling to operators, particularly MNOs.

If the provision of fixed wireless access to premises via 5G was added to 5G architecture already in place for these other purposes, then the incremental costs would only be:

- The provision of additional small cells on existing broadcast locations to run the fixed access frequencies (assuming locations existed every 200m for the other services)
- Provision of the CPE devices as described in scenario 3.

The corresponding incremental Capex and Whole Life Costs would then look like this:



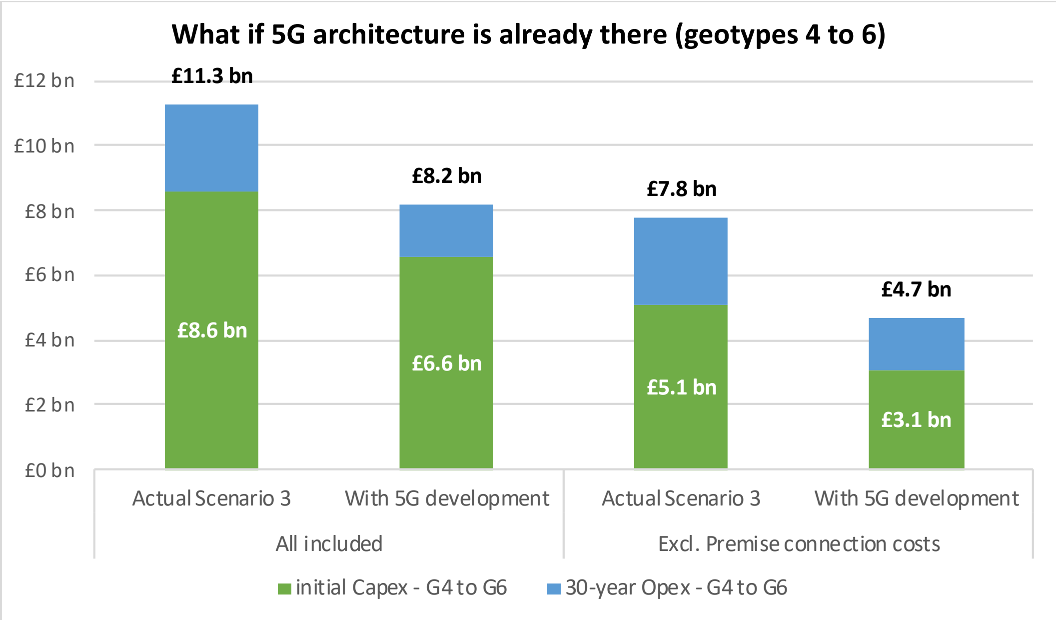
Overall, this represents about a 7% cost reduction on whole life costs across all geotypes, and 10% when removing connection costs too.

There are two reasons why costs do not drop even more:

- Customer Premises Equipment (CPE) comprises the majority of the total modelled cost, while fibre core network is relatively cheap (notably compared to the access network to premises which is absent in this scenario); secondly, the cost reduction only occurs in geotypes G4 to G6, since the model only implements 5G in these more urban areas.

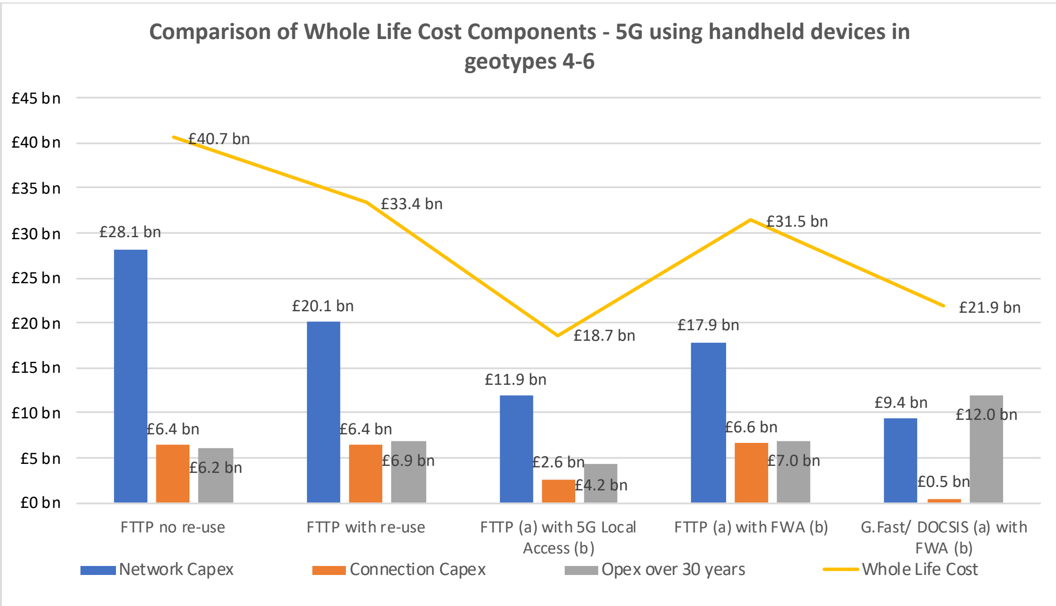
- If CPE is removed, on the assumption that users will connect directly to the local small cell via 5G devices, around 60% of the initial Capex is not required.

- A better way of appreciating the level of change is to focus on geotypes G4 to G6, where 5G is deployed in the scenario. As displayed in the graph below, within urban geotypes the cost reduction reaches 15% and up to 22% when removing premise connection costs.



This assumes that the core network, including a resilient fibre ring, is provided to every base station. The initial Capex is limited to additional small cells at every base station site for premises connections, with CPE also removed in the ''Excl. Premise connection costs' figure above.

On a 'like for like' basis with the other scenarios, the whole life costs for Fibre to 5G become the lowest. The comparison would then look like this:



It is important to note that this adaptation of scenario 3 is reliant on the availability and affordability of 5G devices and the assumption ‘5G enabled set-top boxes’ would become available. This may have an unpredictable effect on managing the rollout of a Fibre to 5G infrastructure.

1.4.3. Switching from FTTDp to FTTP

The appeal of deploying an FTTDp network and then switching to FTTP a few years later is that it provides a relatively cheap upgrade in the short run (to FTTDp) while paving the way for an even faster technology in the longer run.

Revisions were made to the modelling, which indicate that this would be more expensive than both FTTP and FTTDp because of several factors:

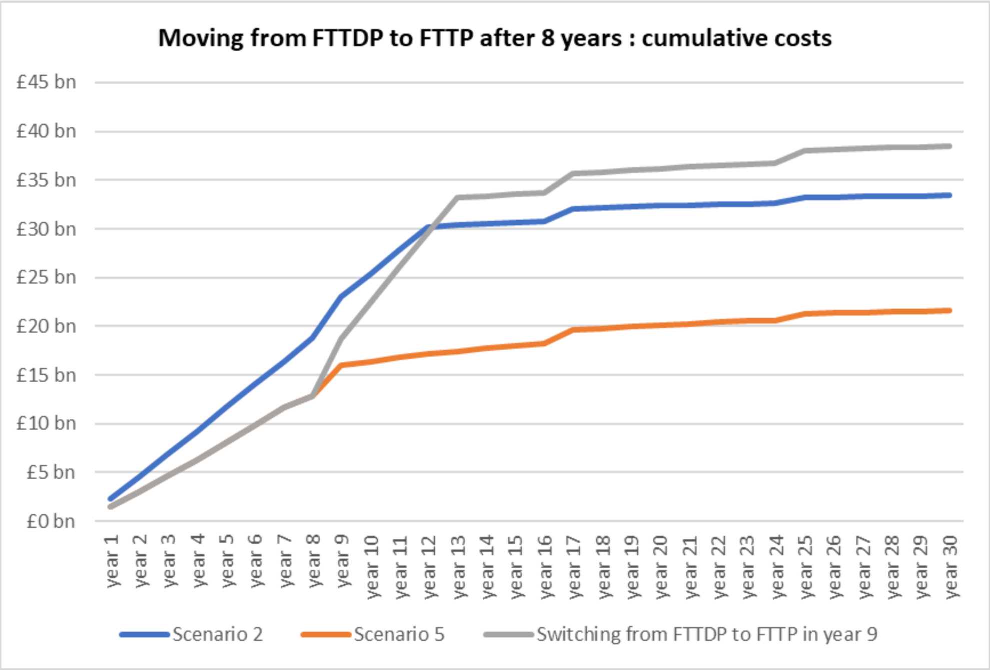
- FTTDp requires higher Opex than FTTP. Therefore, during the number of years before switching to FTTP, the yearly expenses would be higher than it would have been with FTTP in the first place.

- Deployment of G. Fast and DOCSIS devices are sunk costs which would not be reused in an FTTP network. Moreover, removing the devices would cost extra money.

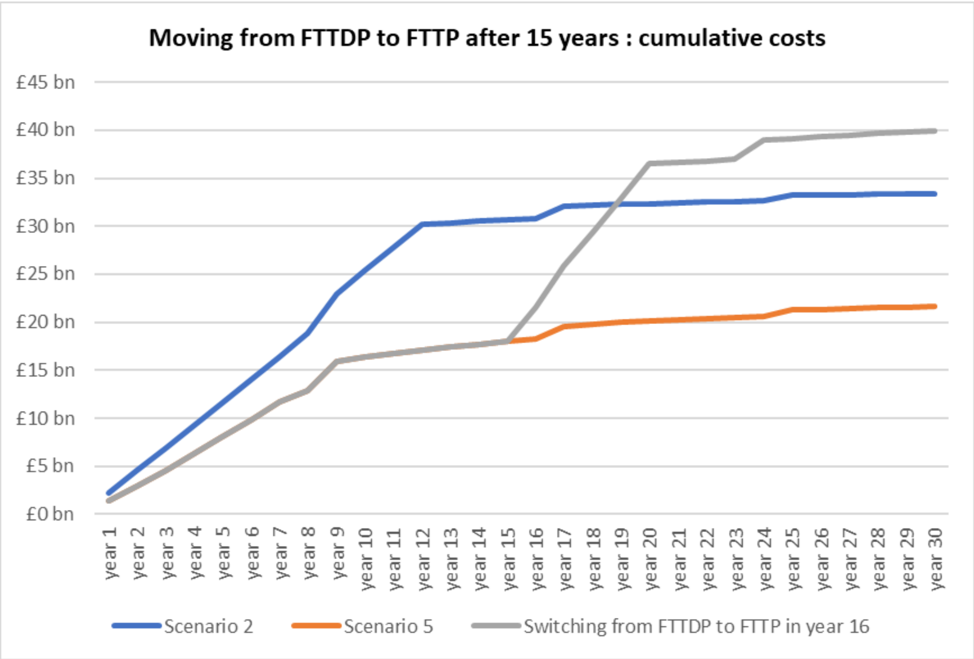
- An FTTDP deployment requires a lower fibre count overall than FTTP. FTTDp can be provided with just a couple of fibre pairs per Distribution Point, while an FTTP network following the same premises distribution needs 40 (assuming one Distribution Point serves up to 40 premises). The cost of installing this additional fibre amounts to £1.8 billion.

In conclusion, switching from FTTDP to FTTP rather than deploying FTTP right away incurs approximately a £460m fixed cost together with a Capex of £1.8bn on additional fibre, whether as part of the FTTDp rollout or the transition to FTTP, plus a yearly £550 million opportunity cost because of higher Opex,

The two diagrams below illustrate a comparison of moving to FTTP 8 years and 15 years respectively after having started an FTTDp network. It is assumed that building the remaining FTTP network would take 5 years, to remain consistent with rollout hypotheses.
The diagrams compare the cumulative whole life costs over the time period. The extra cost incurred by switching technology clearly appears on the curve. On the first diagram, in year 13 –after all Capex has been expended – “technology switch” is 15% more expensive than scenario 2 (£38.5bn versus £33.4bn).



A similar pattern appears when switching to FTTP after 15 years, with an even slightly higher cost:



1.4.4. Re-use of the FTTC Architecture

The ability to re-use the FTTC architecture that has been deployed could help to significantly reduce the costs of FTTP deployment and to accelerate FTTP rollout. In the FTTP design, a transport network is built to an OSC (Optical Street Cabinet) and a distribution network is built from the OSC to the premise. Between 10-15% of the cost of deploying FTTP comes from the transport network hence a 10-15% reduction in Capex can be achieved if the FTTC fibre can be completely reused.

The same considerations should be extended to any technical standards and specifications relating to FTTDp. For example, if a sufficient fibre count is provided in the core network cables to each DP during the initial provision of FTTDp then this will greatly facilitate any subsequent transition to FTTP as described above.

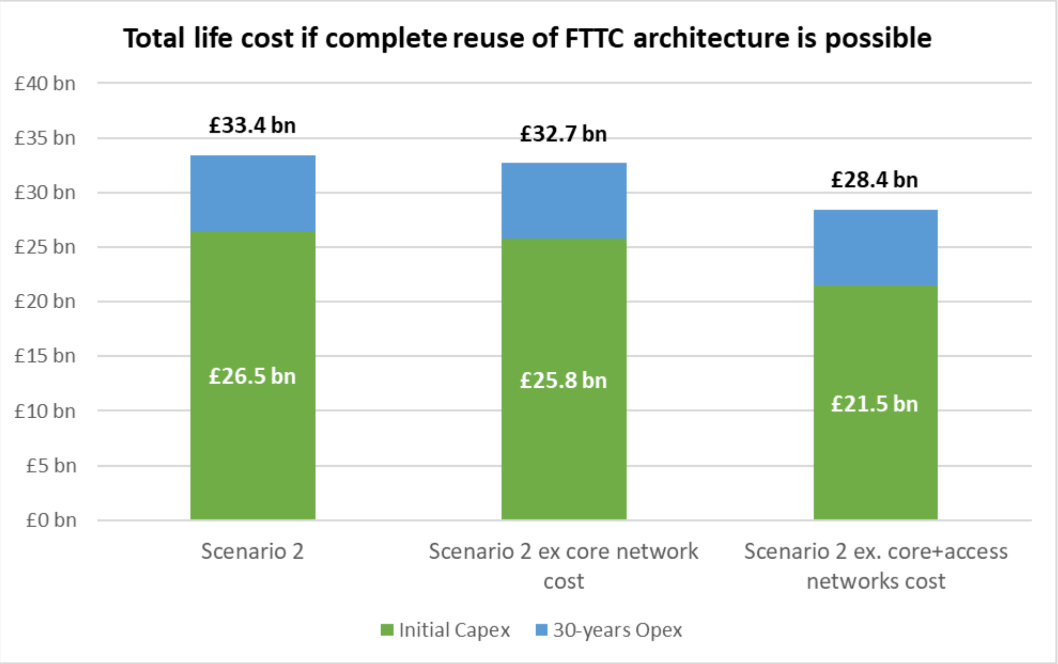
Impact Example of sufficient fibre count existing for FTTP

The following graph models the hypothetical saving in fibre provision on scenario 2 if:

a. Sufficient fibre count exists from the OCN to OSCs (Cabinets)- from FTTC architectures (which reduces core networks Capex)-

b. Sufficient fibre count also exists from OSCs to DPs- from FttDP architectures (which reduces both core and access networks Capex)-

and compares these to the original scenario 2 estimates.



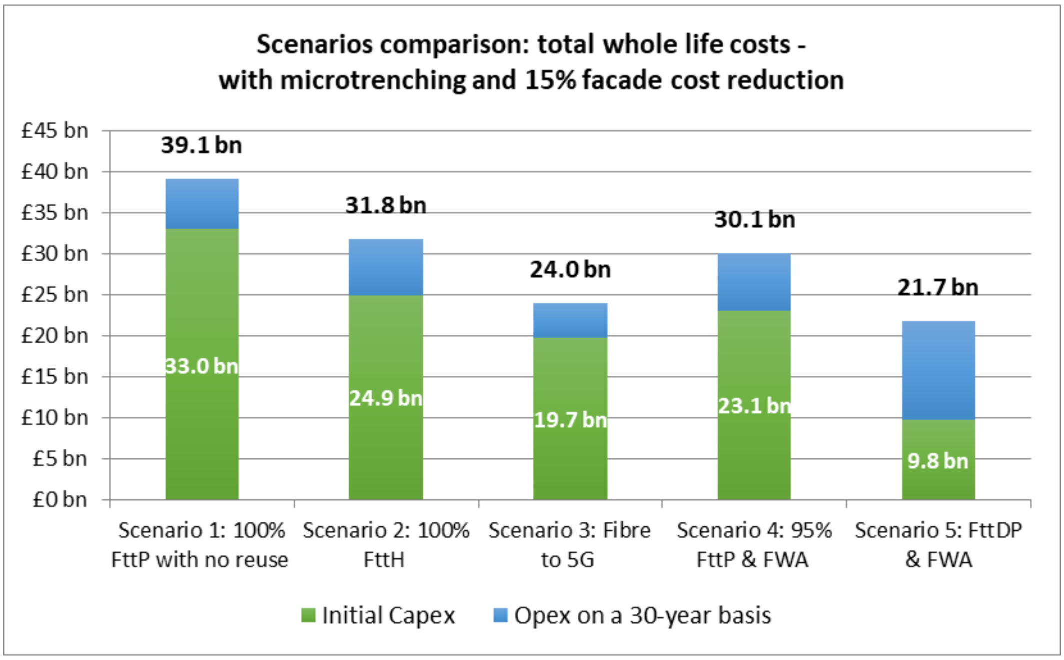
As can be seen, there is a dramatic variation in the Capex required for scenario 2.

However, further granular analysis would be needed on this alternative scenario before it could be effectively validated. This would include the impact of substituting the G.Fast device (DSLAM) with a fibre router capable of delivering FTTP and simply providing new fibre between the DP and each premise.

1.4.5. Impact of Different Construction Techniques

Given a significant proportion of FTTP rollout capital is in civil construction, innovative duct laying techniques have been researched and developed. The most successful is micro- or slot-trenching although there are some local authorities that do not favour this method. This method however has been proved to reduce the relevant elements of build costs by as much as 40%, mainly through laying 2 to 3 times more duct and fibre per day than traditional techniques. Alternative techniques include the use of building facades and other premises access approaches.

Applying a combination of these new approaches to civil construction could have the effect of reducing overall Capex by around 5%. Modelling this in section 5.1 produces the following revised Whole Life cost comparison:

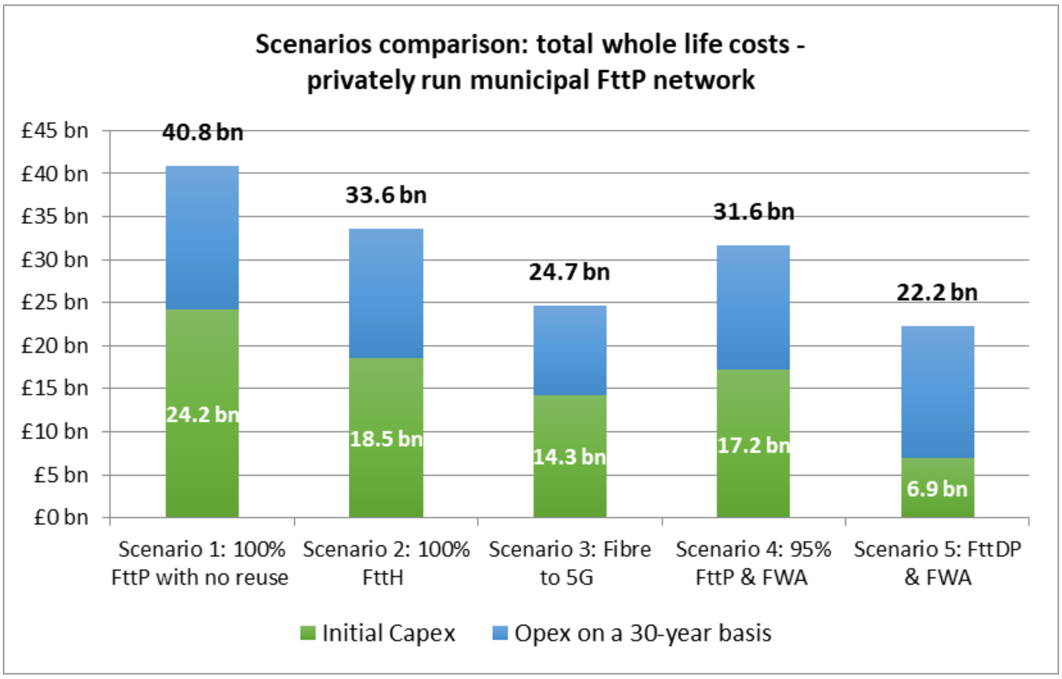


1.4.6. Impact of Different Commercial Models

Build costs could also be reduced by:

- ‘Self-build’ schemes, particularly popular in rural areas where operators find deployment ‘economically unfeasible’. An internationally recognised success story of this is B4RN in the North of England. We expect that the cost of deploying self-build schemes in the most rural environments can be reduced to around a £600 average Capex cost per premise.

- Public sector/ municipal/ utility company involvement in developing or providing infrastructure, often in Joint Venture or ‘Arm’s Length’ Special Purpose Vehicles, or through concession or other contracting arrangements for long term use of assets. All these dramatically reduce the risk and capital burden on FTTP (and other technology) business cases. Using this approach, a Capex reduction of 35% could be achieved but at the expense of up to a 2% per year increase in Opex. Whilst whole life costs would remain very similar to those modelled, Capex would fall as shown below across scenarios 2, 3 or 4- depending on the technology approach adopted by the operator and public-sector/ utility partner:



1.4.7. International Comparisons.

Other EU countries were identified as being the most relevant and representative, in particular Portugal, Ireland and France. Several key components of the study findings were compared where data was available. These can be seen at Section 4.3 but in summary:

- The Capex and whole life costs are broadly in line with the modelled figures.
- Countries which have focused on re-use/ sharing of physical infrastructure, or have invested previously in ensuring robust civil infrastructure for future deployment (e.g. Portugal) have both reduced deployment costs considerably and accelerated rollout.
- Cost benchmarking should be considered with caution since planning and deployment rules vary between countries. However, the initial Capex cost can vary from £160-240 in the densest areas, leading to much higher numbers as density falls (greater than £1,200 seen in very rural environments).

1.5. Conclusions

Based on the outcomes of the analysis, modelling and comparison of options, the study has drawn three key conclusions:

1.5.1. FTTP costs approximately 30% more than G.Fast over a 30-year period

Assuming similar levels of re-use for both technologies (i.e. scenarios 2 and 5), the whole life costs of the infrastructure (i.e. excluding connection costs) are £33.4bn for FTTP and £21.9bn for FTTDp- assuming ‘infill’ for FTTDp of c.6% using FWA.

The key differences are:

- A Capex-heavy FTTP approach versus an Opex-heavy FTTDp one, in relative terms
- Performance levels of 1Gbps designed download versus a modelled 300Mbps (with 6% ‘infill’ achieving 100Mbps).

The variant scenario exploring a transition from FTTDp to FTTP indicates that whilst it offers a migratory path, it is also likely to incur in the region of £2.3bn of additional Capex and c.£550m of additional Opex per year over a 30-year period.

1.5.2. Alternative Construction and Commercial Models can make a significant impact

The breakdown of capital costs for each scenario in section 3 shows that access network costs are the most significant factor- and civil construction is the largest component of those costs. The impact of sharing civil infrastructure is an estimated reduction in the capital costs from around £34bn to around £26bn, as can be seen from the difference between scenarios 1 and 2. The percentage of FTTP Premises Passed can be extended further by also adopting construction techniques such as micro trenching and use of other utility infrastructure, liberating at least 5 to 15% of the build capital as modelled above.

Different commercial models as described in section 5 also reduce the capital and often operating cost of the infrastructure by utilising shared physical assets. It is difficult to project the overall cost reductions, as these would be tempered by the commercial arrangements between operators and asset owners. Nonetheless, the modelled assumptions in section 5 indicate that network build costs represent 75-85% of the total capital requirement for a FTTP network- with the civil component between 52 and 60%.

Hence even at low estimates of 15% reduction in civil capital costs (allowing for an additional transfer of 10% to Opex for rental or concession charges), this could reduce the Whole Life costs for every fixed network component by a further 5-10%.

Whilst the availability of local authority ducts may be limited and patchy throughout the UK, other utility infrastructure could be utilised in similar ways, such as water, electricity, road and rail.

1.5.3. Non-Fibre technologies provide cost-effective capability to achieve 100% coverage

G.Fast, DOCSIS and Fixed Wireless Access can provide credible access to achieve 100% coverage of premises with at least 30Mbps capability, rising to 100Mbps by 2020. These are most likely to have benefit as follows:

- G.Fast/ FTTDp for premises within 200 metres of the distribution point (DP), in both urban and rural environments. The modelled 94% premises reach of all UK premises demonstrates the capability of the technology to extend 100-300Mbps services at low capital impact, as shown in scenario 5 (£9.9bn)

- DOCSIS in urban environments can provide a further reduction on capital cost at these speeds, with end-device costs at around £100 instead of £370 for a G.Fast network device. Whilst there will be significant competitive roll-out of DOCSIS alongside G.Fast (or FTTP), its extended reach beyond 200m makes it a credible technology for extending coverage beyond the capability of G.Fast.

- FWA in rural environments can extend coverage of 30Mbps to 100Mbps services even further, effectively reaching near-100% coverage through deployment of base stations. However, this comes at a cost, as FWA Opex is high at an average of £64 per premise (across scenarios 4 and 5), due significantly to higher licencing, site rental and maintenance costs.

- 5G can serve as an alternative technology in the medium term, bringing benefit as an access option alongside its rollout for other uses and services as described in section 5. The study suggests this is most likely to take effect from around 2020 to 2025. Nonetheless, scenario 3 also signposts the whole life cost advantages of deploying hybrid fibre and wireless technologies in urban as well as rural environments.

2. Study Approach

2.1. Scope and Key Assumptions

2.1.1. Premises Scope

The analysis considered the Digital Communications Infrastructure requirements for all premises within the UK, with a specific emphasis on residential and Small to Medium Enterprises. These are defined as per EU Recommendation 2003/361, i.e.

Company category	Staff headcount	Turnover or Balance Sheet total	
Medium- sized	<250	≤ € 50 m	≤ € 43 m
Small	<50	≤ € 10 m	≤ € 10 m
Micro	<10	≤ € 2 m	≤ € 2 m

We have assumed that this equates to c.29 million (93.5%) of the 31 million current premises in the entire UK.

An increase in the number of premises was also assumed in line with ONS projections as stated in the National Population Projections: 2014-based Statistical Bulletin, released October 2015. This broadly equates to a rise of 1 million premises every 5 years, commencing with 30 million in 2020 and reaching 36 million in 2050.

2.1.2. Geographic Scope

Given there is significant variance between the costs associated with urban vs rural deployment of digital communications infrastructure, the study adopted 'Clusters' of specific Geo-Types that capture and encompass these variances.

The first step consisted in picking the relevant subdivision for the study. The following options were considered:

- Middle Super Output Area (MSOA): There are on average 7200 MSOAs. Each MSOA was therefore considered too small to reflect pooled resources and pooled planning among communities, thus too small to be representative.

- Ward: there are over 10,000 Wards. These were also considered to be too small and often subject to change through electoral reform.

- Local Authority District (LAD): The UK has 380 LA Districts. They have unitary control of the area within their boundary, and generally consist of representative areas with common characteristics.

- County: There are 94 in total – which is too few. Counties are too aggregate and miss the local heterogeneity in settlement patterns; there is a lack of relevant reference data for the study at this level.

By way of comparison, relevant subdivisions used in previous work in France were on average 1677 km² (647 mi²) wide and comprised 329 sectors.

For all these reasons, Local Authority District subdivisions were chosen (average area: 550 km² / 213 mi²). A sample of 40 LADs was then selected as described below.

The second step consisted in defining a global criterion to classify LADs according to their rurality:

The geotypes followed the Rural/Urban Classification (RUC) adopted by DEFRA and used by the ONS. However, the latter only applies to England at the LAD level. Data from Wales and Scotland was thus transposed to make it fit into the same classification in the following manner:

Wales:

- The RUC which exists at the ward level was transposed to the LAD level while making sure that the classification remained as representative as possible, for instance by crossing reference data with density of population.

Scotland:

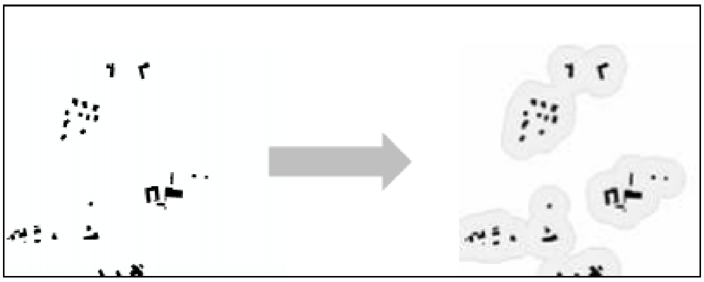
- The Scottish scale[1] was cross-referenced with the urban population distribution in each Local Authority[2] to transpose it to the Local Authority scale.

For the purposes of the harmonization, specific criteria were considered to design a homemade RUC customized for the study. These main criteria were:

- Density of premises
- Road length per premise
- Proportion of sparse dwellings

'Sparse dwellings' were determined according to the following method:

- Measuring premises concentration by counting the number of other premises within a 50m radius. 50m is a proxy when designing networks that is as close as 100 m from each premise.



- When several radii overlap, it makes a built-up zone of a given size

[1] http://www.gov.scot/Resource/0046/00464800.pdf

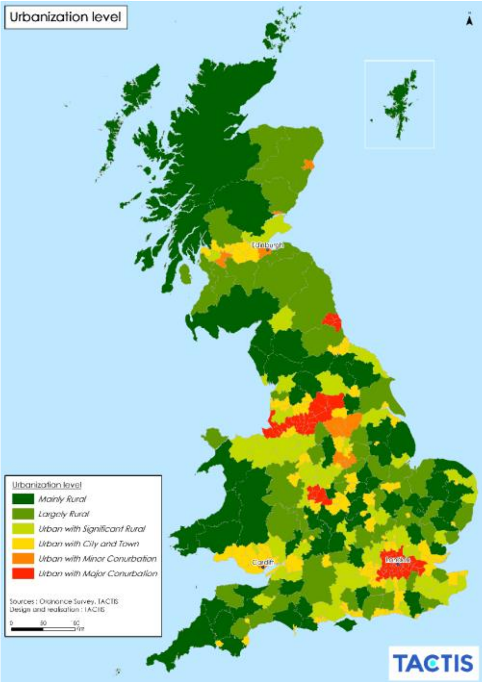
[2] http://www.gov.scot/Resource/0046/00464780.pdf

- Once all zones are identified, they are then classified according to their size:

Built-up area type	Definition criterion	Number of premises (GB)	Number of areas (GB)	Average of premises per zone
Town	>100 buildings	29,179,000 (94%)	10,495 (2%)	2,780
Hamlet	Between 5 and 100 buildings	1,182,000 (4%)	64,845 (13%)	18
Isolated Dwelling	< 5 buildings	759,319 (2%)	440,429(85%)	1.7

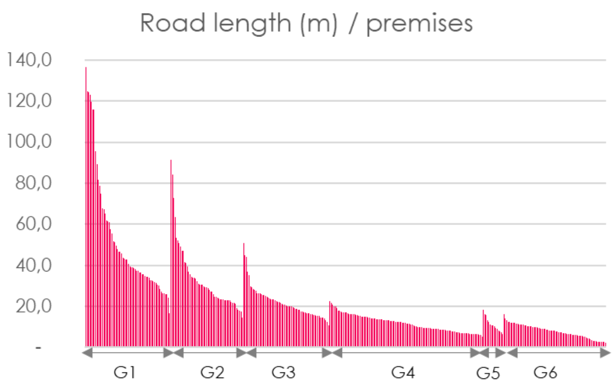
Therefore, the classification used is primarily consistent rather than exact, considering both accessibility and the proportion of rural population.

The 6 geotypes adopted in the analysis are listed below, together with the definition of each UK LAD as shown on the adjacent map:



- Group 1: Mainly rural (comprising 16% of Local Authority Districts)
- Group 2: Largely rural (comprising 14% of Local Authority Districts)
- Group 3: Urban with significant rural (comprising 17% of Local Authority Districts)
- Group 4: Urban with city and town (comprising 29% of Local Authority Districts)
- Group 5: Urban with minor conurbation (comprising 4% of Local Authority Districts)
- Group 6: Urban with major conurbation (comprising 20% of Local Authority Districts)

The distribution of road length per premises in the selected LADs by RUC group is shown below:



2.1.3. Sample Size

A target sample size of 10% of UK premises was agreed as an acceptable sample size to determine the relative costs of each technology option. This was considered large enough to be representationally effective across the Geo-Types, whilst low enough to be manageable in terms of timescales and data gathering requirements.

With an estimated 29 million 'eligible' premises, based on:

- ONS online data of 27 million households
- 2.55 million VAT/ PAYE registered business (less an assumed 20% of business registered to domestic premises) as per ONS online data.

A 10% sample requires a minimum of c.2.7 million domestic premises and c.204,000 business premises.

Volumes were then modelled in each geotype to enable samples that are representative of overall UK distribution in urban, rural etc. To ensure the sample would exceed these targets, a total of 3,187,296 premises were modelled across 40 Local Authority Districts.

2.1.4. Technology Scope

The scope considered within the key technology options are shown below:

- Fibre - Fibre to the home/premise (FTTH/P); including both GPON and Point to Point architectures

- Copper - G.Fast; including Openreach 'extended G.Fast' using Fibre to the Distribution Point (FTTDp) architectures. It does not consider VDSL except the Long-Range VDSL variant for the deep Rural locations.

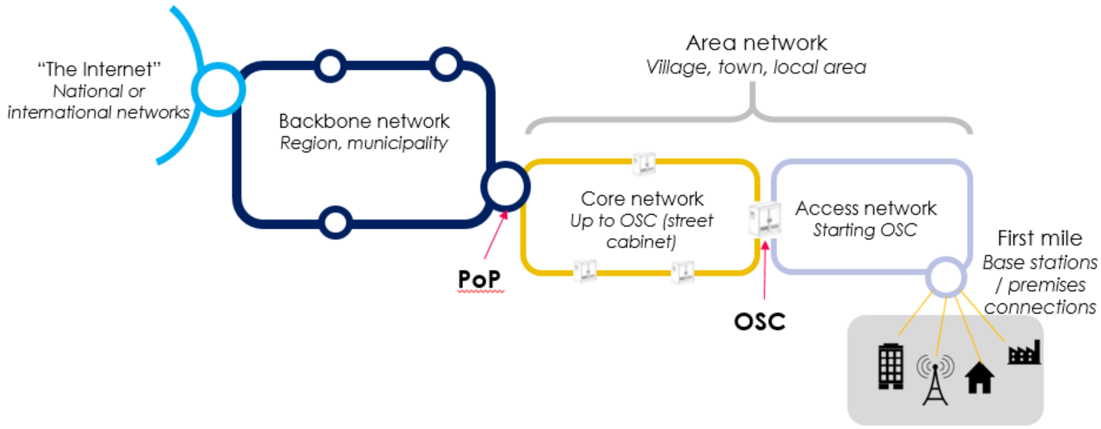
- Co-ax - DOCSIS 3.1 (and subsequent cable based technological advancements); as deployed by cable operators especially Virgin Media; attention was paid specifically to their deployment and transition plans under Project Lightning

- Wireless - Fixed Wireless Access; covering Point to Point and Multipoint, with a focus on non-5G adoption of Long-Term Evolution (LTE) technology

Specifications for each technology option above and the associated physical infrastructure was produced and shared with NIC and Ofcom. These can be found in Appendix A.

2.1.5. Infrastructure Scope

The study adopted the definition of network architecture components used in the EU Guide to High Speed Broadband Investment. These are described in the diagram below:



Connection to the Internet and provision of backhaul through the backbone infrastructure are principally the affair of main Telco operators and 'carriers', in design and economic terms. This extends to where/how they choose to locate Points of Presence (PoPs) to interconnect with local distribution. There is also significant commonality and little variance in the backbone/ backhaul provision between different area and first mile approaches.

The primary cost decisions for the study revolve around the local distribution Area network and the 'first mile' provision to premises, as the technology options scope relates to the technology options for primarily 'first mile' access infrastructure.

2.1.6. Existing Coverage Assumptions

Reported data was used to make the following assumptions regarding existing infrastructure:

- FTTP. Based on government and reported data, current FTTP coverage as at the date of this report is assumed as 2% of all UK premises (i.e. 600,000). These connections are provided by Openreach, Virgin Media (under Project Lightning) and alternative network providers, such as (in alphabetical order) CityFibre, Gigaclear, Hyperoptic and ITS Technology Group, etc.

- Cable/ DOCSIS. Based on information derived from Virgin Media announcements and reports, there are currently 15 million DOCSIS compatible premises across the UK. Assuming planned rollout occurs, Virgin has 57% premises in our model of 30 million as at 2020.

- FWA. Even though significant levels of FWA connections currently exist, no assumptions been made regarding their associated infrastructure in the analysis. This is because apart from mast locations, the infrastructure is owned entirely- and generally exclusively for the use of- the network provider.

- FTTC. Whilst VDSL coverage using FTTC will reach over 95% of all UK premises by 2018, it is not considered in this analysis. The technology is not defined as in scope due to performance constraints with respect to future anticipated capacity.

2.2. Development of Scenarios

Five Scenarios were developed that enabled the study to assess the various cost aspects of upgrading the UK's infrastructure, based upon the scope and assumptions defined above. The scenarios and the purpose of each is listed below:

1) 100% FTTP coverage with no re-use of existing infrastructure (the 'theoretical case' for baseline costing)

2) 100% FTTP coverage with re-use of physical infrastructure (the more likely outcome)

3) Fibre to 5G premises access nodes- e.g. on lamp-posts (the adoption of 'disruptive' technology)

4) FTTP with FWA/ Long-Range VDSL in rural areas (consideraton of economic constraints on FTTP)

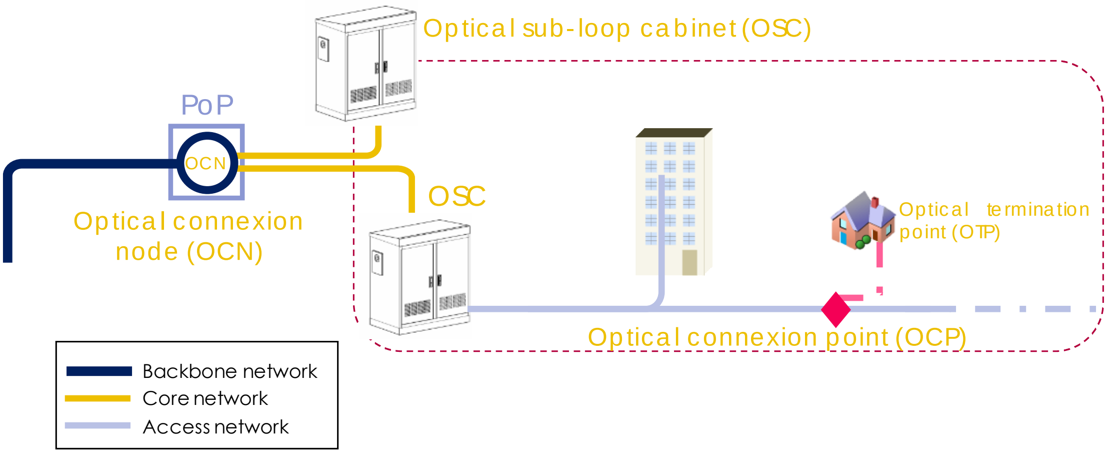
5) A Mixed Technology Deployment (recognising altenatives to an FTTP deployment approach, such as G.Fast over FTTDp and DOCSIS 3.1 over co-axial cable)

2.2.1. 100% FTTP.

Fully pervasive rollout of FTTP to 100% of UK premises assumes:

a. GPON at 64 or 32 way splitting for urban and rural as economically determined
b. Point to Point capability for symmetrical business services
c. New infrastructure throughout (a 'clean slate' approach to arrive at a maximum reference figure)

The architecture adopted for this scenario and scenario 2 is shown below:



This is the ‘Baseline Model’ Scenario. It is highly unlikely to be a realistic option as re-use of physical infrastructure is inevitable. However, it is included to provide a ‘maximum cost’ case.

2.2.2. 100% FTTP with infrastructure re-use.

As above with assumptions a) and b) but instead assumes the following regarding physical infrastructure:

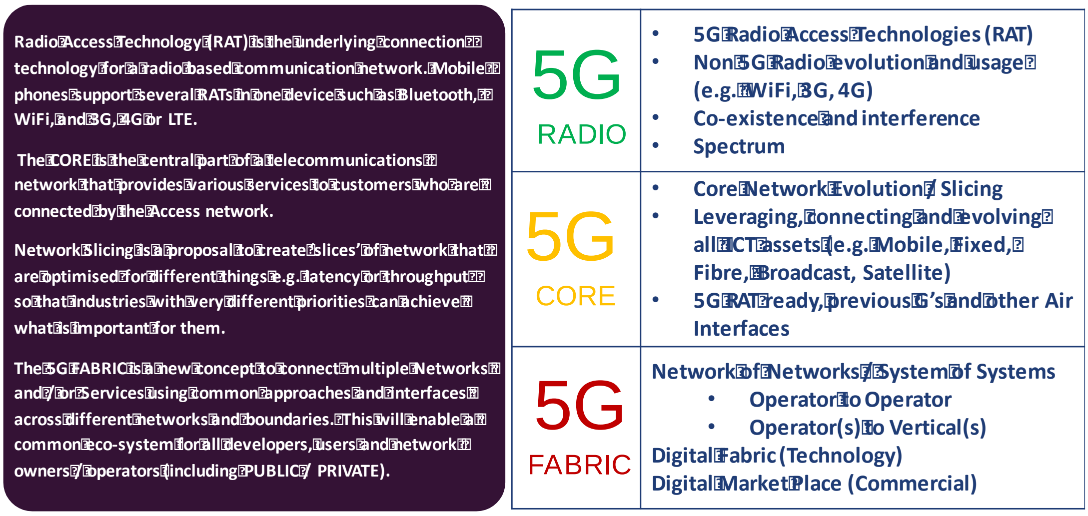
a. Re-use of Openreach duct under PIA etc. (converting high short-term Capex to low long term Opex)
b. Shared use of other utility ducts and poles (power, water etc.)
c. Shared/ open use of local authority/ public sector assets (CCTV, Urban Traffic Control, District Heating and Power, street furniture, etc.)

2.2.3. Fibre to 5G (i.e. lamp-post).

Background and Challenges

The use of wireless technologies for ‘rapid-access’, low capital multi-point deployment has been long established. The issue has always been around efficient use of spectrum, channel allocation etc. to enable high volumes of connections in any one zone. The adoption of cell deployment and channel re-use has greatly improved this - but still to date the greatest effect has been enabling mobile communications.

The development of 5G offers to expand this capability. The proposed strategies, integrated technology platforms and varied frequency bands all imply a new ‘eco-system’ offering many capabilities:



Purpose and Basis of a 5G scenario.

The 30-year timescale provides a lot of uncertainty, particularly in such a fast-moving sector. Fixed and mobile communications are converging at both the services layer and as can be seen in the diagram above, at the infrastructure layers also. However, we are not able to determine what this will look like.

This scenario does not look to predict technology pathways but seeks to understand how the cost proposition changes by deploying a 'mobile' access layer first.

To achieve this, the analysis set down some principle attributes for an effective 'test scenario':

a. 5G would be used principally for connecting premises to a local radio distribution point in a point-to-multipoint configuration; thus providing a faster access deployment than premises connection fibre and rising column distribution points.
b. Small cell networks would be deployed with very low distribution radii, with significant channel re-use. These would typically be on street furniture such as lampposts to avoid a 'substitutional cost' of local monopoles etc.
c. Fibre would be provided to each 'lamp-post', as high speed, high capacity; low-latency transit would be an essential component of the network.
d. Also, this transit network architecture should be designed as a 'ring topology' network between OSCs, and possibly each small cell distribution point. This would be to ensure in-built resilience for high capacity and low-latency IP traffic, as well as providing 'self-healing' capability.
e. Fibre break-out would be provided at each small cell location, enabling not only connection of further small cells but also provision of a fibre from the 5G cabinet to the premises at a slightly reduced cost for dedicated or even higher capacity services.

Whilst some of these attributes would be required more for other functions provided by 5G (e.g. Critical IoT requiring ultra-low latency), it must be assumed that 5G functional and service architectures would be based on them being present regardless. For example, 'network slicing' using Software Defined Networking (SDN) is likely to be used for effective bandwidth management and multi ISP provision to a premise- and would assume a ring topology.

Methodology

The challenge is that the entire 5G strategy including associated technical architecture, standards and therefore costs are currently under development and hence not yet defined. This was highlighted in the 2016 Oughton and Frias report and remains the case at the date of the analysis. This makes the modelling of this scenario to the same detail as the others very difficult.

The hypothetical scenario focused solely on the use of 5G for fixed multipoint radio access to premises has been constructed to test the key questions described in the scenario descriptions section earlier and based on the attributes also described above.

The methodology assumes that the connection to the premises from the final Optical Distribution Point (ODP) is replaced with a radio connection broadcast small cell with an effective radius of c.200m. This small cell is part of a multi-directional base station served by a cabinet at the base station location. The fibre network is provided to these 5G base stations, which then radiate a signal to neighbouring premises. A base station consists of a small cell located on street furniture- typically a lamp-post but not exclusively.

Therefore, far less fibre cable is needed, particularly the costly last mile deployment. Rising columns and premises connections can account for between 50 and 60% of FTTP Capex.

The scenario assumes that this deployment technique is primarily for metropolitan urban areas, i.e. premises in urban areas of geotypes G4 to G6. This is due to three assumed pre-requisites:

a. The presence of regularly-spaced street furniture with associated power (e.g. streetlamps)
b. Initial 5G deployments in urban and suburban areas only. The Oughton and Frias report-also support this assumption with only 21% of total Capex for 5G being required to rollout to urban and suburban locations, this will be the inevitable initial deployment.

Technical Assumptions

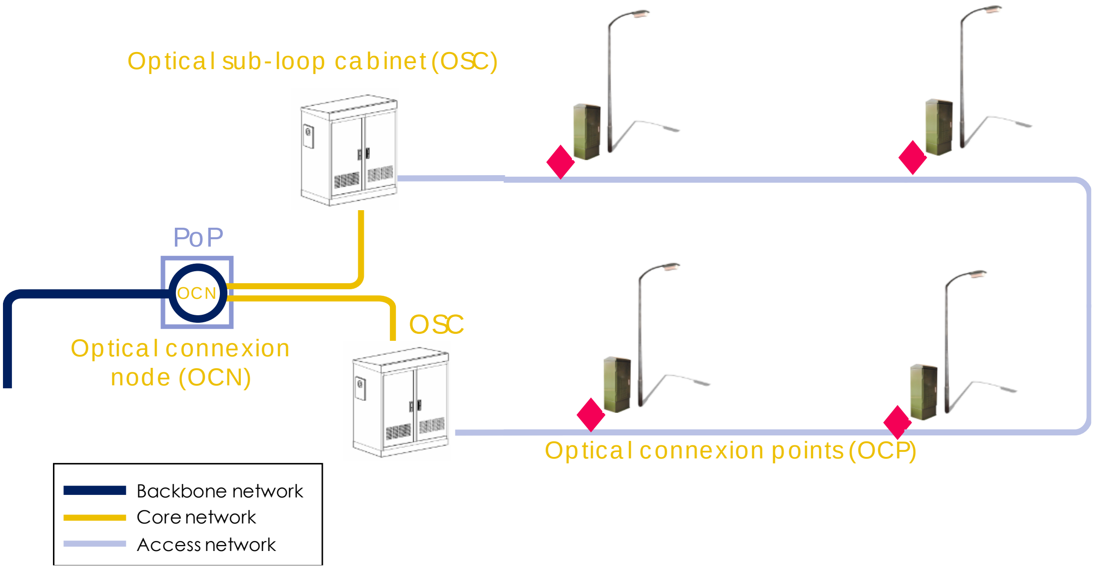
The relevant characteristics need to be verified by results from 5G pilots currently underway in the UK and overseas. However, initial assessment would suggest the following be used for cost modelling:

- The use of higher frequency bands (at least 26GHz). This will enable higher capacity, short-range distribution for more dense premises.

- On this frequency basis, a 5G-cell radius of 200m should be used to provide sufficient capacity and throughput for both fixed and mobile traffic. Consequently:
    - Cells should thus be placed 400m apart from one another
    - The surface area covered by a base station is 0.1 km² - or 10 stations per km².

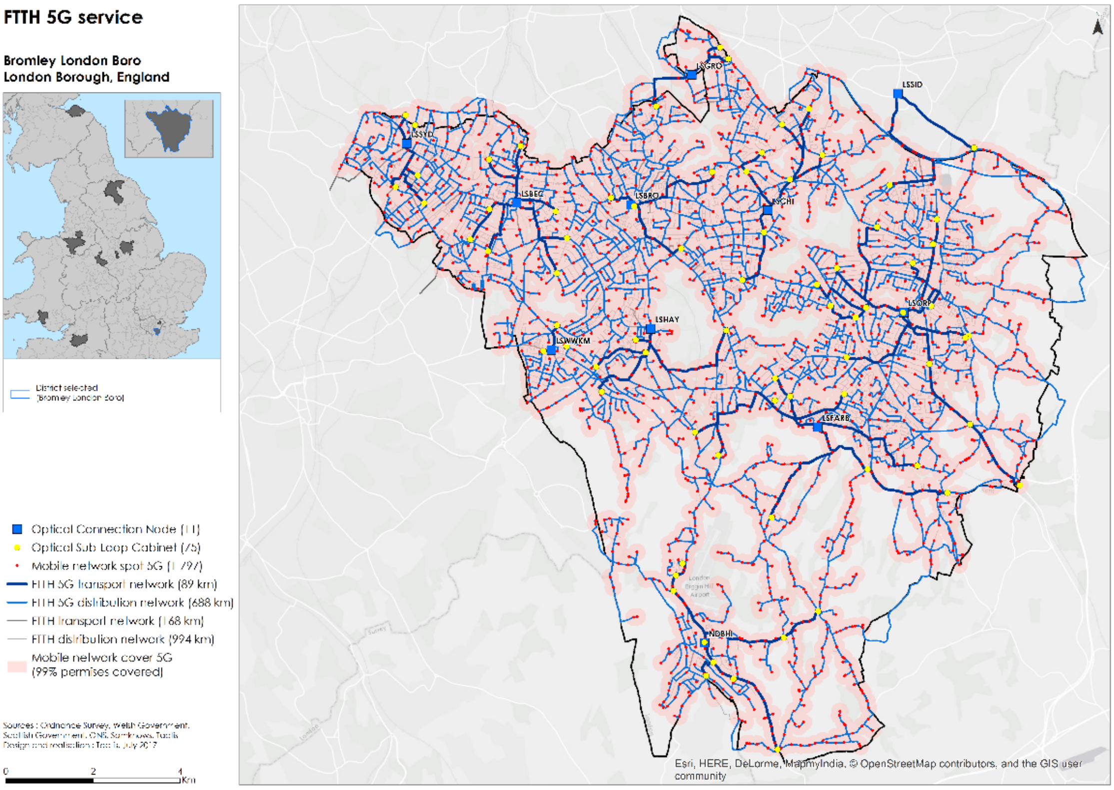
Such design should allow effective integration of mobile traffic to co-exist through these cells alongside the fixed wireless connections.

Regarding the fibre network, assumptions from scenarios 1 and 2 are kept. The core network remains the same but a 'ring' architecture was designed in the access network, as shown in the design:



The possibility of this core network sharing any existing ducts already provided to lampposts should be actively explored. This may be the power lines (where these are not directly buried) and/ or any CCTV provision that utilises the street furniture. The study made the assumption that 50 metres of new civil construction would be required to all of base stations.

Models have been run to test the technical and cost assumptions above. The resulting design from one of these is shown below:



The design outputs (e.g. radius and distribution of base stations) provided effective coverage for the premises anticipated within the assumptions modelled, thus corroborating the assumptions.

2.2.4. FTTP with FWA/LR-VDSL for very rural.

Assumes the principles of 1 and 2 but with FTTP coverage only reaching 95%. FWA or LR-VDSL is used to deploy at least 'Superfast' at >30Mbps to the remaining 5% of premises

As little direct empirical or field data is yet available on LR-VDSL, the scenario models the use of FWA.

Base stations would be deployed on poles located on verges and footpaths. FWA antennas would be located on either:

- Existing high structures (e.g. church towers etc.)
- 15m high masts or
- 25m high lattice towers
- As available and/or required by the nature of the terrain.

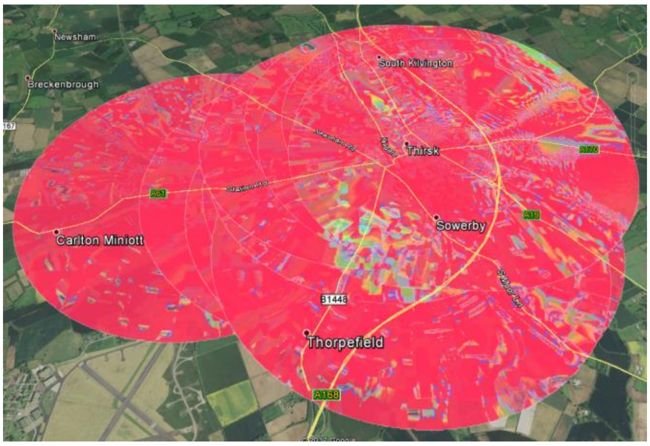
Next to each location would be a small cabinet connecting the fibre network to the antennas.

Premises up to 500m from the antenna would be able (in most cases) to receive sufficient signal strength via a transceiver dish mounted high on the building or on the roof.

On the example overview below (for an FWA covering Thirsk in North Yorkshire), base stations have been distributed based upon initial propagation designs, to serve all premises in the corresponding OCN fibre-serving area as identified in the test FTTP design under scenario 1. The locations selected for these base stations may not be the ideal locations for any given base station but gives a comparison to other technologies and covers at least the same number of customers. Upon implementation and site surveying during the early project phases these locations would be altered or heights adjusted to better serve that area.

(NB: whilst the propagation maps indicate slightly more premises would receive effective signal strength, the corresponding cost comparisons assume connections costs for only 6,252 premises, as per the other scenarios).

The average throughput should reach at least 30Mbps. On this propagation map, the lower signal strength scale is denoted by blues/purples and the strongest signals by red. This map only accounts for the topmost overlay image from all the base stations at each spot; a premise might possibly receive a stronger signal from a sector of another base station.



2.2.5. Mixed Technology Deployment.

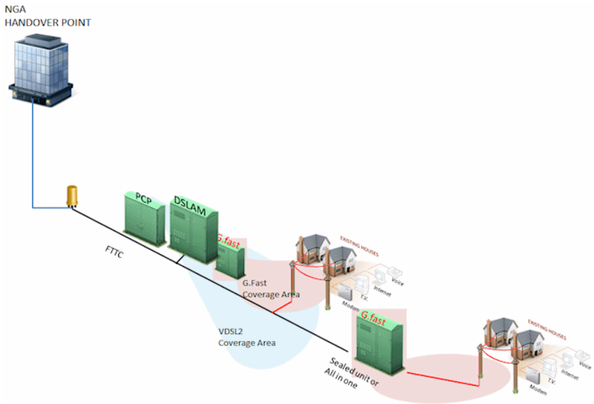
Assumes the use of G.Fast deployed to existing- and some new- PCCP/ OSC and DP/ OCP locations. This would be an alternative approach to large-scale FTTP deployment.

In a significant number of urban areas, the current Virgin Media deployment of coaxial cable networks (as defined in paragraph 2.1.7) would enable comparable and competing access using DOCSIS.

These two technologies provide a connection between an existing network (copper for G.Fast, co-axial cable for DOCSIS) and the fibre network, which thus does not have to go up to premises but instead, utilises the existing copper or coaxial cabling.

G.Fast and DOCSIS technologies are both designed mainly for urban zones with close premise proximity to active distribution points and are best installed in districts in Groups 4 to 6.

FTTDp architecture has been assumed to extend up to 200m from the premises because G.Fast technology becomes less effective further on. That is, for premises more isolated/far away from the OSC, there will be a maximum 200m of copper cables. However, premises beyond this in dense urban areas could still be served by DOCSIS where coax cabling currently exists.



On this basis, the modelling of this scenario assumes that:

Where copper and coax cable infrastructure exists:

1) For premises with cable distances from the Node up to 200m, 50% utilisation of G.Fast and 50% utilisation of DOCIS on coax cable
2) For premises beyond 200m, 100% utilisation over DOCSIS
3) Where only copper infrastructure exists
4) G.Fast utilisation up to 200m from the PCCP
5) FTTP, FWA, LR-VDSL (in descending order of economic viability) beyond 200m cable length
6) Where FTTP is deemed economically viable, this would then be re-applied to the entire premises count in an area, as the entire area business case will be more viable.

Whilst 300m is often used as a reference ‘cut-off’ point for G.Fast at up 300Mbps, experience from various field trials suggest that consistency of performance begins to vary significantly before this threshold. This is due to ‘micro cuts’ in aging copper, the diameter of copper used (0.4mm instead of 0.6mm cores). For this reason, an effective 200m-cable distance has been applied.

Insufficient data was available to the GIS study to enable accurate mapping of existing Virgiin Media distribution nodes. Therefore, an assumption has been applied that DOCSIS (connecting fibre to the cable network) and G.Fast (connecting fibre to the copper network) devices would both be installed at the same locations.

Although this may not be consistent with actual Openreach and Virgin Media cabinet locations, the architecture and distribution criteria used by both remain sufficiently similar to justify this assumption. This simplifies modelling and enables accurate cost estimation against these assumptions.

The extent of fibre network deployment to either a G.Fast node (referred to as Fibre to the Distribution Point – FTTDp) or a DOCSIS 'head end' for onward connection to co-axial cable, was defined using the following two criteria.

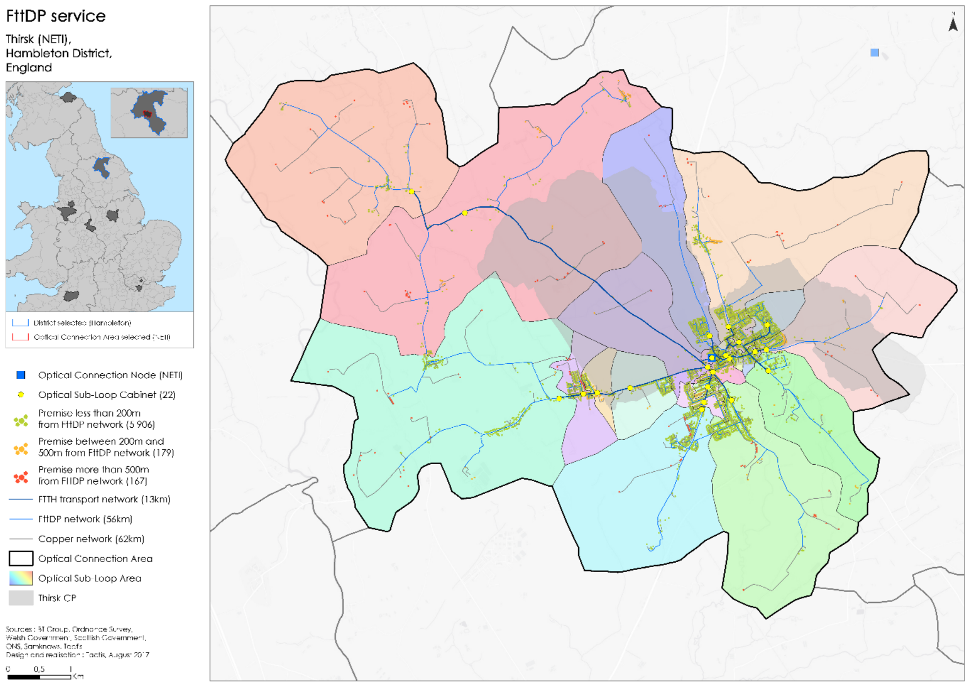
Criterion 1:

- Identify cables with less than 40 lines, and regroup them when several follow the same path.
- If the cable (or group) carries <40 lines and the distance [group separation; termination point] is <250m, then stop the fibre and carry on with copper/ coax.

Criterion 2:

- Identify extremity segments and calculate the distance between the last network intersection and the termination point.
- If that distance is <250m and there are less than 40 lines, then stop the fibre and carry on with copper/ coax.

A DOCSIS/G.Fast device was set up at every end of the fibre network to connect to the cable / copper one. With the FTTDp network defined as above, premises were then graded by their distance from the fibre network, sorted in the cost estimation tables and represented with a colour code on the maps as shown below:



2.3. Baseline Modelling of Geotype Clusters

UK Ordnance Survey and ONS data was used to determine the most appropriate breakdown of UK premises into 'clusters' that best represented the different economic and environmental conditions for digital communications infrastructure. This was important as there is significant variance in the cost base between dense urban and deep rural areas.

40 Local Authority Districts were identified for modelling, that best represented an appropriately weighted sample across the 6 geotypes, derived from DEFRAs Rural/ Urban Classification and described in section 2.1.2 above.

Network Designs were then produced for a sample of 'fibre serving areas' to test the assumptions and models.

2.3.1. Definition of relevant sample area for modelling

The considerations of the geographic and sample size scope assumptions described above were applied to UK demographic data to ensure the target 3.1 million premises sample was set to be diverse enough and reflect the significant variance between regions.

As described in section 2.1.2, DEFRA's Rural/Urban Classification was adopted to divide LADs. Within each of the 6 groups, LAD-level figures were then calculated for the following 3 parameters (which were already mentioned in part 2.1.2):

c. Density of premises

Premises and places were extracted from Ordnance Survey's AddressPlus database. The ones that were not connectable (caravans, cemeteries, etc.) were excluded from the model, as illustrated on the following screenshot:

rank	Concatenated_Classification	Class_Description	To_be_connected
1	R	Residential	1
2	RB	Ancillary Building	1
2	RC	Car Park Space	
4	RC01	Allocated Parking	
2	RD	Dwelling	1
4	RD01	Caravan	
4	RD02	Detached	1
4	RD03	Semi-Detached	1
4	RD04	Terraced	1
4	RD06	Self Contained Flat (Includes Maisonette / Apartment)	1
4	RD07	House Boat	

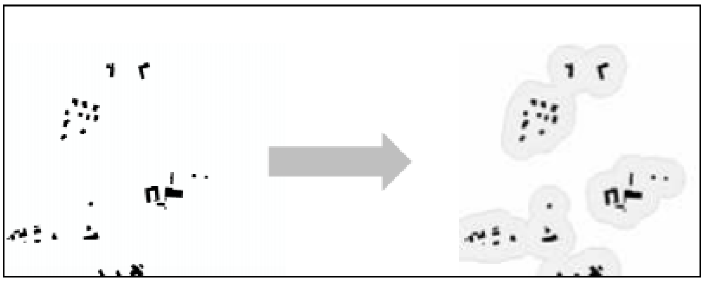
The number of premises per km² was then calculated for each district.

d. Road length per premise

e. Proportion of sparse dwellings

'Sparse dwellings' were determined according to the following method:

- Measuring premises concentration by counting the number of other premises within a 50m radius. 50m is a proxy when designing networks that is as close as 100 m from each premise.



- When several radii overlap, it makes a built-up zone of a given size

- Once all zones are identified, they are then classified according to their size

Built-up area type	Definition criterion	Number of premises (GB)	Number of areas (GB)	Average of premises per zone
Town	>100 buildings	29,179,000 (94%)	10,495 (2%)	2,780
Hamlet	Between 5 and 100 buildings	1,182,000 (4%)	64,845 (13%)	18
Isolated Dwelling	< 5 buildings	759,319 (2%)	440,429(85%)	1.7

Within each Rural/Urban Classification (RUC) group, these three criteria were applied to include LADs in the sample with major conditions:

- The proportions of each RUC group should approach the overall proportion for the whole of Great Britain, with a slight overweighting of rural LADs – since they are the most diverse and challenging ones.

- Within each RUC category and for each of the 3 parameters, the mean of the selected districts should be equal to the mean of the whole group with a 5% error margin.

- Within each RUC category, heterogeneous districts should be picked – both geographically and according to each parameter (at least one district from each quartile whenever possible).

Final list of LADs included in the sample:

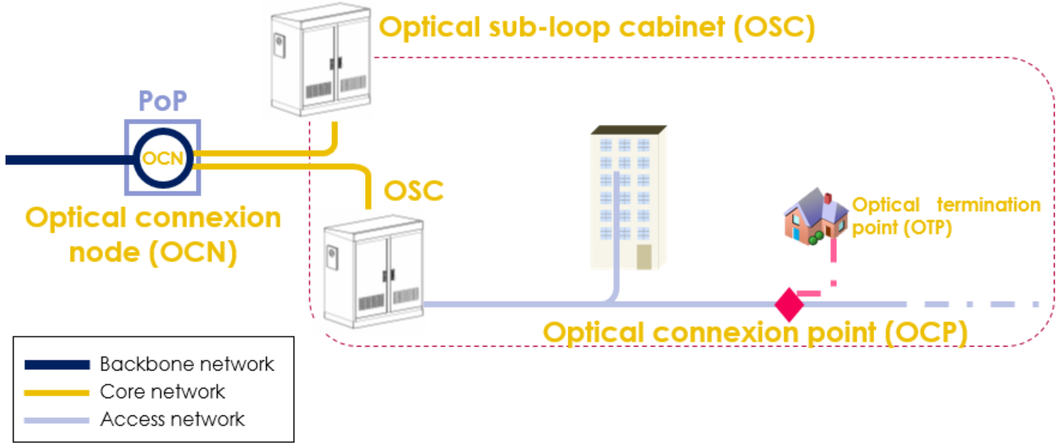
Name	Country	Rural / Urban Classification
Allerdale	England	Mainly Rural

Name	Country	Rural / Urban Classification
Argyll and Bute	Scotland	Mainly Rural
Ceredigion	Wales	Mainly Rural
Eden	England	Mainly Rural
Hambleton	England	Mainly Rural
Huntingdonshire	England	Mainly Rural
Mendip	England	Mainly Rural
North Dorset	England	Mainly Rural
North Warwickshire	England	Mainly Rural
Pembrokeshire	Wales	Mainly Rural
Stratford-on-Avon	England	Mainly Rural
Aylesbury Vale	England	Largely Rural
Central Bedfordshire	England	Largely Rural
East Lothian	Scotland	Largely Rural
Midlothian	Scotland	Largely Rural
Moray	Scotland	Largely Rural
Newark and Sherwood	England	Largely Rural
Shropshire	England	Largely Rural
Staffordshire Moorlands	England	Largely Rural
Boston	England	Urban with Significant Rural
Carlisle	England	Urban with Significant Rural
Cheshire West and Chester	England	Urban with Significant Rural
Dacorum	England	Urban with Significant Rural
East Staffordshire	England	Urban with Significant Rural
Merthyr Tydfil	Wales	Urban with Significant Rural
New Forest	England	Urban with Significant Rural
Wellingborough	England	Urban with Significant Rural
Blackburn with Darwen	England	Urban with City and Town
Bristol, City of	England	Urban with City and Town
Cheltenham	England	Urban with City and Town
Eastleigh	England	Urban with City and Town
Neath Port Talbot	Wales	Urban with City and Town
Newport	Wales	Urban with City and Town
Peterborough	England	Urban with City and Town
Plymouth	England	Urban with City and Town
Warrington	England	Urban with City and Town
Wokingham	England	Urban with City and Town
Broxtowe	England	Urban with Minor Conurbation
Barking and Dagenham	England	Urban with Major Conurbation
Bromley	England	Urban with Major Conurbation

2.3.2. Network modelling within sampled OCN service areas

The infrastructure and technology scope described in paragraphs 2.1.4 and 2.1.5 were then used to define an FTTP network design between the operator's Point of Presence and customer premises.

The schematic drawing of the infrastructure design applied is shown below:



Precise GIS and technical modelling was then undertaken on 3 OCN catchment areas using the network principles above to test and validate the assumptions. FTTP designs were produced for the following as representatives of deep rural, market town and urban areas respectively:

- Comberbach (LAD of Cheshire West and Chester, G3)
- Thirsk (LAD of Hambleton, G1)
- Barking (LAD of Barking and Dagenham, G6)

Designs for these areas were modelled based on the road network since they are broadly analogous with the routing of telecommunications ducts, particularly for the existing copper network. The location of OCNs and OSCs was also gathered, using exchange data for typical OCN locations and copper Primary Cross Connection Points (PCCP)- or other points of node and distribution density- for OSC locations. Where an OCN had no associated OSC, one was added at the OCN location. Similarly, when an OSC served too few or too many lines, the network was slightly redesigned to optimise it, by removing or redefining an OSC.

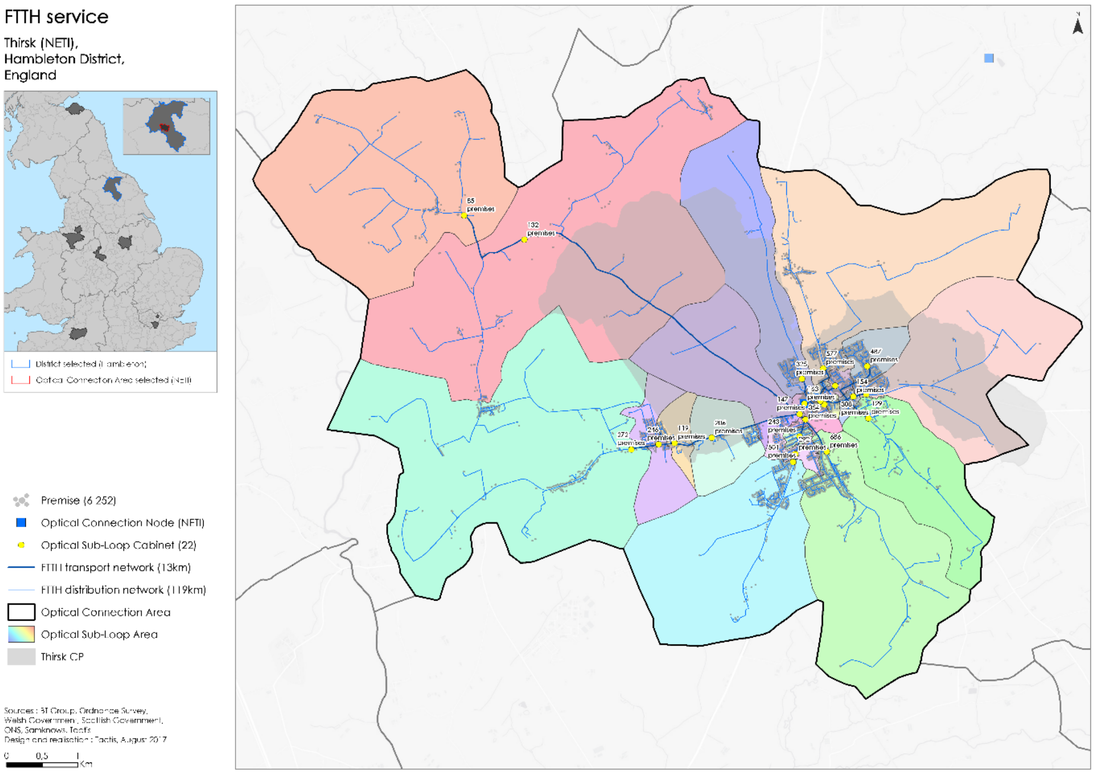
A point-to-multipoint architecture was used to design access for most of the premises: it consists in using a GPON (Gigabit Passive Optical Network) splitter to connect one fibre cable to either 32 or 64 access fibres for connection to the terminating devices inside premises. These would consist of:

- An Optical Network Termination (ONT) which constitutes the Optical Termination Point for the network operator

- Customer Premises Equipment (CPE), which constitutes the demarcation, point for the service provider.

The architecture was designed to also enable point-to-point connections for business premises that require them. Point-to-point is more expensive but allows faster and more consistent throughput and symmetrical speeds (i.e. the same download and upload). A point to point connection would also be used by other network operators for transit or backhaul connectivity, such as that required for mobile base stations and Internet of Things applications.

The FTTP network design used in the three areas is shown in the example below:



2.3.3. Premises length

The length of access connections from the Optical Connection Point (OCP- also referred to as the Optical Distribution Point-ODP) to premises across each of the 40-geotype sample clusters was also calculated. This was achieved through GIS modelling using OS data for geographic and demographic factors and Openreach data on PCCP locations and other network factors.

This data was then used for three purposes:

- To validate the infrastructure routes in the test designs
- To calculate the access (or distribution) network costs
- To determine the number of premises reached by various technologies based upon their performance over distance (see section 2.3 below).

2.4. Key Assumptions used in the Report

The analysis was then conducted, using a combination of obtained data and key assumptions. The basis of the main analysis components and assumptions used are listed below.

2.4.1. Capital Costs

Reference input capital costs were obtained from suppliers and infrastructure projects undertaken by operators. These included operators in the UK, France and elsewhere in Europe.

2.4.2. Operating Costs

The reference data for these was derived from actual costs and through a number of assumptions. These are fully listed in Appendix C and were shared with external reviewers for corroboration

Operational cost overheads were also considered; those considered relevant were then included in the opex calculations. For example:

- A fixed overhead covering all support costs not directly attributable on a core network component basis or to premises connection
- A fixed overhead covering all support costs for infrastructure information systems

One other additional consideration should be taken into account when looking at the 'pure costs' of each scenario and the comparative positions between them. Scenarios 1 to 4 are based primarily on new networks deployed in some (or none in the case of scenario 1) of existing UK infrastructure. This means they could be deployed by various operators. Scenario 5 however, relies heavily on the use of both infrastructure and network technologies that already exist and are deployed. As such, they are very likely to be much more relevant to principal existing operators, such as Openreach or Virgin Media. This has no material impact on Capex- but does on Opex, as support and maintenance costs will likely be distributed across both 'old' and 'new' platforms.

As it is outside of the scope of this study to comment or hypothesise over how operators might identify and treat such Opex elements in their accounting principles, 'pure' Opex costs have been considered that relate directly to the support of the 'new' technologies under consideration.

2.4.3. Methodology

The cost models were then populated with input/ unit data using the following approach:

1. Existing figures in the cost models from modelling French network designs were checked and validated before being adopted as the 'baseline'.

2. These baseline figures were then tested against UK comparators from previous and existing projects and amended accordingly.

3. Finally, other international comparisons were used to 'sense test' the revised figures

Whenever an item aggregated several cost components, they were compiled 'bottom-up', i.e. all cost items were taken into account and summed to obtain a single result. For instance, regarding maintenance, the cost of an engineer was allocated to the assumed number of operations required per year.

All FTTP and FTTDp opex unit costs relate only to the incremental maintenance costs. For example, the existence of a copper network for other technologies and services to premises is recognised- and the related costs of the support of this is not included in the model. However, the incremental costs of running a G.Fast solution over FTTDp are included.

Discussions were held with companies maintaining both copper and fibre networks (giving us a real “field” view) and operators to help model the respective cost of maintenance of FTTP and FTTDp. All have stated that in the long run, maintaining a full passive infrastructure (FTTP) is cheaper than maintaining FTTDp with lots of transient faults generating tickets and interventions.
Therefore, in increase in the support cost of copper from the DP to premise has been included.

2.4.4. Connection Costs

Premises connections are defined in the analysis as the connection from the final distribution point in the infrastructure to the premises. Premises connections costs were included separately from the Capex for building the core and access networks. The rationale for this is that:

a. The costs are not incurred until a customer requests service and a premise is connected from the distribution point

b. The cost is generally borne by the service provider, not the infrastructure provider.

c. The cost can vary widely, especially by geotype, as the distance between premises and local distribution points in any technical architecture can be anything from typically 10 metres for dense urban areas in geotypes 6 to 1km for sparse rural locations in geotype 1.

2.4.5. Infrastructure re-use

Various assumptions were made on the extent of infrastructure re-use, depending on the nature of each of the 5 scenarios and the technology used within them. The assumptions also varied by the nature of the infrastructure and the geotype concerned. These base assumptions are detailed in Appendix B and were applied equally to scenarios 2 to 5 (scenario 1 assumed no re-use as the ‘baseline’ scenario).

The overall assumptions made regarding re-use were:

a. No fibre is shared; only physical infrastructure assets such as ducts and poles.

b. Only passive infrastructure owned and managed by Openreach is available for re-use. Given the requirements of the Civil Infrastructure Directive, assets managed by other utilities should be considered and would have a beneficial effect on the level of re-use. However, as at the date of this report considerations and negotiations over their use were not sufficiently developed to enable a robust level of inclusion to be determined. NIC could be a valuable contributor in developing this aspect.

c. Congested and collapsed ducts are not rectified so as to be made available for re-use. Whilst current regulated products from Openreach for shared use (PIA) make provision for clearing ducts, accurate assessment of the impact of this would require significantly more granular design and analysis than permissible within the scope of this report. Instead, the proportion of re-use is set to assume only ducts that are 'fit for purpose' are used

d. No separate consideration is made regarding special environmental conditions. Such conditions would include Sites of Special Scientific Interest (SSSIs), Conservation Areas, etc. Instead pragmatic levels of re-use were applied as shown in Appendix B, that allows for greater 'new build' distances per geotype to accommodate longer runs to circumvent these situations.

e. The analysis recognised the existence of the current copper networks and is based on the assumption that the copper network remains (i.e. there is no 'copper cutover'); hence the related support costs are currently separately accounted for. Therefore only 'pure costs' relating to the incremental support of a G.Fast solution over FTTDp have then been applied entirely to the infrastructure described in scenario 5 - and may therefore represent a portion of the operating costs allocations of operators, particularly incumbents.

2.4.6. Deployment and rollout

Deployment models were built based upon actual project experience and referenced against stated plans by operators. Some variations exist between technologies and scenarios, due mainly to the differences between the balance of active and passive component deployment involved; the latter requires longer lead times and more labour due to the nature of civil construction.

There are three key assumptions relating to deployment:

a. Planning processes and timescales are not considered in the analysis. In practice, this could have a significant, detrimental effect on overall time to deploy. However, planning times can vary significantly between both local authorities and the nature of the civil construction involved.
b. The analysis assumes that there is no constraint to resource availability. In practice, there has been a lack of skilled labour in certain areas, notably fibre splicing and network planning. These are being addressed but will have an impact either on deployment times or the associated cost of labour as a scarce resource
c. The analysis has also assumed free availability of materials. This is a reasonable assumption; however there have been periods when fibre supply particularly has been limited. This will equally have an effect on material costs and deployment timescales.

2.5. Cost analysis by Scenario in each Geotype

Cost estimation tables were then produced for each technology type. These consisted of a breakdown of validated costs for each component identified in the design, including the associated labour costs.

No allowance was made for operator margins for the construction of the infrastructure as a project for a third party (e.g. Government under a grant scheme or for public ownership; for a service provider wishing to own the infrastructure, etc). However, rate card charges were assumed for contractors required for elements of the build, such as the civil constructions works for ducts, poles, radio poles and towers etc.

The assumptions relevant to each technology scenario and geotype were then applied, using also the test reference designs to validate the cost and quantity profiles. This produced cost estimates for:

Capex

- OCN build
- OSC build
- Core (transport) network build
- Access (distribution) network build (including active equipment where appropriate such as G.Fast DSLAMs, DOCSIS terminating equipment, base stations, etc)
- Premises connection

Opex

- Core network equipment support and maintenance, including an 8-year replacement/ upgrade of all active equipment
- Access network support and maintenance
- Fibre, copper wireless ‘break-fix’ maintenance
- Running costs of energy at each active network component (excluding CPE)
- Administration costs such as Wayleaves, licences etc. as appropriate.

The Capex and Opex tables were constructed so as to enable updates, amendments and additions to both the assumptions and unit costs/ rates.

Summary tables were then compiled for each Scenario, which identified by geotype technology and within each scenario the costs of the geotype sample by:

- Capex total
- Opex total
- The whole life cost, assuming a 30-year supported life of the assets
- Capex per Premise Passed
- Capex per Premise Connected
- Opex per Premise Connected
- The whole life cost per Premise Passed.

The Summary Table then applied weighting factors to the samples to reflect the number of premises and lines in each total Geo-Type. This produced a total Capex, Opex and whole life cost for the Scenario across the whole UK premises count in scope.

A summary of the results is found in Section 3.

2.6. Review against ‘Real-Life’ Experience

An operator survey was developed and released to a focus group of key operators and interested related parties with valuable knowledge and experience of the digital communications infrastructures as defined or key components within it.

The survey consisted of three Parts:

- Part A asked reference questions about the respondent's span, scale, scope of experience

- Part B asked the respondent to comment on the test reference designs and associated costs. This included validating or suggesting adjustments to the key cost criteria from their experience, with the opportunity to comment on why and where any variances might arise (such as from a different design or set of assumptions)

- Part C asked the respondent's views and opinions on various aspects and how they might impact cost and development of digital communications infrastructure. These included:

  a. The development and rollout of 5G
  b. The re-use and sharing of physical infrastructure
  c. The adoption of different construction techniques
  d. The adoption of different commercial models

A total of 34 organisations were directly invited. A further 18 asked if they could submit and were sent the web-link to the survey.

The survey was published as 'Open' for a period of 2 weeks to elicit a focused response. It was then held open for a further period to allow any later responses, which were considered separately from the initial response group.

A total of 15 completed responses were received

Key points to note regarding respondents are:

a. BT Group and Openreach were individually invited to respond; they acknowledged receipt but declined to respond
b. Virgin Media did not respond.

A summary of the results can be found in Appendix F and relevant responses have been included under each scenario in the Costs Analysis at Section 3. It should be noted that access to the full details are held under strict NDA and hence authorised persons under password control can only access full results.

2.7. Reference with International Comparisons

International cost comparisons were sought to provide a further reference and benchmark of the analysis results.

The approach taken was to review specific countries where FTTH has been successfully deployed, identify what stimulated the market to invest in FTTH, the speed of rollout, cost and whether sharing of/or, use of, alternative assets facilitated the deployment of FTTH.

The team researched this through various information sources including commercial experiences and active projects along with the Fibre to the Home Council Europe reports and specifically the report titled "The cost of meeting Europe's future Network Needs".

The most relevant and analogous comparisons were then chosen from France, Sweden, Ireland and Portugal.

Particular focus was placed on Portugal and its meteoric rise in the world FTTH deployment in both cost and speed of rollout. France was also considered in general and its unofficial recognition of not overbuilding FTTH networks and instead actively promoting Wholesale access both with the telecom incumbents and private design, build wholesale operators. In France, the cost of deploying the first 60% of the population percentile can be kept around 500 € making private investment possible.

Appendix G International Projects contains a specific project case study in France in for the deployment of FTTH.

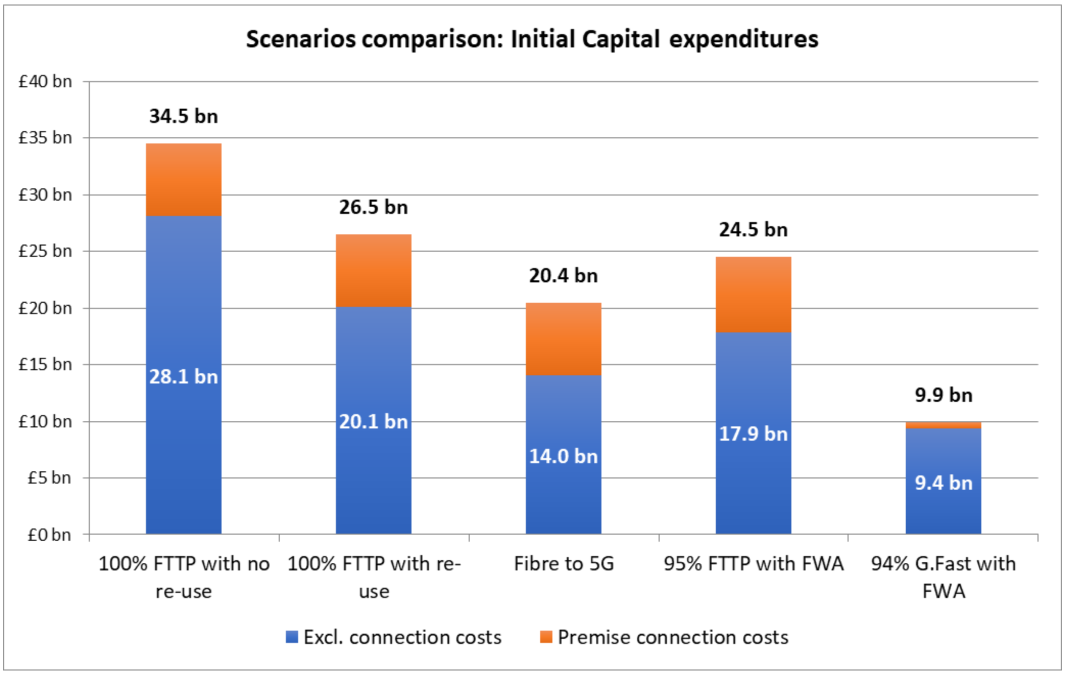
The focus was on the following key elements and how they impacted the costs:

- Regulatory position
- Incumbent activity and alternative operators entering the market
- Cost of Build
- Sharing of existing utility assets
- Sharing of/joint build projects between operators

3. Cost analysis results

Full cost models have been produced for each Scenario by each of the 6 geotypes.

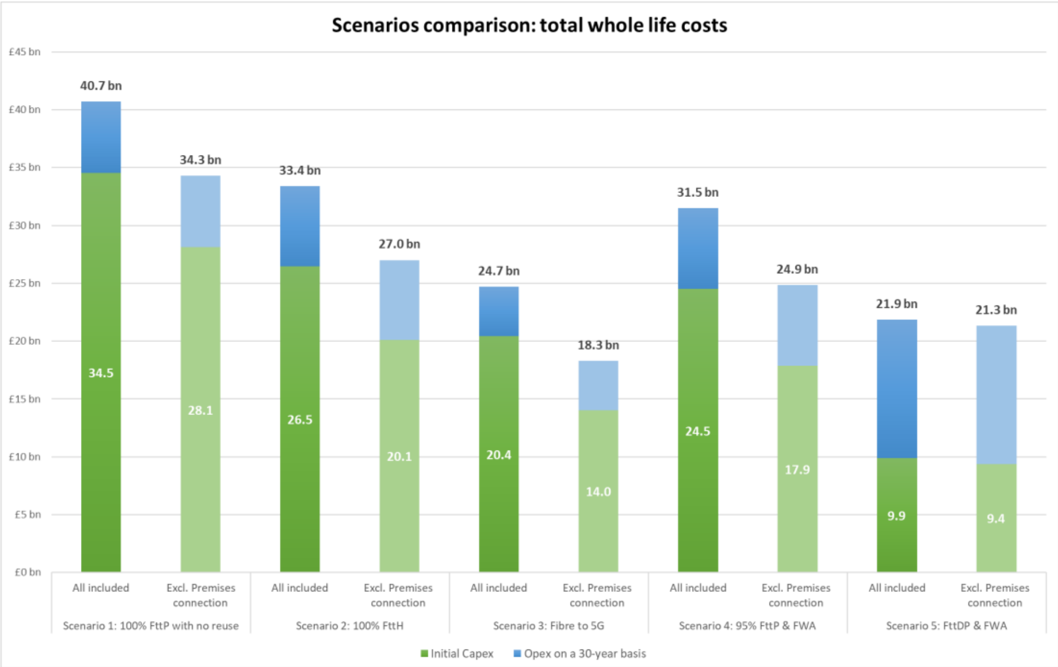
This section contains a breakdown of the costs for each scenario. As a headline, the graph below shows how the capital costs compare between them:



Whole Life costs are estimated in each scenario that are based on yearly Opex with a 9.3% discount rate on a 30-year basis. The 9.3% figure comes from the latest Ofcom agreed WACC on Openreach regulated products[3].

The Whole Life cost comparison, including capital and 30-year operating expenditure is found below. Note that excluding premises connection costs, which will be justified hereunder, modifies the ranking of scenarios:

[3]http://www.ukrn.org.uk/wp-content/uploads/2017/05/20170503-UKRN-Annual-WACC-Comparison-Report_FINAL.pdf. 9.3% is the mean of 8.8% (Openreach rate) and 9.8% (other operators). See also Appendix E.



In this section, each scenario is examined in the following order:

- Technical and cost assumptions
- Performance
- Unit cost table
- Initial Capital expenditures
- Operational expenditures per year
- Whole life cost on a 30-year basis

3.1. 100% FTTP with no infrastructure re-use

In this hypothetical scenario, everything is built from scratch. In other terms, in the mix of physical infrastructure applied in the design and cost models, every piece of infrastructure is considered as 'yet to be built'. Hence an additional cost is included for budgeting new ducts and new poles, with the nature of physical infrastructure being determined by premises density, terrain etc. in line with current industry practice.

Several assumptions have been made for evaluation:

Cost Assumptions

- Cost of an OCN at existing exchange: £49,500 (based on active equipment costs of £28,000 and location costs of £21,500)
- Cost of a new OCN: £32,280 (lower equipment costs because no cost of removing existing material)
- Cost of a street cabinet: £4,800
- Cost of end equipment: £212 (based on ONT and router at £74 and Set-top box at £138 per premise)
- Cost of deploying a metre of underground cable with less than 144 fibres: £3.62
- Cost of deploying a metre of overhead cable: £4.05

- Cost of civil works to deploy 1m of underground cable: ranging from £22 to 42.50 across geotypes
- Cost of civil works to deploy 1m of overhead cable: £16.40

- Assumed distribution of the number of premises per building:

Distribution of building size:	Geotype 1	Geotype 2	Geotype 3	Geotype 4	Geotype 5	Geotype 6
Building with less than 12 optical fibres	95%	95%	92%	92%	90%	90%
Between 12 and 24 optical fibres	2%	2%	5%	5%	5%	5%
Between 24 and 48 optical fibres	2%	2%	2%	2%	2%	2%
Above 48 optical fibres	1%	1%	1%	1%	3%	3%

- Assumed distribution of fibre to premises:

Premises connection type:	Geotype 1	Geotype 2	Geotype 3	Geotype 4	Geotype 5	Geotype 6
Floor to flat	20%	20%	20%	20%	40%	40%
Underground house connection	45%	45%	55%	65%	50%	50%
Aerial house connection (<100m)	32%	32%	22%	13%	10%	10%
Aerial house connection (≥100m)	3%	3%	3%	2%	0%	0%

These two tables explain the differences in connection costs across geotypes. Full details on geotypes characteristics are provided in Appendix D.

The following yearly Operating expenditures have been assumed:

- Fixed overhead (hotline, material, legal & paperwork): about £1,500,000 per geotype in total
- Duct rental: £0.26 per metre
- Line maintenance: £11.5 per premise. Includes preventive and reactive maintenance fee per premise connected
- Optical connection node maintenance: £1,382 per unit. Includes fee for maintaining passive (buildings and optical distribution frame) and optical equipment
- Optical sub-loop cabinet maintenance: £460 per unit
- FTTH information system maintenance: £0.92 per premise. It consists in the IT management system costs, for inventory, maintenance workflow and wholesale
- Energy cost per optical connection node: £691. Based on typical Optical Line Termination benchmarks, assumes 0.15£/kWh
- Energy cost per premise: £0.70. Assumes a power consumption of a 2W Network Termination at 0.15£/kWh

Performance Assumptions

As per the design and performance assumptions in Appendix A, premises with FTTP will be able to receive download speeds of at least 1Gbps and beyond. In this scenario 100% of premises can receive FTTP.

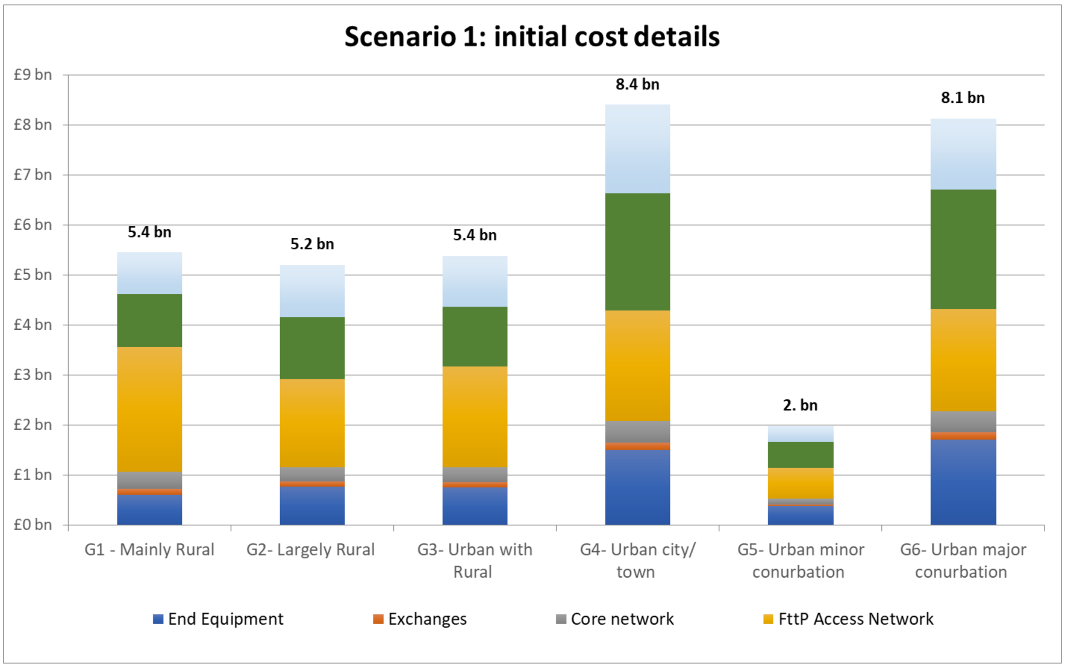
Based on these assumptions, the summary of Capex and Opex costs per premise (calculated from the 10% sample) is shown below, with a yearly discount rate of 9.3% on Opex.

Note that the difference between "premises passed" and "premises connected" lies in premises connection costs. They are excluded in "premises passed", on the basis that these costs would be:

- Only incurred when a customer adopted a service from a provider over the infrastructure
- Borne by the service provider or the customer in line with the service provider's commercial model

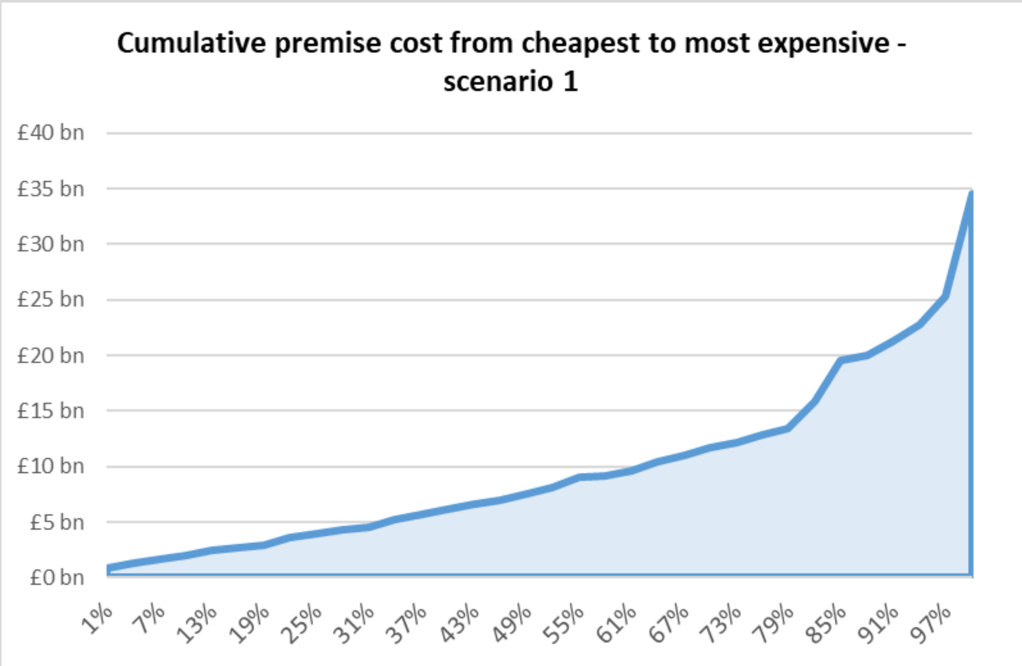
	G1 - Mainly rural	G2 - Largely rural	G3 - Urban with significant rural	G4 - Urban with city and town	G5 - Urban with minor conurbation	G6 - Urban with major conurbation
Capex per premise passed	£1,397.41	£1,002.41	£1,056.04	£810.09	£810.49	£721.22
Capex per premise connected	£1,647.88	£1,252.88	£1,303.31	£1,026.67	£963.29	£874.02
Opex per premise connected	£25.45	£21.49	£19.18	£16.71	£19.07	£16.18
Whole life cost per premise excl. connection costs	£1,882.55	£1,466.67	£1,504.56	£1,214.73	£1,163.54	£1,059.28
Whole life cost per premise (on a 30-year life)	£1,632.08	£1,216.20	£1,257.29	£998.15	£1,010.74	£906.48

The data summed up in this table enables calculation of costs for the whole of Great Britain. The detail of capital expenditures per cost item is shown below for each geotype:

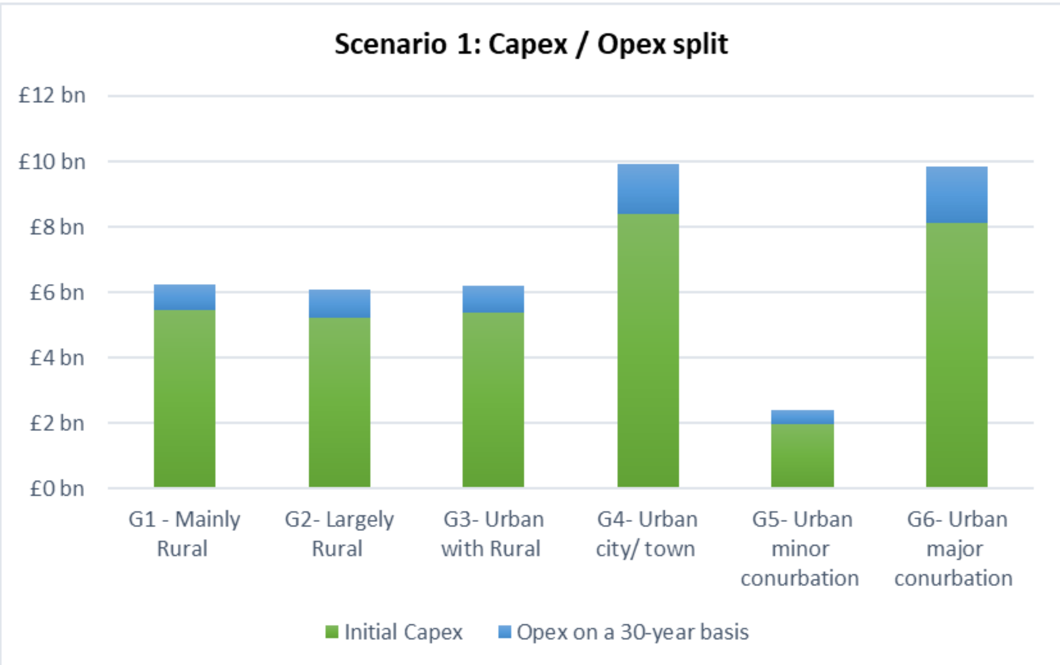


The total Capex for the whole of the UK in this scenario is therefore £34.5 billion. It would decrease to £28.1 billion if connection costs were excluded.

The average unit cost incorporates an important variation of premises costs according to their location, geotype and connection type. The graph below describes how fast unit costs increase. Thus, it shows that connecting the most expensive 5% of premises pushes up the total cost significantly:



Opex amount to a total of £579 million per year. The whole life cost projection for the UK is therefore £40.7bn – or £34.5bn if excluding connection costs - distributed across the six geotypes as shown in the graph below:



3.1.1. Operator Feedback on Scenario 1 and 2- FTTP

Based on the structure of the questions, the responses relating to FTTP costs can be applied equally to Scenarios 1 and 2.

Capex: The 6 responses for the 'City' scenario (geotype 6) 'normalised' on Capex quoted in the design. There was wide variance but these related mainly to the extent of new build versus re-use of infrastructure.

This was a recurring theme in the underlying trends regarding cost reductions. In the 'Town' Scenario (geotype 3) the trend suggested the costs may be overstated by up to 14% due to re-use of infrastructure.
Strangely, some responses on FTTP in the 'Rural' scenario (geotype 1), suggested cost reductions of up to 70%- due to heavy reliance on re-using infrastructure.

This would corroborate the savings identified in scenarios 2 and 1 through re-using infrastructure.

3.2. 100% FTTP with infrastructure re-use.

This scenario distinguishes existing infrastructure which can be reused from non-existing infrastructure which needs building like in scenario 1. Regarding the underground network, a given share of existing ducts has been assumed per geotype. As for aerial poles, it has been assumed that 20% of them would have to be rebuilt (versus 100% in scenario 1).

The detailed technical assumptions made for the calculation of infrastructure re-used or shared are as follows:

- Infrastructure mix. Assumptions were made by geotype on the current physical infrastructure that could be used. Full details are provided in the assumptions at Appendix B and an example of the assumed mix in physical infrastructure in geotype 3 is shown below:

Core network: share of…	Total	144 fibres or less	Above 144 fibres
Aerial	25%	25%	0%
Underground - existing duct	65%	63%	2%
Underground - non-existing duct	10%	9%	1%

Access network: share of…	Total	72 fibres or less	Above 72 fibres
Aerial	40%	40%	0%
Underground - existing duct	52%	50%	2%

Underground - non-existing duct	8%	7.5%	0.5%

- The cost and performance assumptions remain as for scenario 1 above.

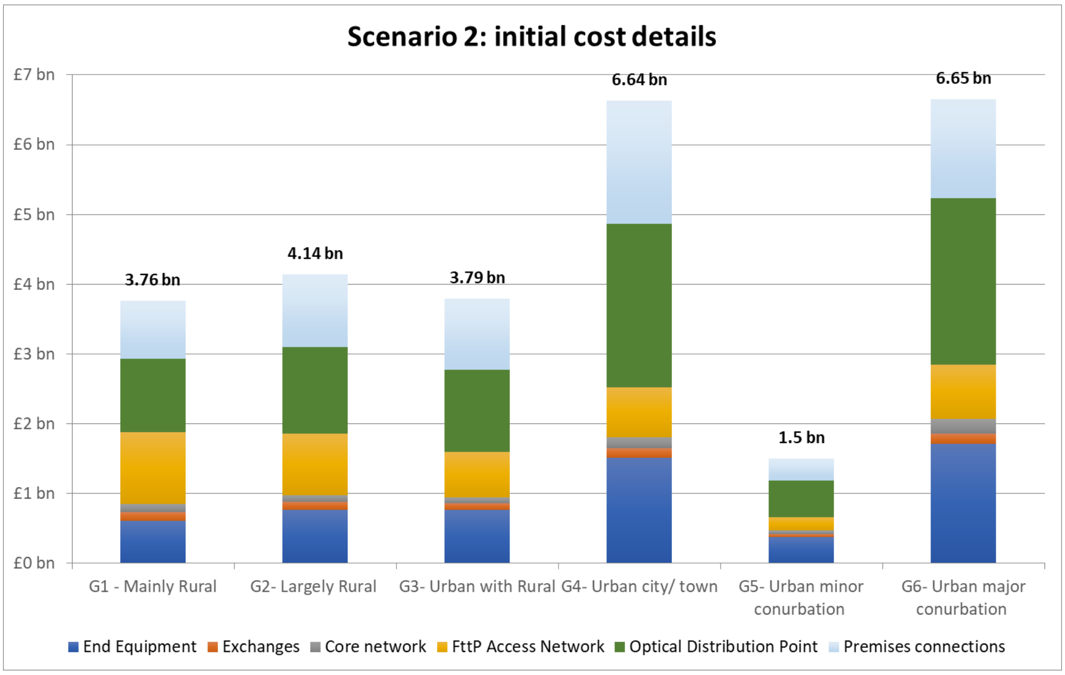
Based on these assumptions, the summary of Capex and Opex costs per premise (calculated from the 10% sample) is shown below, with a yearly discount rate of 9.3% on Opex.

Note that the difference between Premises Passed and Premises Connected lies in premises connection costs. They are excluded in Premises Passed, on the basis that these costs would be:

- Only incurred when a customer adopted a service from a provider over the infrastructure
- Borne by the service provider or the customer in line with the service provider's commercial model

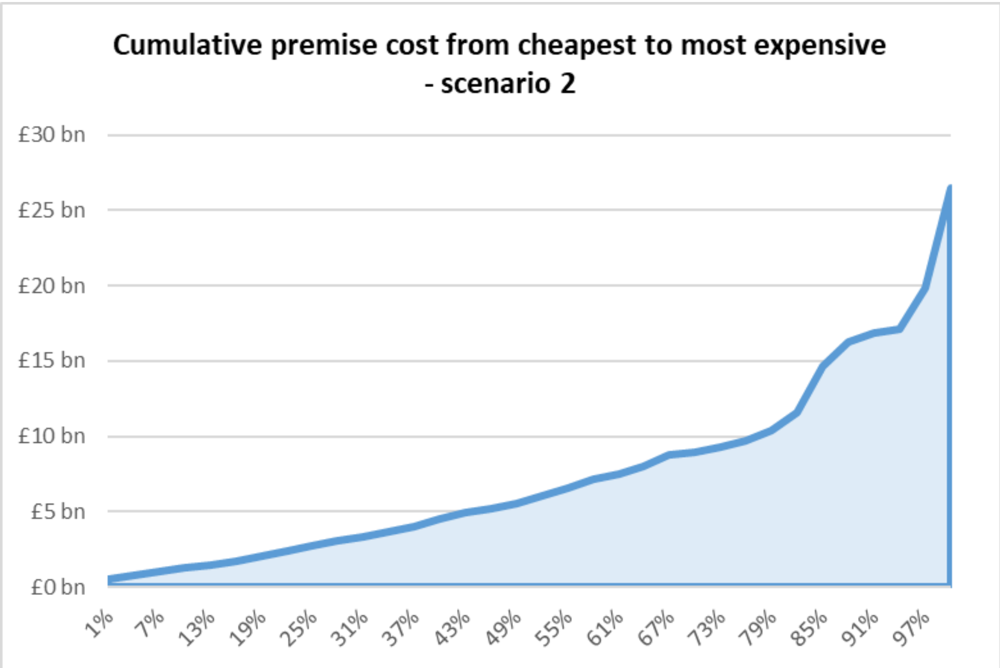
	G1- Mainly rural	G2- Largely rural	G3- Urban with significant rural	G4- Urban with city and town	G5- Urban with minor conurbation	G6- Urban with major conurbation
Capex per premises passed	£886.77	£746.83	£671.42	£594.62	£577.60	£562.59
Capex per premises connected	£1,137.24	£997.30	£918.69	£811.20	£730.40	£715.39
Opex per premises connected	£25.45	£21.49	£19.18	£16.71	£19.07	£16.18
Whole life cost per Premises (on a 30-year life)	£1,400.95	£1,237.35	£1,144.53	£1,022.10	£955.11	£923.11
Whole Life Cost per Premises Excl. Connection costs	£1,150.48	£986.88	£897.26	£805.52	£802.31	£770.31

The data summed up in this table calculates costs for the whole of Great Britain. The detail of capital expenditures per cost item is shown below for each geotype:



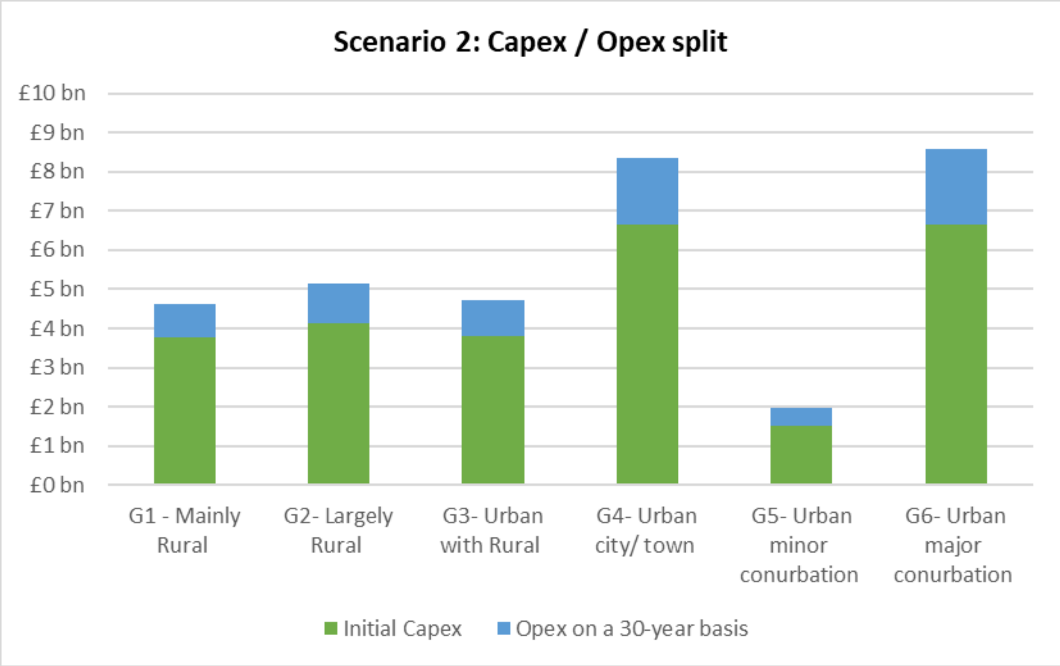
The total Capex for the whole of the UK in this scenario is therefore £26.5 billion. It would decrease to £20.1 billion if connection costs were excluded.

The average unit cost incorporates an important variation of premises costs according to their location, geotype and connection type. The below graph describes how fast unit costs increase. Thus, it shows that connecting the most expensive 5% of premises pushes up the total cost significantly:



Opex amount to a total of £579 million per year, which is identical to Scenario 1 since they only differ in capital requirement. Total Opex are not equal because of a different distribution of Capex refresh costs in time. The whole life cost projection for the UK is therefore £33.4bn – or

£27.0bn if excluding connection costs – distributed across the six geotypes as shown in the graph below:



3.2.1. Specific Feedback on Scenario 2- Re-use of infrastructure

In addition to the comments at 3.1.1, responses relating to the savings from re-use were very strong.

Respondents believed that use of Openreach PIA would result in an average of 33% anticipated reduction in cities and towns; some respondents felt it could be as high as 70% saving in Capex.
There was even greater confidence in savings from PIA in rural; the average was 63%, with responses ranging from 50% to 80%.

Reductions were anticipated from re-use and sharing of municipal or utility assets, with an average of 32% saving in urban and 35% in rural, with less responses in the 60-80% range than for PIA.

3.3. Fibre to 5G (i.e. lamp-post).

The principle purpose of this scenario is to determine the extent to which the cost of rising columns / optical distribution points and premises connections could be offset through using the RAN layer of 5G architecture to provide a fixed wireless access connection.

Since 5G would only be put in place in urban areas, scenario 3 involves FTTP in geotypes 1 to 3 and is therefore identical to scenario 2 in those areas.

Such a deployment will also increase dramatically available mobile capacity: provided the frequencies are available in the mobile chipset, this should also benefit mobile users.
Assumptions have been made on the following elements:

3.3.1. Fibre to the Lamp-post

As explained in part 2.2.3, the design attribute assumed 10 base stations per square kilometre. GIS simulation calculated the built-up surface area in geotypes 4 to 6; it indicated an average premises density in urban areas of 2,000 premises per square kilometre. This would equate to 200 premises covered per small cell – enabling 1Gbps+ bandwidth consumption per customer, given use of the 26GHz frequency band.
Therefore, 200 premises per small cell is a valid hypothesis on both surface area and capacity grounds.

On this basis, approximately 90,000 small cell base stations would be required to cover the areas under geotypes 4 to 6.

GIS designs were made of a core fibre network between OCN to OSC and on to lamppost; to serve modelled base station locations as shown at section 2.2.3. An extra 'civil works' cost was also added to 10% of the network to plan for non-existing ducts to connect both the ring and any 'drops' to street furniture. The above-mentioned possibility that existing ducts are already provided to lampposts has been taken into account in determining this figure.

These produced a capital cost of £25.2m for the sample size across geotypes 4 to 6, giving a weighted total Capex for a core fibre network to all base stations across geotypes 4 to 6 of £318m (geotypes 1 to 3 being served by FTTP as per the scenario design).

3.3.2. Ring topology core network

The fibre link between OSC and lampposts was then designed as a 'ring' topology; the cable connects two OSCs while passing through several stations in street furniture along the way. This architecture provides additional resilience in the design.

The ring topology was then simulated in the GIS design to measure network length. This calculated an average network length of 500m per base station.

Provision of ring topology added an extra £4.5m to the samples in the model, giving a revised weighted total Capex for a ring topology core network in geotypes 4 to 6 of £413.5m.

The cost of the OCN and OSC was then added, along with the active equipment at each of these locations.

This produced a weighted total Capex for an active fibre ring core network to serve the 5G base stations in geotypes 4 to 6 of £1.08bn

This breaks down to £12,000 Capex per base station, which is £60 per premise.

3.3.3. Cells

The development of 5G standards is still in progress and will take some time yet. Associated 5G trials also use 'pre-production equipment', which make both performance and unit costs unreliable for this cost analysis.

Nonetheless, available data and information has been gathered and compiled from various sources, including:

- Research from the 5G centre of excellence at Surrey University
- Outputs and usability estimates from the LSTelecom study
- Cost assumptions from the Oughton and Frias report, 2016
- IEEE TechFocus Briefings, June 2017
- Unattributable cost estimations from equipment vendors and operators
- Early feedback from current 5G trials by Arqiva, Huawei, etc.

General estimates based on the above suggest the following cost points as reasonable modelling assumptions:

- Cost of an interconnect cabinet/ facility at each base station: £2,000.
- Cost of 5G small cell base station: £4,000
- Provisioning costs per base station: £1,500

  The sum of the 3 items equals £37.50 per premise, being 38% of the cost of 5G network (versus 62% for ring architecture).

Estimated Opex of the network up to lamp-posts consist of:

- Energy consumption for each base station: £150 per annum. This is based on a typical output power of 30 dBm and a typical cost of 0.15£/kWh.
- Wayleaves and licence costs per base station, dependent on whether council (or other) owned street furniture is used: £1,000 per annum. This figure, which is hard to predict accurately, has been given to us by Arqiva.
- Support and maintenance costs: £1,000 per base station.

3.3.4. Customer premises

- Cost of Premises dish and transceiver: £180 per premise including installation. With a modelled 200 premises per base station, the total premises connection cost equals £36,000 per base station.
- Provision has also been made for a set-top box similar to FTTP scenarios (for £138).

The total customer premises connection costs add up to £318 per premise.

3.3.5. Overall Cost Profile

Total estimated Capex amounts to £19,500 per base station excluding premise connection costs. When including them, Capex jumps to £55,500 per base station, or £278 per premise.

3.3.6. Performance

As per the design and performance assumptions in Appendix A, premises with FTTP will be able to receive download speeds of at least 1Gbps and beyond. In this scenario 37% of premises (i.e. those in geotypes 1 to 3) have been modelled as receiving FTTP. The other 63% of premises with 5G access could receive up to 500Mbps.

Based on these assumptions, the summary of Capex and Opex costs per premise (calculated from the 10% sample) is shown below, with a yearly discount rate of 9.3% on Opex.

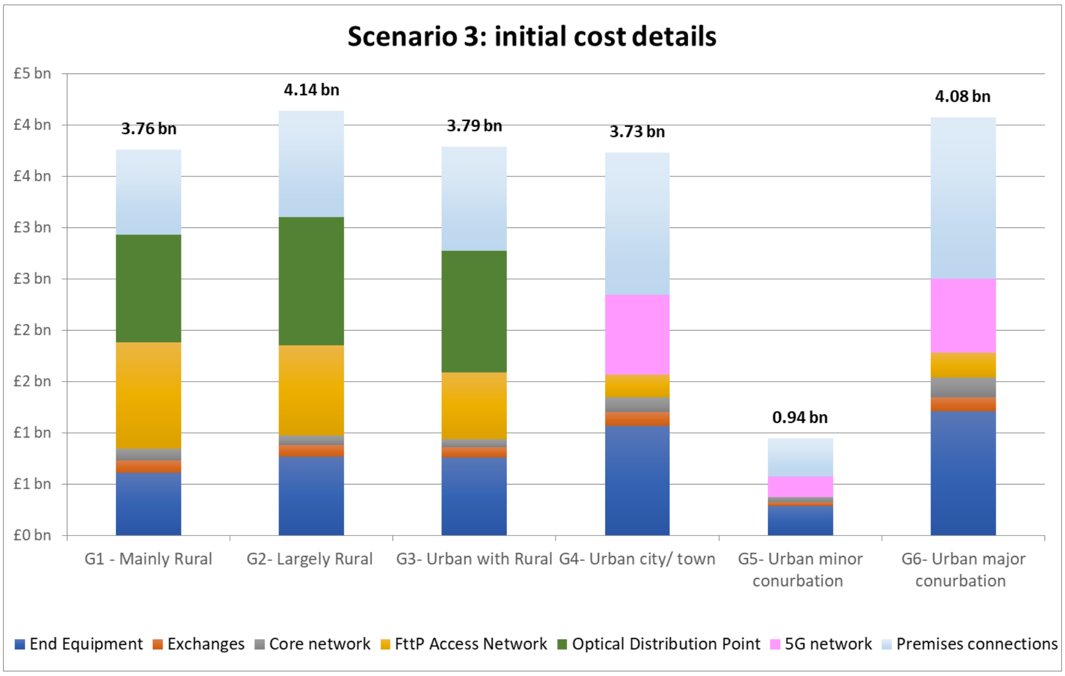
Note that the difference between "premises passed" and "premises connected" lies in premises connection costs. They are excluded in "premises passed", on the basis that these costs would be:

- Only incurred when a customer adopted a service from a provider over the infrastructure
- Borne by the service provider or the customer in line with the service provider's commercial model.

	G1- Mainly rural	G2- Largely rural	G3- Urban with significant rural	G4- Urban with city and town	G5- Urban with minor conurbation	G6- Urban with major conurbation
Capex per premises passed (= excl. connection costs)	£886.77	£746.83	£671.42	£275.93	£277.56	£258.27
Capex per premises connected	£1,137.24	£997.30	£918.69	£455.93	£457.56	£438.27
Opex per premises connected	£25.45	£21.49	£19.18	£26.37	£28.22	£24.20
Whole Life Cost per Premises (on a 30-year life)	£1,273.01	£1,132.51	£1,051.24	£595.09	£587.80	£576.53
Whole Life Cost per Premises excl. Connection costs	£1,022.54	£882.04	£803.97	£415.09	£407.80	£396.53

(Costs above for geotypes 1 to 3 are for 100% FTTP coverage as per the scenario assumptions)

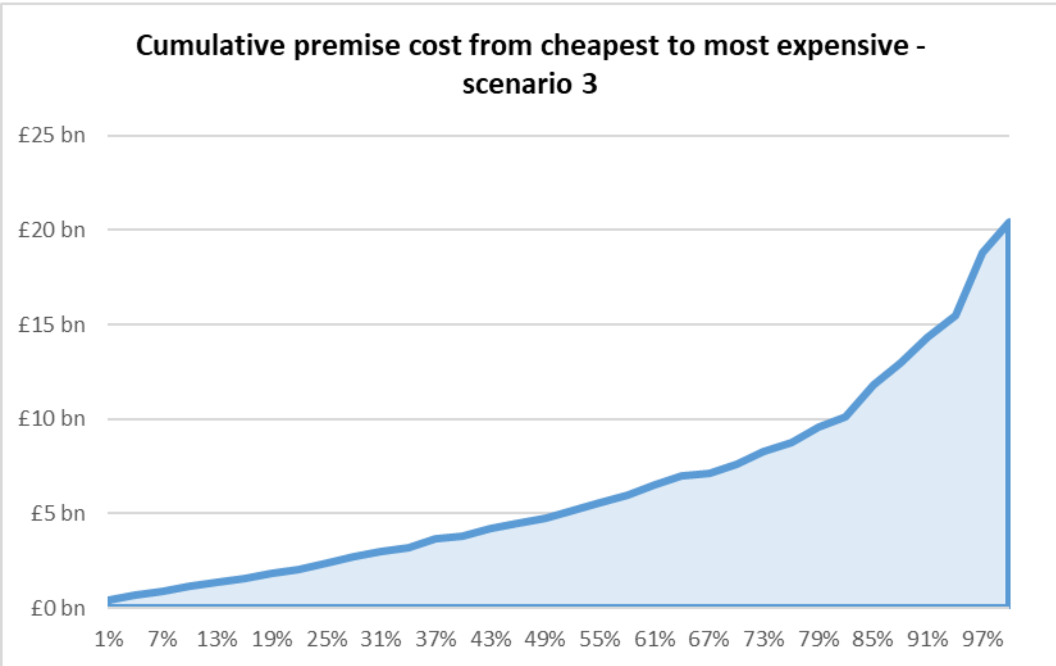
The data summed up in this table calculates costs for the whole of the UK. The detail of capital expenditures per cost item is shown below for each geotype:



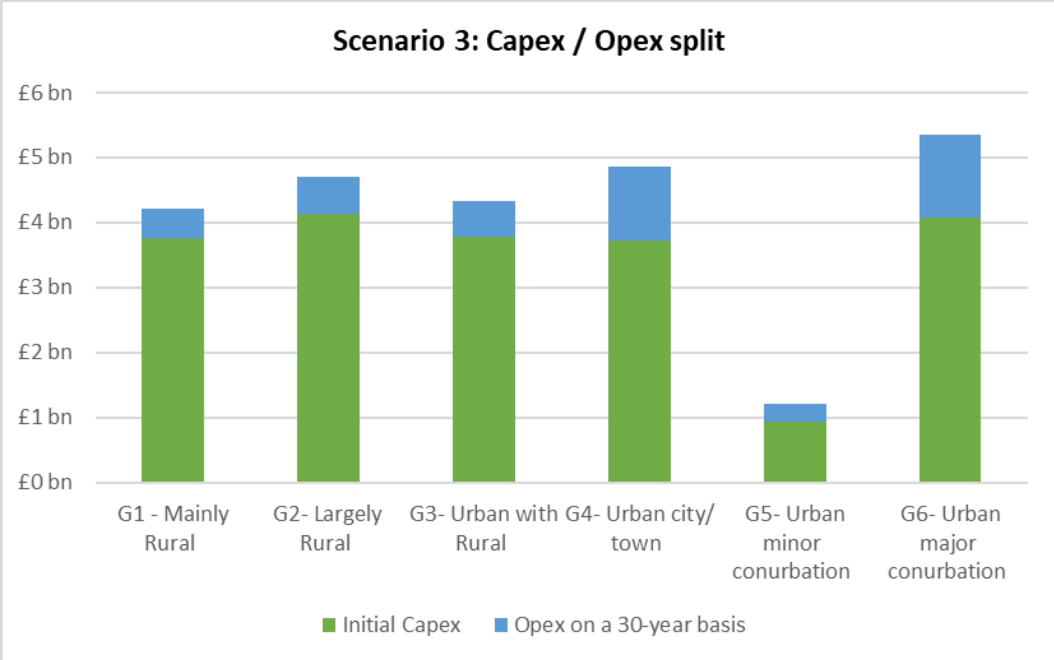
(The 5G-network cost includes the specific elements described above for a 5G-access solution, i.e. the provision of a ring topology fibre transit network and small cell base stations)

The total Capex for the whole of the UK in this scenario is therefore £20.4 billion. It would decrease to £14 billion if connection costs were excluded.

The average unit cost incorporates an important variation of premises costs according to their location, geotype and connection type. The graph below describes how fast unit costs increase. Thus, it shows that connecting the most expensive 5% of premises pushes up the total cost significantly:



Opex amounts to a total of £751 million per year. The whole life cost projection for the UK is therefore £24.7bn – or £18.2bn if excluding connection costs – distributed across the six geotypes as shown in the graph below:



3.3.7. Feedback on Scenario 3- 5G for Access

Opinion on how much of an impact 5G would have as an alternative access technology was relatively consistent, with around 50% of respondents feeling it would have moderate impact in the next 5 years in urban and very limited impact in rural over the same timeframe.

There was little consistency around the impact on 5G access costs; with opinion on Capex ranging from a 60% reduction to a 30% increase and Opex increasing between 10% and 40%. This reflects the uncertainty at this time around 5G technology deployment costs and models.

3.4. FTTP with FWA/ LR-VDSL in rural areas

This scenario consists in modelling a fibre network that covers the most accessible 95% premises in the UK. The remaining premises are connected via fixed wireless access.

The assumptions made in scenario 2 are still valid regarding the FTTP component of the model. As for the FWA component, the following assumptions have been made in deriving the cost estimates:

- Base stations have a 500m radius, hence a coverage per location of 1 square kilometre.
- There are 4 sectors per base station (90-degree beam-forming spread)
- Network dimensioning is based on a 1Watt ERP (30dBm) from each base station sector and a 100dB link budget overall

- Sectors are loaded to 37.5 premises per sector, thus one base station can serve 150 premises on average
- Base stations are not sited on an FTTP cable route and therefore rented leased lines have been costed into the design to provide effective transit to the OCN.
- Backhaul rental: £28,000 per Optical connection node. This is based on cluster designs and typical average backhaul length per OCN (about 12 km)
-

Fixed wireless access induces important Opex which have been estimated as follows:

- Licencing and administration cost per premise: £1
- Transit connection rental from Broadcast Location to Node: £800 per base station
- Support and maintenance: £53 per premise

As per the design and performance assumptions in Appendix A, premises with FTTP will be able to receive download speeds of at least 1Gbps and beyond. In this scenario 95% of premises have been modelled as receiving FTTP. The other 5% served by FWA could receive up to 100MBps.

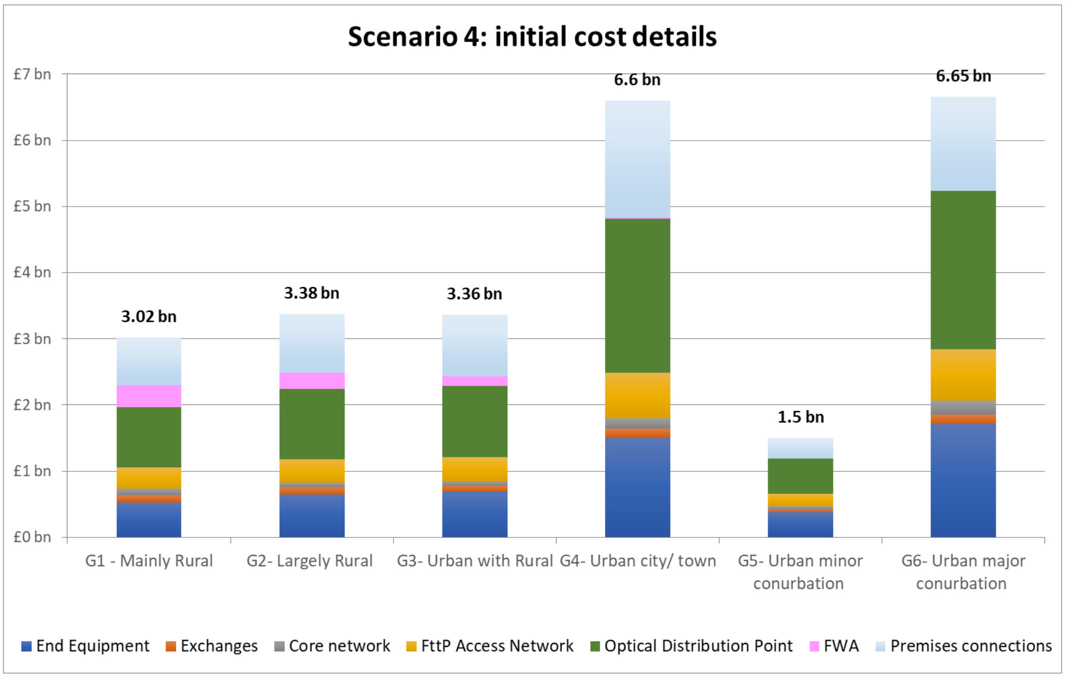
Based on these assumptions, the summary of Capex and Opex costs per premise (calculated from the 10% sample) is shown below, with a yearly discount rate of 9.3% on Opex.

Note that the difference between "premises passed" and "premises connected" lies in premises connection costs. They are excluded in "premises passed", on the basis that these costs would be:

- Only incurred when a customer adopted a service from a provider over the infrastructure
- Borne by the service provider or the customer in line with the service provider's commercial model.

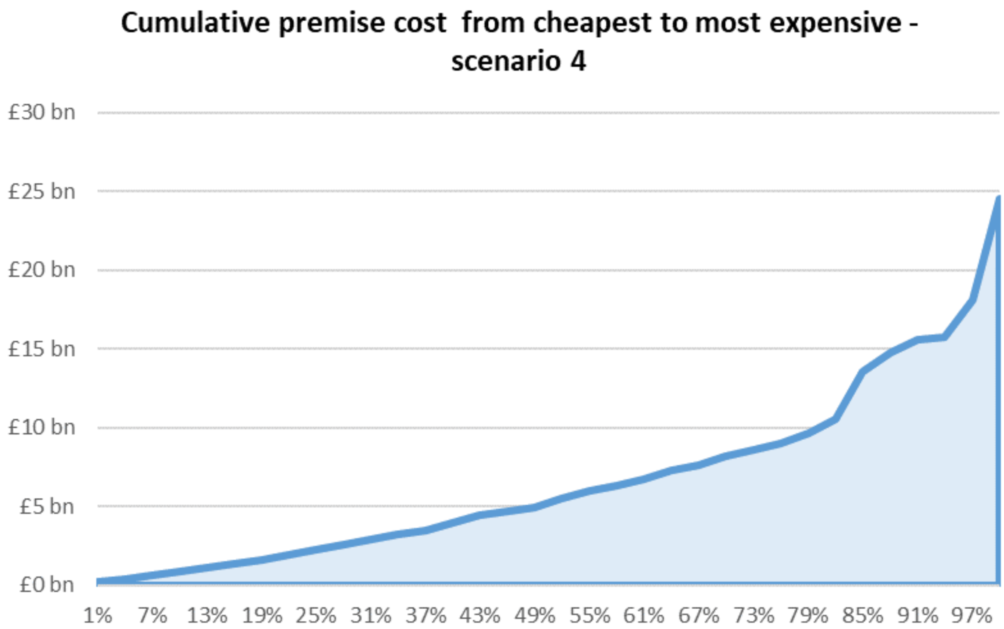
	G1- Mainly rural	G2- Largely rural	G3- Urban with significant rural	G4- Urban with city and town	G5- Urban with minor conurbation	G6- Urban with major conurbation
Capex per premises passed (FTTP)	£690.87	£635.15	£610.23	£591.53	£577.60	£562.59
Capex per premises connected (FTTP)	£941.34	£812.95	£814.79	£806.75	£730.40	£715.39
Capex per premises connected (FWA)	£737.89	£807.53	£778.48	£1,506.63	£0.00	£0.00
Capex per premises connected TOTAL	£913.07	£812.95	£814.79	£806.75	£730.40	£715.39
Opex per premises connected (FTTP)	£20.11	£18.55	£17.73	£16.66	£19.07	£16.18
Opex per premises connected (FWA)	£70.00	£66.00	£62.00	£60.00		
Opex per premises connected TOTAL	£27.04	£22.44	£19.93	£16.74	£19.07	£16.18
Whole Life Cost per Premises (on a 30-year life)	£1,203.93	£1,068.91	£1,058.13	£996.42	£955.11	£923.11
Whole Life Cost per Premises excl. premises connection	£988.26	£905.26	£861.95	£782.75	£802.31	£770.31

The data summed up in this table calculates the costs for the whole of the UK. The detail of capital expenditures per cost item is shown below for each geotype:

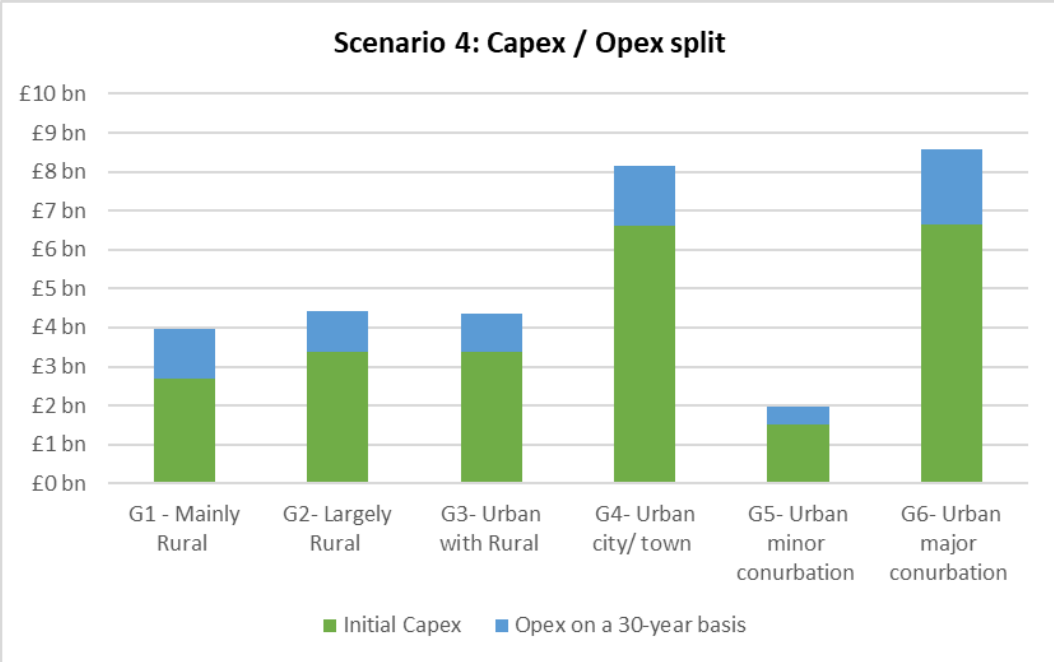


The total Capex for the whole of the UK in this scenario is therefore £24.5 billion. It would decrease to £17.9 billion if connection costs were excluded.

The average unit cost incorporates an important variation of premises costs according to their location, geotype and connection type. The graph below describes how fast unit costs increase. Thus, it shows that connecting the most expensive 5% of premises pushes up the total cost significantly:



Opex amount to a total of £591 million per year. The whole life cost projection for the UK is therefore £31.5bn- or £24.9bn if excluding connection costs- distributed across the six geotypes as shown in the graph below:



3.4.1. Feedback on Scenario 4 and 5- FWA

Capex: Survey respondents felt that capital costs were over-estimated in the model by between 5% and 25%. The greatest variation related to town/ semi-urban use.

This is to be expected, as detailed designs would be required for denser environments and the design principles applied vary between operators.

There was also some variance relating to the costs of active equipment. Again, this is to be expected, as there is currently a significant range in quality and costs of radio equipment available in the UK.

Opex: Opex were felt to be slightly over-estimated (10%- 20%). Much of this related to costs of backhaul, which operators claimed to be slightly cheaper in general than the modelled values.

Nonetheless, the feedback overall supports the principles of using FWA as described in the approach and points to the potential for FWA Opex to be lower in practice that the models imply.

3.5. Mixed Technology Deployment.

The cost model for this scenario relies heavily on the assumptions described in paragraph 2.3.5. These have been applied to the cost estimations as follows.

- It is assumed a G-Fast device costs £370 per port and a DOCSIS device costs £92; each of them can connect 40 premises.

- Based on the premises lengths calculated through the GIS FTTDp model (see 2.2.5 for details on the modelling), 94% of UK premises are located within 200m of the fibre network in a scenario deploying G.Fast nodes over FTTDpand therefore would receive acceptable service performance. The breakdown of eligibility can be found in the table below.

- Of the 6% remaining premises, very few can be connected via DOCSIS.

- The assumed breakdown and distribution of the 15 million premises (57% coverage) currently reached by Virgin Media coax as stated in paragraph 2.1.7 is as follows:
  - 100% coverage of G6 premises
  - 100% of G5 premises
  - 77% of G4 premises (the most urban parts, e.g. Bristol).

The cost model assumes premises in G4 to G6 beyond 200m will be served with DOCSIS where available. Where both G.Fast and DOCSIS infrastructure is available, a 50% usage of each is assumed. As for the remaining premises located in rural areas, this scenario uses FWA as a cost-effective technology for very rural areas.

Yearly Opex are similar to the ones induces by FTTH with a few changes:

- Line maintenance: £13 per premise instead of £11.5 because copper maintenance needs to be added
- G.Fast and DOCSIS devices maintenance: £200. It assumes one intervention per Distribution Point per year on active equipment
- G.Fast and DOCSIS devices energy cost: £187.5. Assumes powering from the Central Office at a cost of 0.15£/kWh

The following table shows the distribution of technologies used in this scenario:

	Percentage of premises eligible to G.Fast	Percentage of premises allotted to G.Fast	Percentage of premises allotted to DOCSIS	Percentage of Premises allotted to FWA
G1	88%	88%	-	12%
G2	92%	92%	-	8%
G3	95%	95%	-	5%
G4	96%	50%	49%	1%
G5	95%	50%	50%	-
G6	97%	50%	50%	-

As per the design and performance assumptions in Appendix A, the design maximum for G.Fast and DOCSIS premises assumes up to 300Mbps download. This applies to the 94% (plus) of premises in this scenario served by G.Fast or DOCSIS. The other 6% served by FWA could receive up to 100MBps.
In this scenario no premises have been modelled as receiving FTTP download speeds of at least 1Gbps and beyond.

Based on these assumptions, the summary of Capex and Opex costs per premise (calculated from the 10% sample) is shown below.

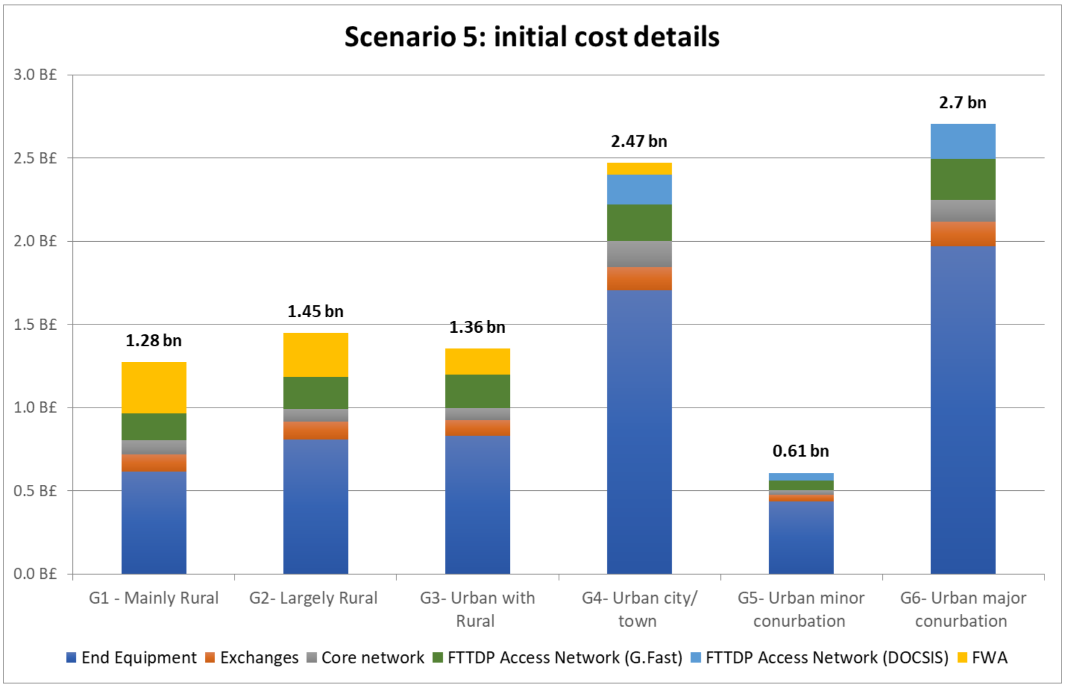
Note that the difference between “premises passed” and “premises connected” lies in premises connection costs. They are excluded in “premises passed”, on the basis that these costs would be:

- Only incurred when a customer adopted a service from a provider over the infrastructure
- Borne by the service provider or the customer in line with the service provider’s commercial model

In this specific scenario, premises connection costs are only incurred by FWA since the FTTDpFTTDp network relies on existing infrastructure.

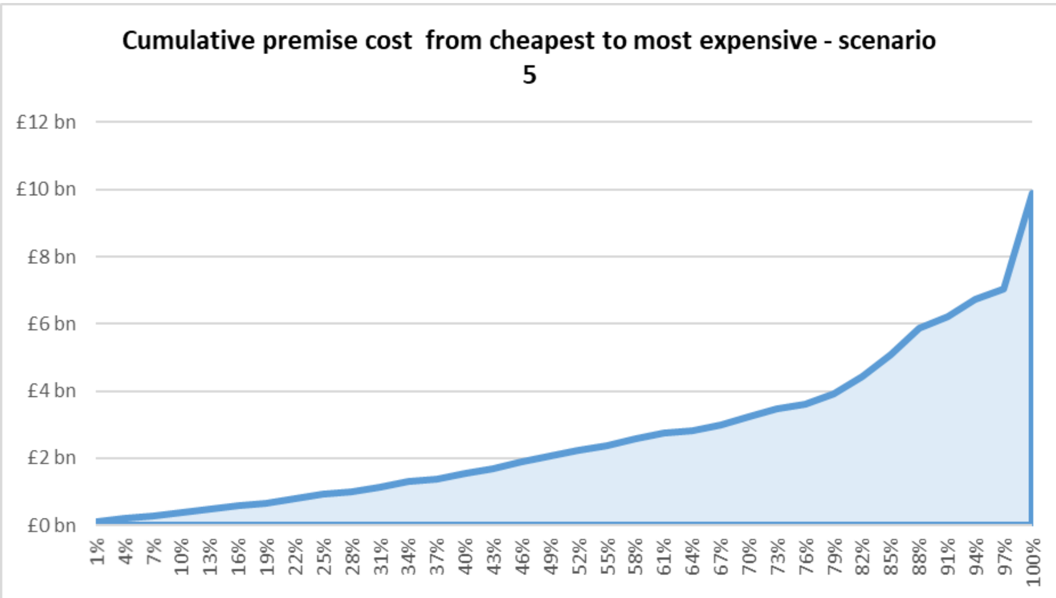
	G1- Mainly rural	G2- Largely rural	G3- Urban with significant rural	G4- Urban with city and town	G5- Urban with minor conurbation	G6- Urban with major conurbation
Capex per premises (G.Fast)	£323.80	£306.57	£303.41	£151.78	£150.59	£147.55
Capex per premises (DOCSIS)	£0.00	£0.00	£0.00	£144.01	£145.72	£143.24
Capex per premises (FWA)	£353.03	£345.23	£307.05	£364.52	£0.00	£0.00
Capex per premises connected TOTAL	£846.93	£841.64	£804.60	£946.35	£0.00	£0.00
Opex per premises connected (FTTDp)	£373.08	£349.37	£328.47	£302.30	£296.31	£290.79
Opex per premises connected (FWA)	£48.49	£41.82	£36.84	£32.36	£33.58	£29.40
Opex per premises connected TOTAL	£64.00	£64.00	£64.00	£64.00		
Whole Life Cost per Premises (on a 30-year life)	£50.35	£43.60	£38.20	£32.68	£33.58	£29.40

The data summed up in this table enables the calculation of costs for the whole of the UK. The detail of capital expenditures per cost item is shown below for each geotype:

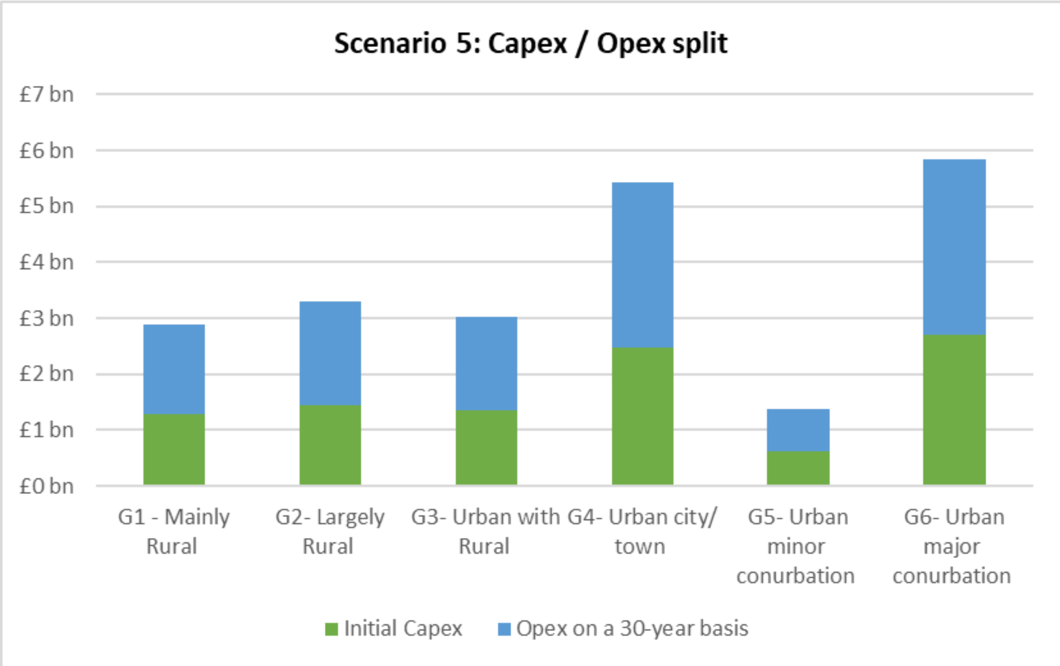


The total Capex for the whole of the UK in this scenario is therefore £9.9 billion. It would decrease to £9.4 billion if connection costs associated with FWA were excluded.

The average unit cost incorporates an important variation of premises costs according to their location, geotype and connection type. The graph below describes how fast unit costs increase. Thus, it shows that connecting the most expensive 5% of premises pushes up the total cost significantly:



Opex amounts to a total of £1.11 billion per year. The whole life cost projection for the UK is therefore £21.9bn – or £21.3bn if excluding connection costs, distributed across the six geotypes as shown in the graph below:



4. Supporting analysis

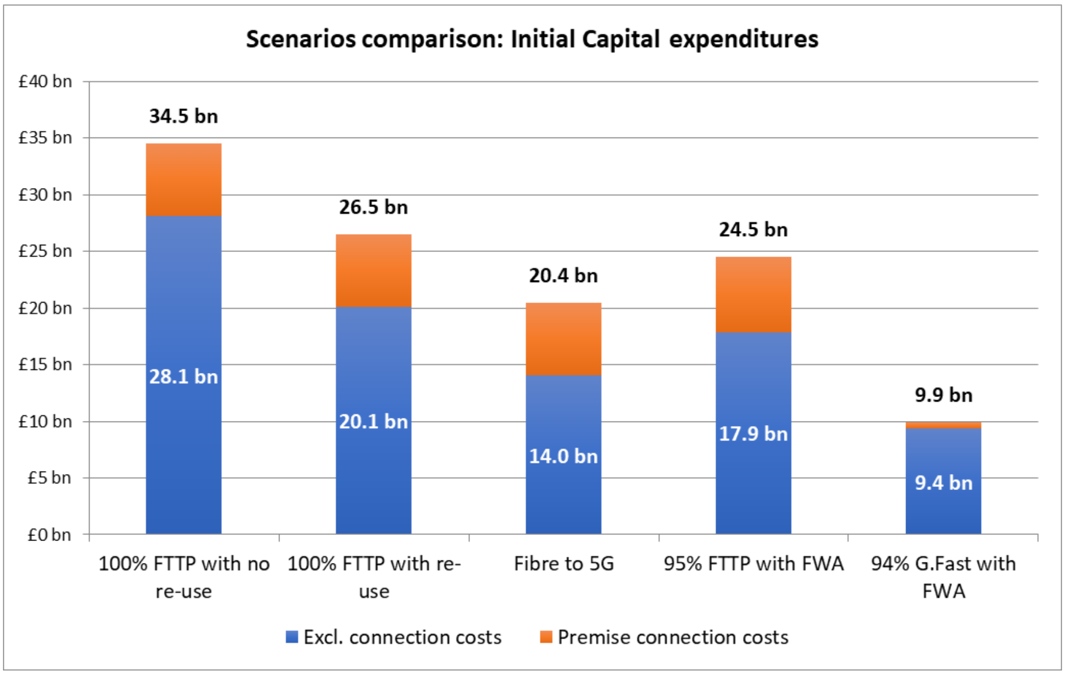
4.1. Comparison of Technology Options

There are significant differences between the cost profiles of the different scenarios modelled for this analysis. This section compares the various key components and highlights these differences.

4.1.1. Capital Requirements of each Scenario

A summary of the Capital required by each Scenario is shown on the diagram below. The Capex is separated into:

- Capex relating to Total Premises Passed (in blue)
- The additional Capex relating to Premises Connected (in orange)



Scenario 5 is obviously highly competitive for a network provider in terms of Return on Capital Employed, as it provides access to the same number of premises as the other scenarios for much lower capital, albeit with lower performance in terms of achievable download speeds (300Mbps for the 94% reached by FTTDp and 100Mbps for the 6% infill using FWA).

Also, implicit in Scenario 5 are the following:

a. Unfettered access to the existing copper or co-axial infrastructure for operators using it

b. Field trials and subsequent deployments corroborate the performance and quality assumptions described in Appendix A.

The marginal difference in capital requirement between Scenarios 2 and 4 is also noteworthy. The difference in providing FTTP to 95% and FWA for the remainder, versus 100% FTTP with infrastructure re-use is

- £2.2bn for Total Premises Passed- or £70.69 more per premise for the final 5% when distributed over the 31.1m assumed UK premises
- £1.97bn for Total Premises Connected- or £63.30 more per premise for the final 5% when distributed over the 31.1m assumed UK premises

This highlights the importance of apportionment and allocation of premises connection costs; the study has assumed the typical industry model where the network provider and operator carries the Premises Passed costs and the service provider connecting the customers carries the Premises Connection components.

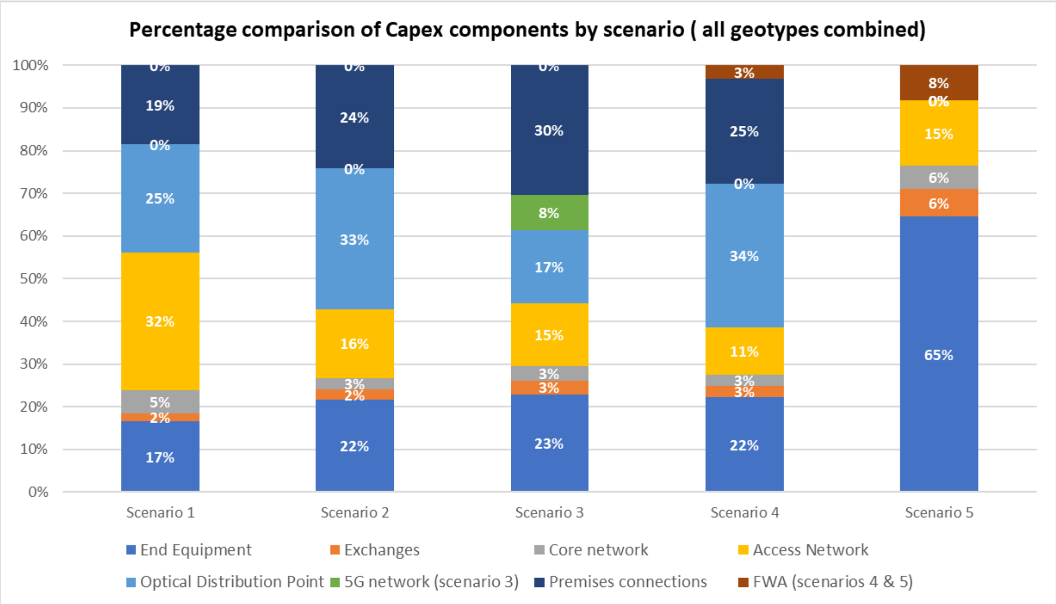
Different Network architectures will place the final Optical Distribution Point (ODP) at different average distances from premises; the assumptions used in this analysis are in Appendix A. If ODPs are placed closer to premises, the network operator cost components increase- whilst ODPs placed further away increase service provider costs.

A differential of less than 11% between 100% and 95% Premises Passed with FTTP as above could be absorbed through judicious network design, making premises connections for service providers higher and hence compromising the business case. Whilst outside of the remit of this analysis, ‘like for like’ comparisons assessing both the costs of Premises Passed and Connections costs must be carefully considered.

4.1.2. Comparison of Capex Cost Components

The cost component breakdowns in each individual analysis were also combined to identify any common key components.

The graph below shows the percentage breakdown of Capex components in each scenario:



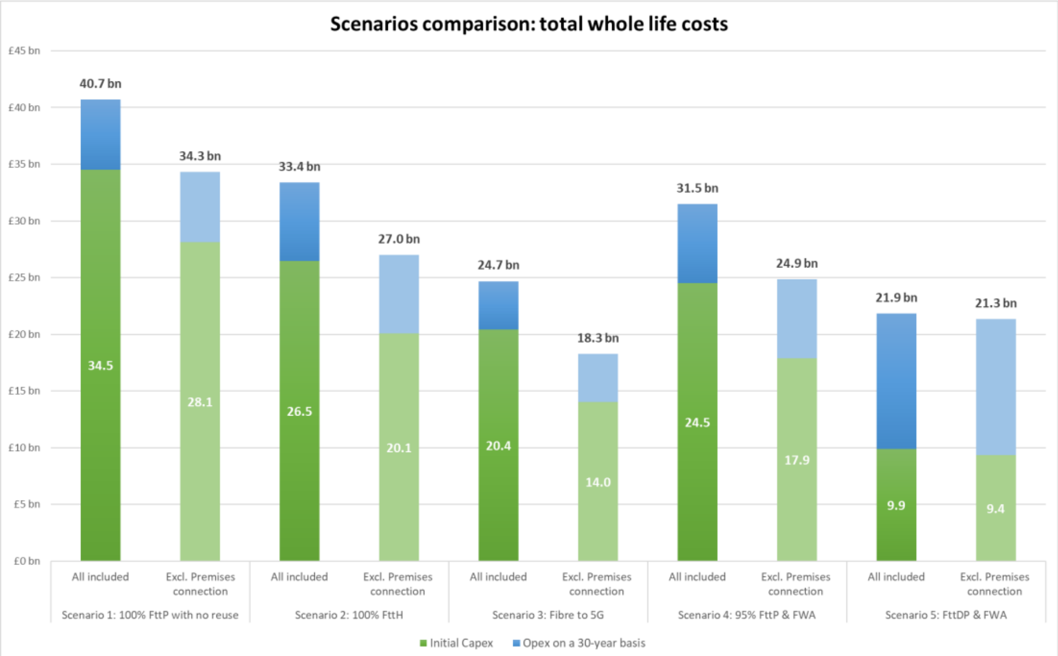
In every FTTP/ fibre scenario, the access and premises distribution network components (including the Optical Distribution Points) make up the highest percentage, namely:

- 58% in scenario 1
- 49% in scenario 2
- (even) 32% in scenario 3
- and 45% in scenario 4

This is a much smaller percentage in scenario 5, purely because a significant element of the access network exists already (but still represents 15%) and there is no distribution network Capex as the existing copper is used. Therefore, the cost of the end equipment (including the G.Fast network terminating equipment) becomes dominant, at 65% of the total Capex.

4.1.3. Whole Life Cost Comparison

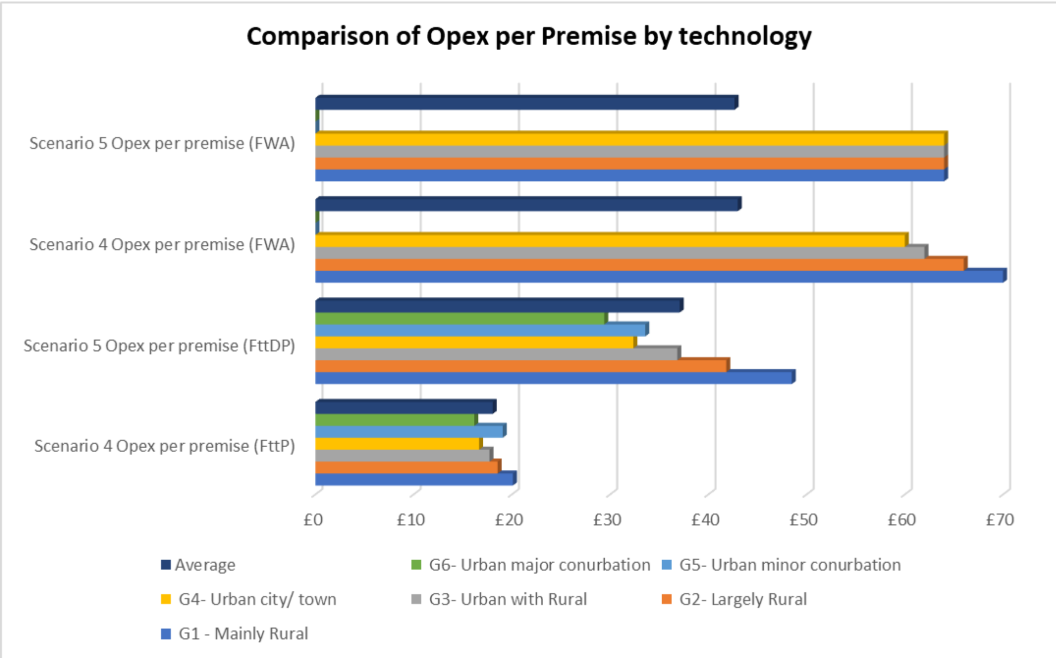
The overall costs vary greatly when considering whole life expenditures. The graph below displays Capex, Opex and whole life costs per Premises (for a life assumed to last 30 years) in each scenario:



Even though scenarios 1 and 2 carry the second lowest Opex per premise, (at £0.6bn that is 15% of the total cost), capital costs even with the re-use of infrastructure are the highest.

However, when premises connection costs are passed to the service provider, scenario 3 becomes the cheapest of all, the second cheapest being 15% more expensive.

The key driver for such a change in scenario costs is Fixed Wireless Access Opex. FWA offers an alternative up to 100Mbps but carries higher Opex as is shown on the graph:

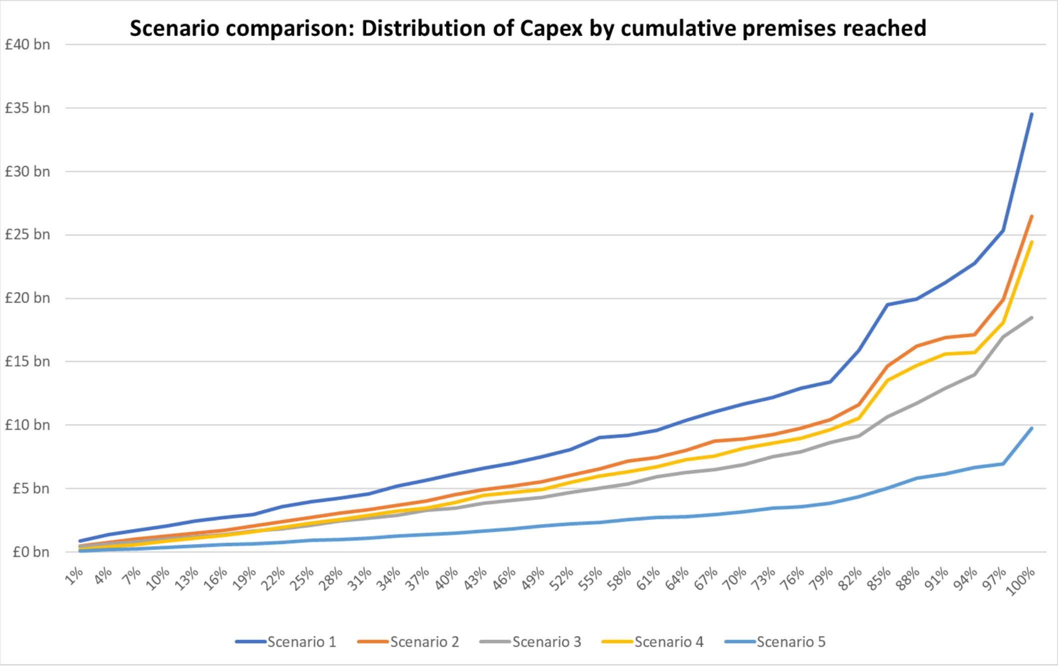


FTTP carries significantly lower Opex than FTTDp, which in turn is around half the Opex of FWA. The higher FWA Opex arises from higher levels of maintenance and licensing. There would also be high rental costs to FWA operators for backhaul provision to base stations; however to maintain consistency between the scenarios for comparison, these have not been included. Instead, provision has been made in the associated Capex of these scenarios for the deployment of fibre to base stations.

4.1.4. The Cost of Increased coverage

The whole life life cost charts display an almost identical "hockey stick" shape to the initial Capex cumultaive premises profiels shown by scenario in section 3 above. The figures definitively present a steady increase in cost during the first two thirds of premises, with a sharp rise in premises from geotypes 1 and 2. The marginal costs of the last 5% are on average 4 times higher than the ones around the median.

The cross-scenario graph below demonstrates this overall view:



It is therefore important to consider the relative whole life costs of other technologies to determine the suitability of a blended mix, particularly in geotypes 1 and 2. Keeping this shape in mind may be useful when considering the fact that building the initial infrastructure may take years (see following part). Therefore, the order in which it would be deployed, and thus areas covered first, should be chosen with care.

4.1.5. Rollout Assumptions

A final key component in comparing the overall economic value of the infrastructure scenarios is the time it is likely to take to rollout each of them. This has an impact in three ways (in ascending order of potential business case value):

a. It has economic impact on the national GDP

b. Longer rollout times incur an overall larger cost of capital (even with 'patient investment' such as is likely to be attracted to longer term infrastructure)

c. Faster deployment generates higher volumes of connection sooner, which has a profound impact on the overall return from each connected customer and Average Revenue Per User (ARPU)- business critical KPIs in telecommunications business cases.

A further element of analysis conducted, as part of this study was the development of a model to simulate rollout of various scenarios, using input data gathered from the industry and contractors. International reference cases were also used to test the model.

The full report can be found at Appendix H but in summary, the indicative rollout durations modelled for scenarios 1, 2 and 5 were as follows:

- Scenario 1 (FTTP with new infrastructure)- c.15 years (180 months)
- Scenario 2 (FTTP with re-use)- c.12 years (144 months)
- Scenario 5 (G.Fast, DOCSIS and FWA)- c.7.5 years (89 months)

These are based on the deployment of c.900 construction and implementation crews across the UK, covering all 6 geotypes in proportion.

The projections for Scenario 5 include the time required to extend deployment of active G.Fast equipment further into the infrastructure and is line with the projections given by Openreach for the rollout of 10million premises by 2020.[4]

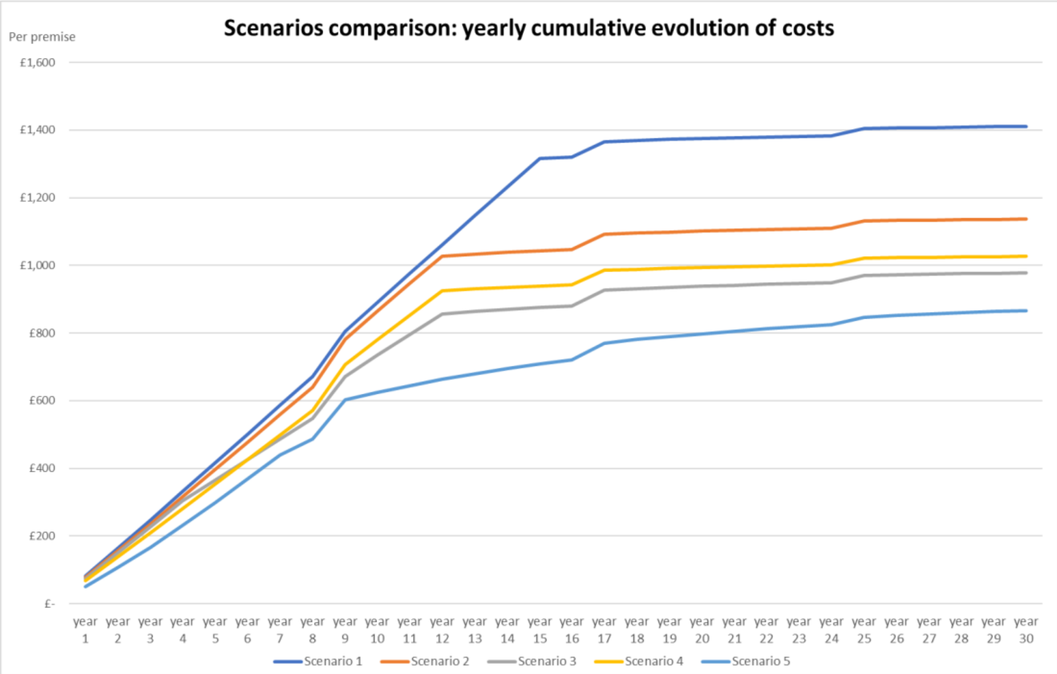
Conversely, Scenario 2 assumes a simpler rollout and deployment programme, where the greatest resource effort will be fibre splicing at the distribution and connection points.

However, it is important to ensure the cost comparisons across all scenarios are based on the same assumptions. The cost analysis therefore 'normalises' the build time for each scenario to 15 years.

4.1.6. Profile of Costs during rollout

The time scale below provides a comprehensive view on the evolution of costs as time passes:

[4] Openreach press and market statements on G.Fast deployment plans https://www.ispreview.co.uk/index.php/2017/05/bt-details-coverage-first-330mbps-g-fast-broadband-pilot-areas.html



5. What if analysis

5.1. Varying scenario assumptions

Following analysis and comparison of the results, the study was then extended to consider three key 'what if?' questions:

1. What if the Universal Service Obligation required 100Mbps minimum download speed to every UK premise?

2. What if FTTP was provided to every premise as an evolution of an initial G.Fast/ FTTDp rollout?

3. What if the deployment of 5G for premises access utilised infrastructure already provided for other 5G applications?

These three questions were considered by developing 'sub-scenarios' which allowed a high-level impact analysis of each.

The results of this analysis are shown below.

5.1.1. Changing the Universal Service Obligation (USO) Threshold

UK Government currently intends to establish a Universal Service Obligation (USO) to ensure provision of at least 10Mbps headline download to every premise in the UK.

Openreach plan (with support from BDUK) to reach at least 98% of UK premises with VDSL through FTTC by the end of 2018. Various alternative providers have plans to use FWA and other techniques to deliver the remaining premises with the aid of vouchers provided through BDUK's Better Broadband Scheme.

Given these initiatives, the intended USO is achievable using currently planned infrastructure. The BSG Report of May 2017[5] supports this and provides helpful guidance, which is now being considered by DCMS as part of the decision on the approach to a USO.

However, as consumer needs evolve, the USO is likely to increase. This study was asked to consider the infrastructure and cost implications if the USO increased to 100 Mbps. The study found that:

a. VDSL will not be suitable

b. FWA base stations will only be able to provide effective performance if cell radius and user loading is reduced, requiring a greater cell density (say 200m even in rural areas).

c. 5G will be subject to similar issues as FWA. In a rural environment, the scarcity of the deployment might affect the economics of the solution as well requiring a trade-off between a lamp-post deployment and the frequencies being used

d. G.Fast will only be able to guarantee 100Mbps to a smaller number of premises closer to each DP (say within 100m of the nearest node); to overcome this, DP deployment would need to be extended even further into the infrastructure.

In the case of (b) to (d), all technologies will also require greater capacity backhaul to distribution nodes or base stations 'deeper' into the infrastructure. This is likely to require fibre provision to those points.

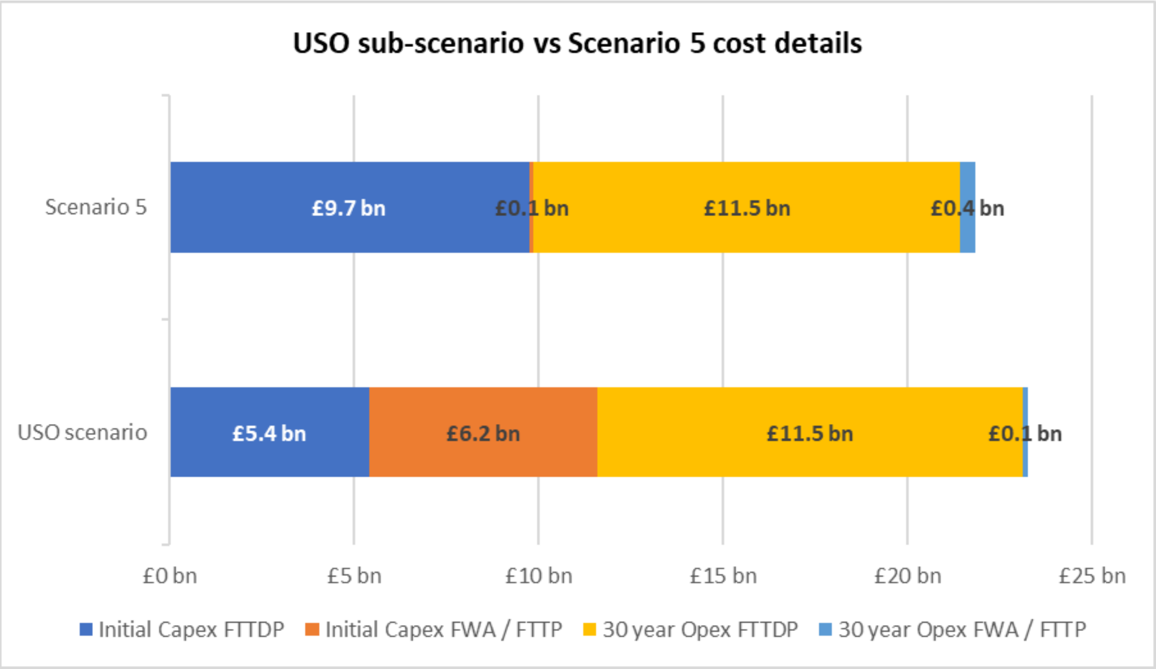
In the case of (d) particularly, it is unlikely that G.Fast nodes can be extended without the architecture closely resembling FTTP.

More granular data is required to provide a reasonable cost estimation for an increase of USO to 100 Mbit/s. However, in the absence of this, an indication of likely cost can be achieved by assuming a variation to scenario 5 as follows:

- FTTDp still reaches 94%
- However, FWA is substituted with FTTP for the remaining 6%- guaranteeing 100Mbps performance for these premises alongside providing an effective contingency for any premises receiving poor G.Fast performance.

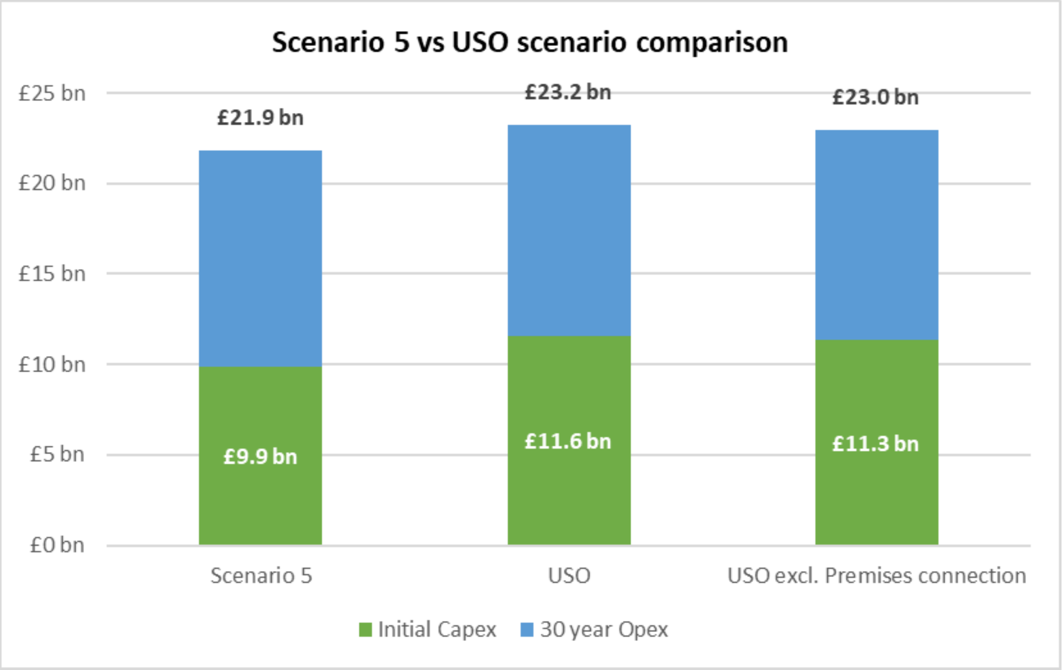
The details of cost components are displayed below. As expected, most of the expenses are Opex carried by FTTDp:

[5] Impact of a Broadband USO in the UK, published 4 May 2017 from Plum Consulting, commissioned by the Broadband Stakeholders Group.



(Note: FTTDp Capex is higher in Scenario 5 than in USO scenario because of the way costs are allotted to technologies. Indeed, a portion of the fibre network is used for both FTTDp and FTTP, and thus its costs are equally divided between the two technologies).

This hypothesis was modelled as a 'mini-scenario' in order to compare it with scenario 5. As expected, the initial Capex requirement is higher since FTTP infrastructure is more expensive than setting up FWA. Regarding whole life costs, it appears USO remains slightly more expensive than Scenario 5 in the long run. Despite being lower than FWA Opex, the appeal of FTTP Opex is offset by the initial cost.



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5.1.2. Switching from FTTDp to FTTP

The purpose of this part is to examine the idea of deploying an FTTDp network and then switching to FTTP a few years later. It could seem appealing because it provides a relatively cheap upgrade in the short run (to FTTDp) while paving the way for an even faster technology in the longer run.

However, this scenario is more expensive than both FTTP and FTTDp because of several factors.

- All the costs of FTTP would have to be borne at some point, so in the long run there would be no absolute cost savings compared to scenario 2- unless the FTTDp deployment and/ or any previous FTTC deployment had provided sufficient fibre count to the cabinet and beyond to reduce materials costs (see section 5.1.6 below)

- Deployment of G. Fast and DOCSIS devices are sunk costs which would not be reused in an FTTP network. Moreover, removing the devices would cost extra money.

- FTTDp requires higher Opex than FTTP. Therefore, during the number of years before switching to FTTP, the yearly expenses would be higher than it would have been with FTTP in the first place.

- Finally, cables that were deployed for FTTDp may not carry enough fibre. Indeed, an FTTDp network does not require as many fibre ends as FTTP: usually a couple of fibre ends per Distribution Point, while FTTP needs 40 of them (note: one Distribution Point serves up to 40 premises). The cost of installing these fibre amounts to £1.8 billion.

- However, whether or not too few fibre ends were installed and thus could only provide for FTTDp has no quantitative impact in absolute on total cost at the end of the day. This is because it is considered the necessary cost will be paid at some point, whether it is in year 1 or 15. However, it has a sizeable qualitative impact on deployment in terms of:
- Financing (spending on fibre either in year 1 or 15)
- Operational organization
- Potential extra cost from redundant interventions
- In the developments below, it has been assumed the fibre count is insufficient. Had it been assumed otherwise, total cost would not have been changed at the end of the day: the only difference is that £1.8 billion would have been spent earlier. (This number accounts for the extra fibre cost for retrofitting; it was obtained in the cost model by counting 40 fibre ends instead of 2 fibre ends from Optical Subloop Cabinets to Distribution Points.)

The below table summarizes sunk costs and the opportunity cost bore by the Opex – in one year, thus undiscounted:

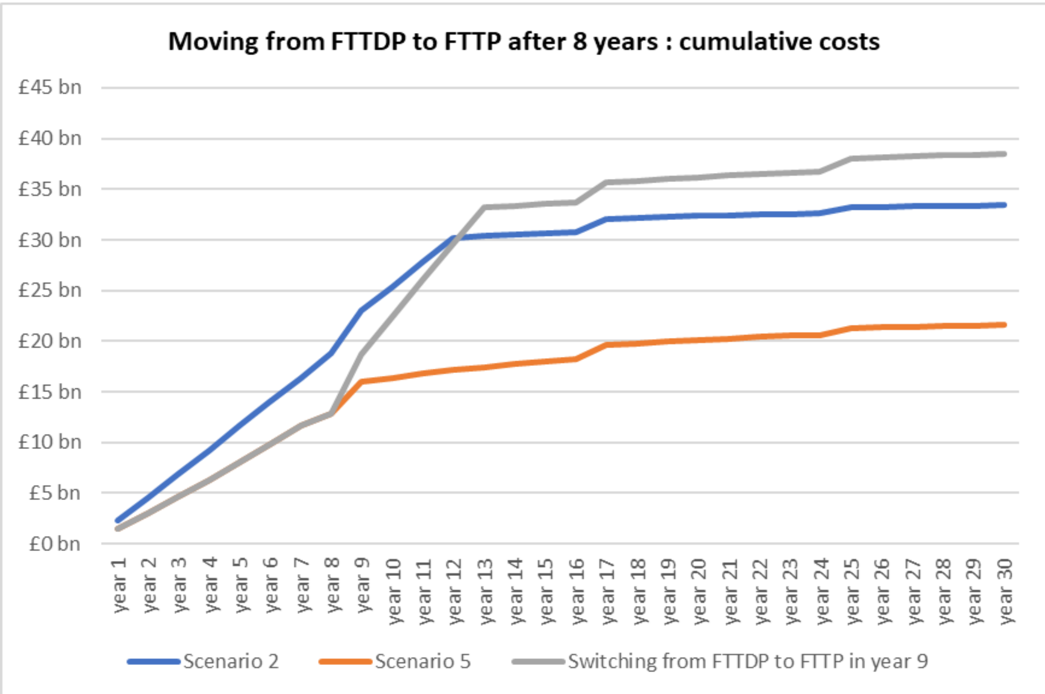
	quantity	Unit cost	cost
Installing G.Fast devices [SUNK COST]	851,387	£370	£315, 013,121
Installing DOCSIS devices [SUNK COST]	329,924	£92	£30, 352,991
Removing FTTDp devices [SUNK COST]	1,181,311	£100	£118, 131,063

Difference between FTTDp Opex and FTTP Opex in 1 year	31,120,065	£17.7	£550,825,150
Total – with 1 year Opex			£1,014,322,325

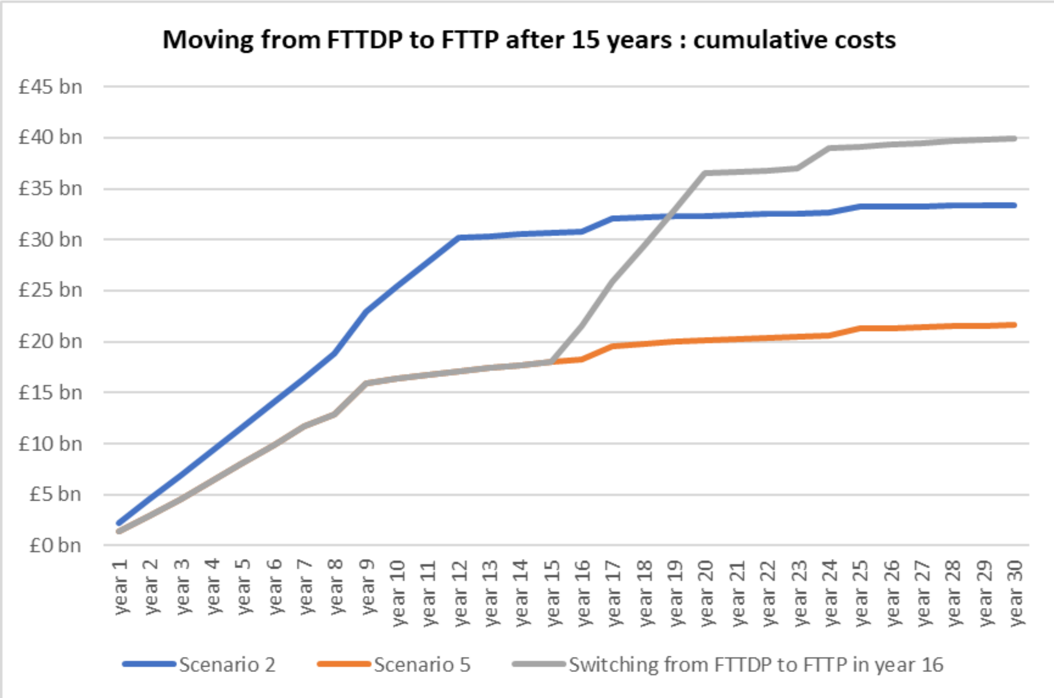
In conclusion, switching from FTTDp to FTTP rather than deploying FTTP right away incurs approximately a £460m fixed cost plus a £550m opportunity cost because of higher Opex.

As an example, below are two diagrams to illustrate the comparison, in the event that it would be decided to move to FTTP respectively 8 years and 15 years after having started an FTTDp network. It is assumed that building the remaining FTTP network would take 5 years, to remain consistent with rollout hypotheses. Capex refresh and Opex are discounted in the below figures for consistency with the approach of the study.

The diagrams compare the yearly cumulative evolution of unit costs. The extra cost induced by switching technology clearly appears on the curve. On the first diagram, in year 13 – thus after all Capex have been paid – scenario "technology switch" is 15% more expensive than scenario 2 (£38.5bn versus £33.4bn).



A similar pattern appears when switching to FTTP after 15 years, with an even slightly higher cost:



5.1.3. Re-use of the FTTC Architecture

The ability to re-use the FTTC architecture that has been deployed could help to significantly reduce the costs of FTTP deployment and to accelerate FTTP rollout. In the FTTP design, a transport network is built to an OSC (Optical Street Cabinet) and a distribution network is built from the OSC to the premise. Between 10-15% of the cost of deploying FTTP comes from the transport network hence a 10-15% reduction in Capex can be achieved if the FTTC fibre can be completely reused.

Our initial calculations indicate that a 48-fibre cable transport core network is required to deploy a FTTP G-PON network (no matter what the level of network openness might be).

If this has been provided to BT Group by Openreach as a Leased Line of fixed capacity (e.g.an Ethernet backhaul Direct- EBD- circuit or equivalent) it will be important to confirm the status of the fibre laid to provide this, the number of fibres available in the cables and the architecture of the network providing the circuits.

We have assumed that the PCCP cabinets cannot be reused (as they were never designed for this purpose and there is probably insufficient space) but that the PCCP cabinet location is a central aggregation point in the network.

More clarity on the FTTC specifications and network dimensioning is required to assist in determining its re-use value.

The same considerations should be extended any technical standards and specifications relating to FTTDp. For example, if a sufficient fibre count is provided in the core network cables to each DP during the initial provision of FTTDp, then this will greatly facilitate any subsequent transition to FTTP.

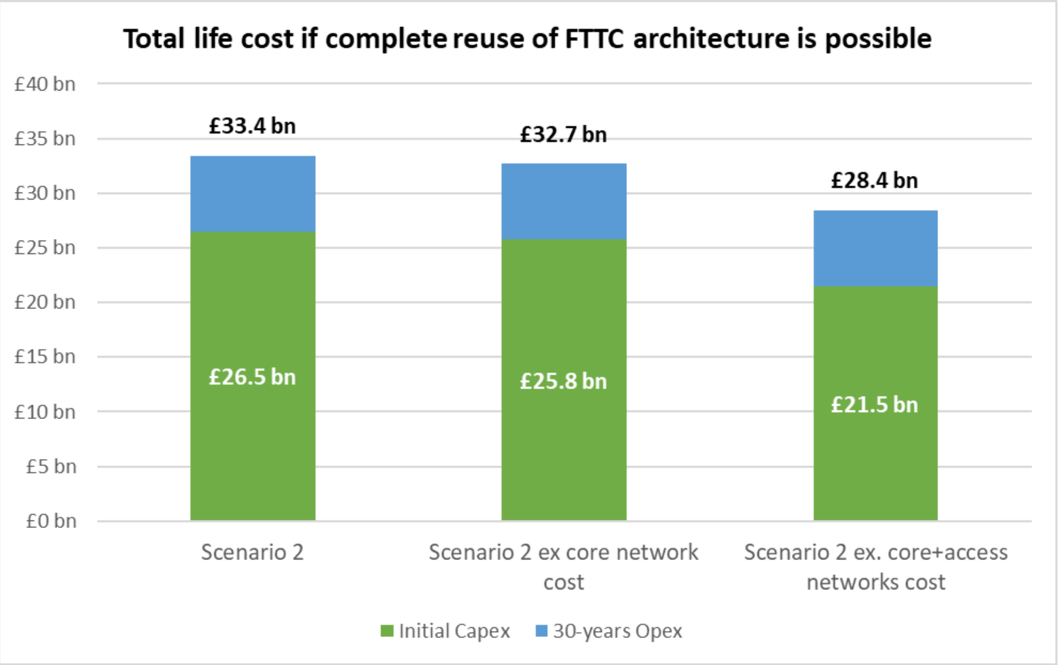
Impact Example of sufficient fibre count existing for FTTP

The following graph models the hypothetical saving in fibre provision on scenario 2 if:

f. Sufficient fibre count exists from the OCN to OSCs (Cabinets)- from FTTC architectures – which is equivalent to sparing core network building costs –

g. Sufficient fibre count also exists from OSCs to DPs- from FTTDp architectures – which is equivalent to sparing both core and access networks building costs –

and compares these to the original scenario 2 estimates.



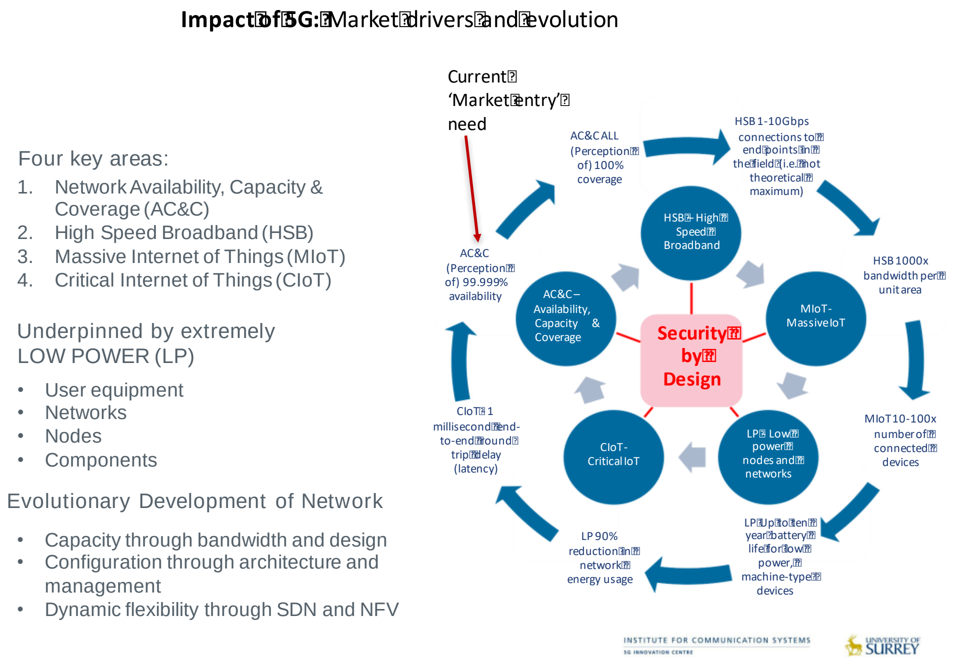
As can be seen, there is a dramatic variation in the Capex required for scenario 2. However, further granular analysis would be needed on this alternative scenario before it could be effectively validated. This should include:

- Confirmation of fibre counts and network architecture configurations
- More detailed estimates on the nature and value of ‘sunk costs’ from switching from FTTDp to FTTP
- Clarification of removal/ reconfiguration costs from this transition
- The impact of substituting the G.Fast device (DSLAM) with a fibre router capable of delivering FTTP and simply providing new fibre between the DP and each premise.

5.1.4. 5G Development

Scenario 3 indicates that 5G as a fixed wireless access solution is competitive in whole life cost terms against other techniques, for example G.Fast and FTTP. However, the entire 5G ‘ecosystem’ covers a much wider scope of future capabilities and requirements than ‘pure broadband’.

Research and existing studies clearly identify a range of services and capabilities that will be enabled and realised through wide-scale adoption of 5G at the RAN, Core and Fabric layers of its proposed architecture. These are shown on the ‘market drivers and evolution’ diagram below:



Current thinking by organisations engaged in strategic development of 5G is that sometime between 2020 and 2030, the 5G core and fabric layers may need to accommodate an average in dense urban environments of 1 million active connected devices per square kilometre.

Network capacity and throughput projections for volumes of this kind could well result in a ‘hyper dense’ architecture of micro-cells (say) 20 metres apart with a minimum of 1Gbps transit. Whilst this will meet even the most demanding of situations such as very low latency for Critical IoT, it will heighten the challenges regarding synchronisation etc already being identified.

Nonetheless, it will impact the scope of this study in two important ways:

a. The capital requirement for 5G ‘fixed access’ will merely be ‘additive’ to the overall business case. Whilst it will not have the capacity offered by FTTP, it is likely to then become cost-effective against other alternative techniques.

b. A network design architecture requiring (probably symmetrical) 1Gbps provision to micro-cells every 20m for transit connection, will greatly strengthen the need for a full-fibre core network down to nearly FTTP levels.

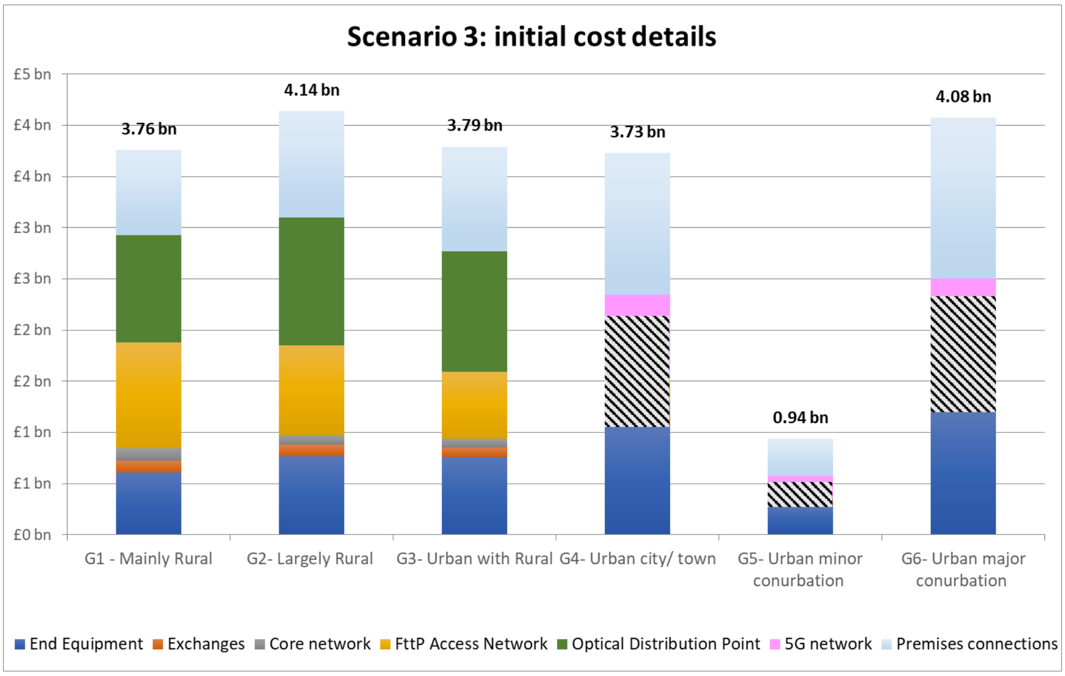
5.1.5. 5G Fixed Access to Premises, assuming 5G architecture is already in place

Scenario 3 assumes that the 5G architecture is rolled out to support fixed 5G access connections to premises only. Therefore, all deployment costs of the 5G architecture are attributed to this one 'use case' for 5G. Whilst this approach is necessary to determine the full 'comparative pure cost', it is also highly improbable, as the business cases for the other services and capabilities described above are likely to be more compelling to operators, particularly MNOs.

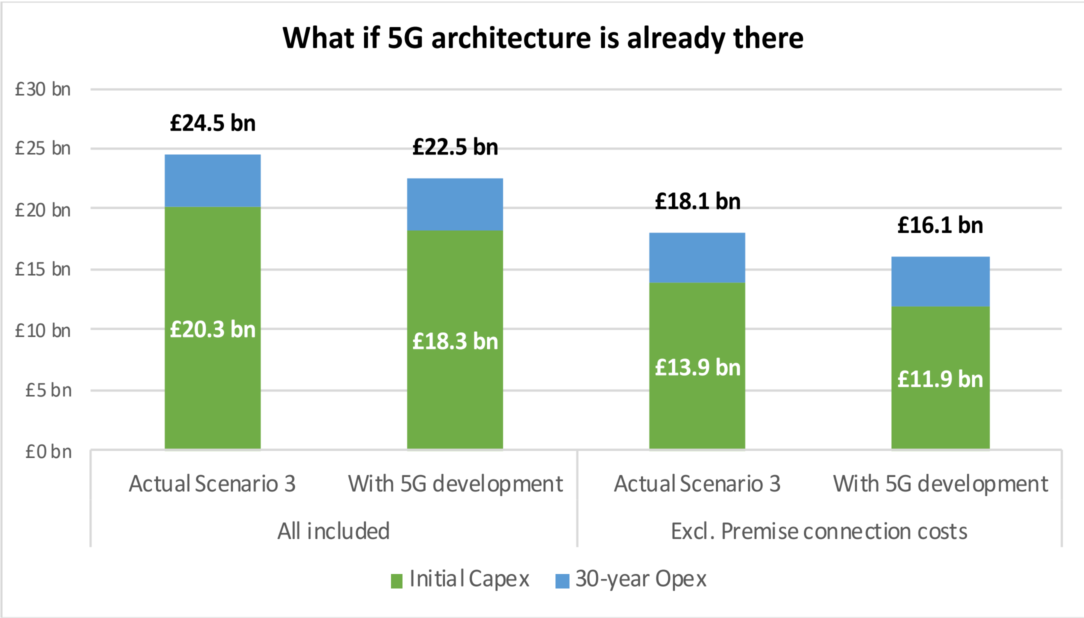
If the provision of fixed wireless access to premises via 5G was added to 5G architecture already in place for these other purposes, then the costs would only be:

- The provision of additional small cells on existing broadcast locations to run the fixed access frequencies (assuming locations existed every 200m for the other services): £4,000 each.
- Provision of the CPE devices as described in scenario 3 (£180 per premise)
- Provision of the set-top box (£138 per premise).

All other cost items would be removed – even though they account for a minor part of the total cost. To give a visual idea of the impact, the cost reduction is represented below by the hashed areas:



The corresponding incremental Capex and Whole Life Costs would look like this:

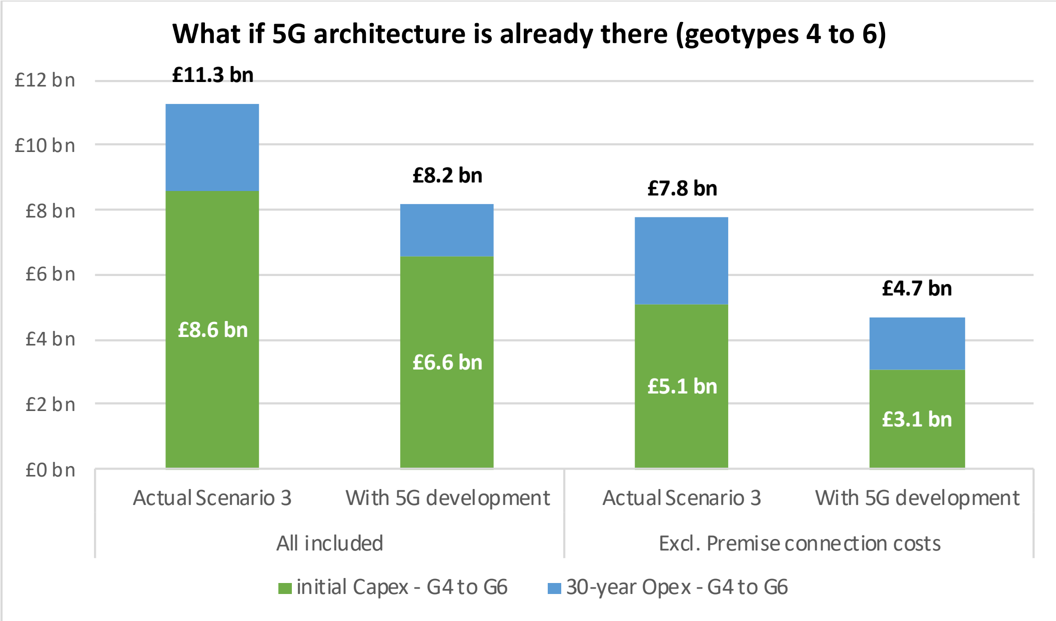


Overall, this represents about a 7% cost reduction on whole life costs across all geotypes, and 10% when removing connection costs too.

There are several reasons why the removed costs in the hashed areas are not greater:

- The cost reduction only occurs in geotypes G4 to G6, since the model only implements 5G in these more urban areas.
- Customer Premises Equipment (CPE) comprises the majority of the total modelled cost in scenario 3, while fibre core network is relatively cheap (notably compared to the access network to premises which is absent in this scenario)
- The higher premises densities in geotypes 4 to 6 mean that the length of core network is significantly smaller than the overall average
- If CPE is removed, on the assumption that users will connect directly to the local small cell via 5G devices, around 60% of the initial Capex is not required.

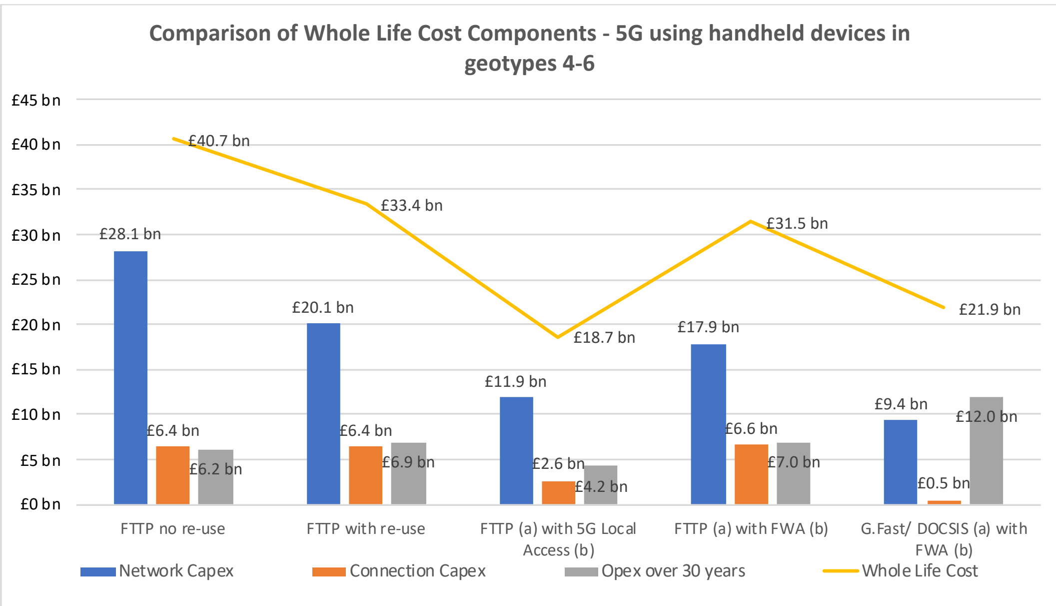
Therefore, a better way of appreciating the level of change is to focus on geotypes G4 to G6- where 5G is deployed in the scenario- and identify the differential with and without CPE.
As displayed in the graph below, within urban geotypes the cost reduction reaches 15% and up to 22% when removing premise connection costs.



This assumes that the core network, including a resilient fibre ring, is provided to every base station. The initial Capex is limited to additional small cells at every base station site for premises connections, together with the Customer Premises Equipment (CPE).

It should be noted that if existing commercial arrangements prevail for 5G, then Mobile Network Operators (MNOs) will bear the CPE costs. This means that mobile infrastructure operators, who will bear the costs of the active and passive components of the core network architecture, will see a greater impact if the fibre core network costs are not shared between the different use cases.

If CPE is removed, on the assumption that users will connect directly to the local small cell via 5G devices, around 60% of the initial Capex is not required. On a 'like for like' basis with the other scenarios, the whole life costs for Fibre to 5G become the lowest. The comparison would then look like this:



5.1.6. Copper Cutover

An assumption has been made that there will be no enforced copper cutover. Whilst this is clearly a factor that would significantly change the cost dynamics and imperatives of the infrastructure, it is either a political policy decision or a commercial strategy decision on the part of the copper asset owners.
In either case, these are externalities to a pure cost review and therefore out of scope of this assignment.

If the copper networks were to be 'retired', the impact on the costs dynamics would include:

- Variations in Opex, as all support costs would then be borne by the fibre networks
- Greater re-use given more availability in the existing ducts, resulting in lower Capex for FTTP deployment
- A lower cost of capital for FTTP deployment, based on increased attractiveness of these technologies to investors.
-

5.2. Impact of Initiatives and Innovation

This section looks at the impact of different initiatives and innovative techniques on the cost analysis above. Due to the stage of development or availability of reference data, the impact they have is described through case studies rather than detailed cost assessment.

Where possible, information has been interpreted from case references to provide indicative figures regarding the percentage change to the cost models.

5.2.1. Impact of Different Construction Techniques

Narrow/ Slot Trenching: Experience shows that trenching in urban environments is a very costly method, both in terms of materials cost and time (through noticing periods etc.). Operators and network providers consider it to be the biggest contributor to urban build costs by a significant percentage. There is also a dramatic 'social cost' in terms of the impact on the day-to-day lives of people living in the construction zone. This is compounded in dense urban areas due to the level of footfall and traffic etc.

As a result, significant effort has been applied to research and development of alternative construction techniques. Of these, micro trenching has developed the furthest and been adopted the most.

Micro trenching refers to civil works using narrow and low depth trenching making use of purpose-built machines that can be used in urban environments. As a consequence, the cost per metre deployed using such techniques is drastically reduced versus normal trenching. This is particularly in three areas (in decreasing order of impact):

- Speed of construction
- Cost of noticing (e.g. micro-trenching enables 'rolling road closures')
- Materials costs

The greatest impact is found through the dramatic increase in metres per day. Construction crews using traditional 'dig and backfill' techniques tend to average 100 metres per day in dense urban areas. Micro-trenching crews report between 200 and 250 metres per day. This is quite often limited to this output due to traffic management planning constraints of 200 metres per day per location.

With the civil labour cost alone representing up to 50% of network deployment, a 40% reduction in build time could reduce the Capex by up to 20% overall.

This was corroborated by responses to the Operator Survey. Six of the 15 responses gave an opinion on the overall reduction that could be achieved from micro trenching or slot cutting techniques. Opinions ranged from 10 to 40% overall, with the average being 28%.

Use of Water Systems: Alternative approaches have also explored the use of other utilities that already have a direct 'path' both along roads and into premises. These include the use of both the potable water and sewage systems, both of which have ubiquitous and highly connected coverage in urban areas, and allow existing pipe infrastructure to be re-purposed to also carry broadband fibre. Extra-urban and rural areas generally have potable water trunk mains to service them, so these existing pipes may provide a conduit to carry bulk fibre to the hard or expensive to reach locations. An additional benefit that would derive from large-scale use of water infrastructure is the notable contribution towards next generation SMART Water Networks for telemetry, control and condition monitoring. Both potable and sewage lines have their benefits and constraints; the table below describes the most relevant:

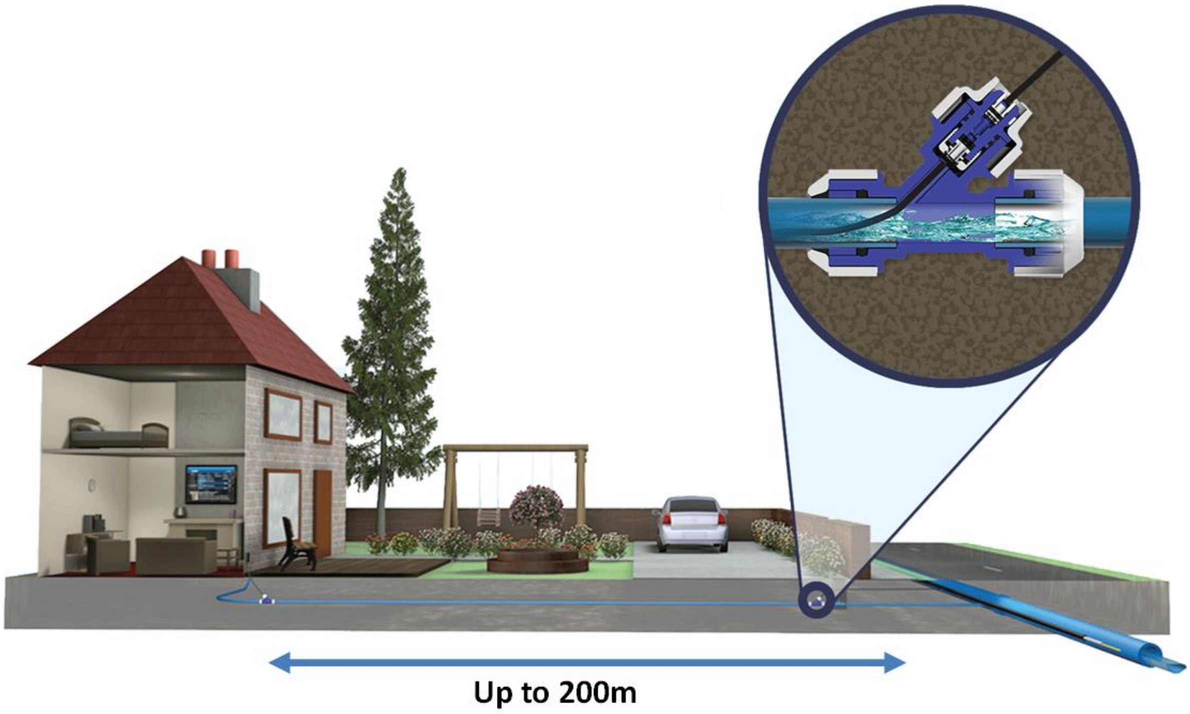
	Sewage Systems	Potable Water Systems
Benefit	• Less regulation, accreditation and certifications • Larger bore piping • Many and regular access points in urban areas (man holes)	• Useful for both home-drop and trunk deployment • Long extra-urban and rural trunk connections
Constraint	• More hazardous and 'uncontrolled' working environment • Poor condition of many sewer pipes • Potential for blockage and ragging due to introduced cable	• Not ideal for trunk main use in urban areas • WRAS (for home-drop) and DWI Reg 31 (for trunk mains) approvals required • Public perception • Pressurised systems (some downtime may be required)

Generally, innovation has tended towards finding ways to overcome the constraints of using potable water systems, such as accreditation and the use of 'non-disruptive jointing'.

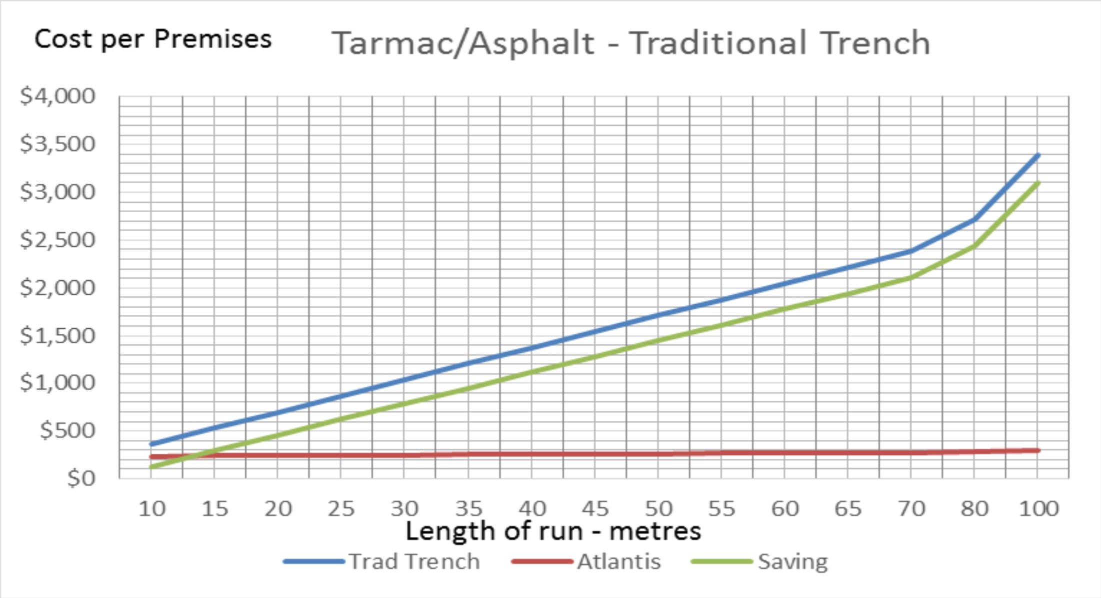
One such set of products for the potable water network is the Atlantis Hydrotec System, developed by CRALEY Group in the UK. The solutions have the capability to utilise both domestic runs for premises access (the D Series) and main water pipes for core transport networks (the T Series). The solution is based on a pipe-in-a-pipe concept where a hollow messenger pipe made from approved materials is installed within a water pipe, down which fibre cables may then be blown; the messenger pipe fully isolates the fibre cable from the water.

Details are provided at Appendix G but in summary:

- The Atlantis Hydrotec D Series (home drop)
- The solution has WRAS accreditation
- It requires only a small pit at each end to access the domestic water supply pipe
- The network provider simply connects to micro-duct tail and installs blown-fibre through to the premises demarcation box
- Easy install regardless of terrain, driveway construction, type or length
- Typical 1 to 2 hour install for any length of run



Cost comparisons have been conducted in the US and New Zealand against all forms of traditional home drop civil construction; high-end savings can be claimed versus asphalt surfaces as shown in this cost comparison chart:



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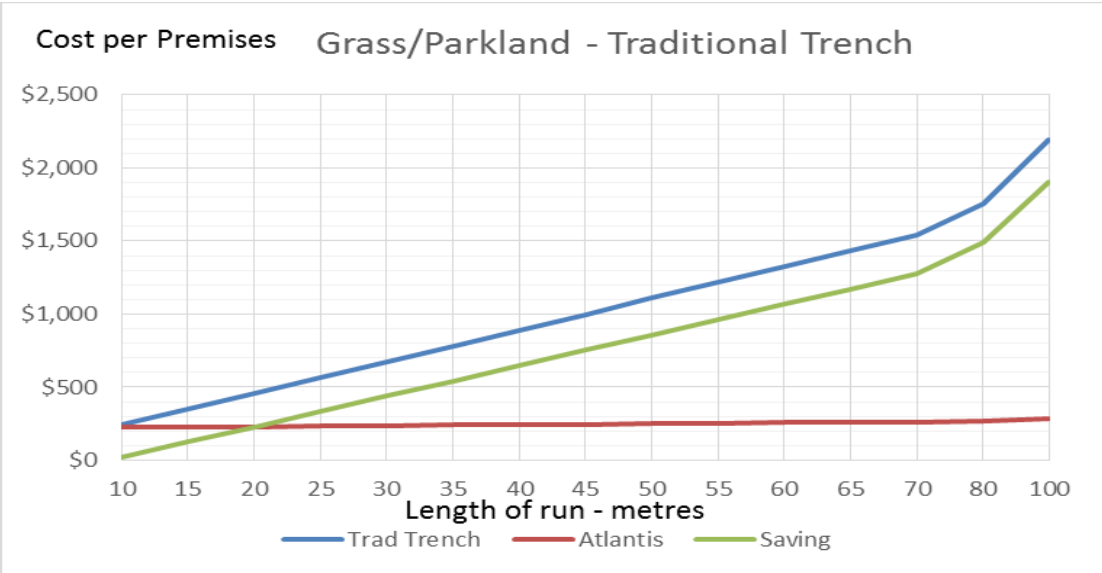


Savings are also claimed against cheaper traditional home drop methods, such as soft dig:

Overall cost benefits have been projected from US trials. These can be seen in terms of the variance in deployment time and cost per premise below

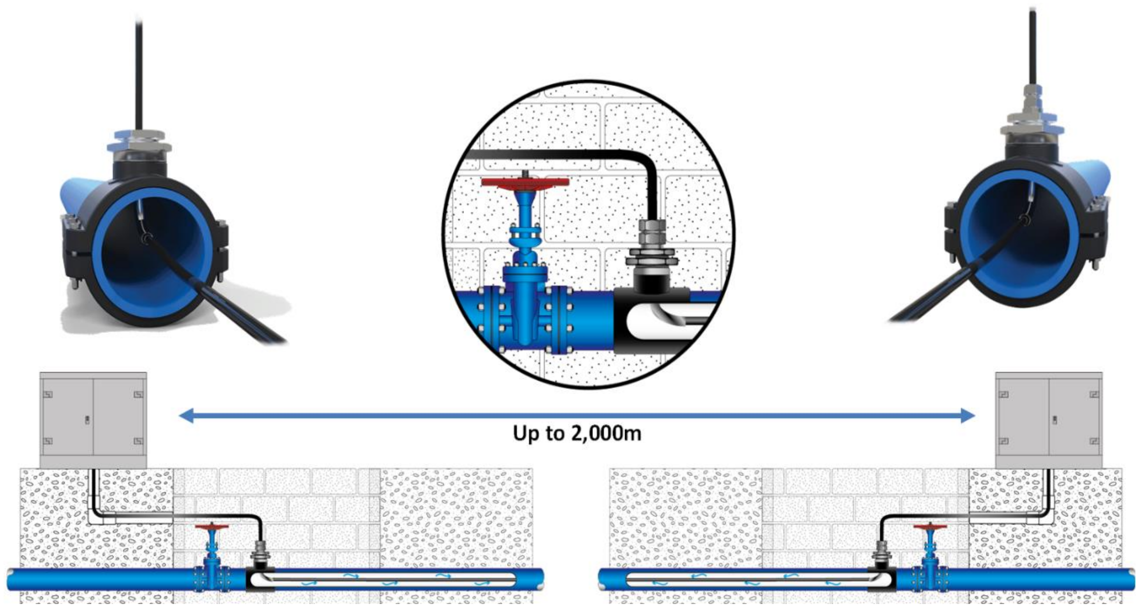
US comparison model of Atlantis Hydrotec provision for a typical city profile

Total 10,000

			Traditional		Atlantis	
	Av % of Homes	No. of Homes	Av. Team Hrs/Home	Av. Cost/Home	Av. Team Hrs/Home	Cost/Home
Grass/parkland - %	45	4,500	4.43	$398	1.04	$228
Concrete slab - %	20	2,000	6.15	$536	1.14	$236
Block paving/Stone sets - %	15	1,500	7.88	$674	1.24	$244
Tarmac/asphalt - %	20	2,000	7.01	$605	1.19	$240

Volume production deployments of the D Series are now scheduled in South Africa, and a number of other territories, for the home drop.

- The Atlantis Hydrotec T Series (trunk main)
- DWI Reg 31 approval is underway with a UK Water Company
- Installed Messenger Pipe will readily allow 288 or more fibres to be deployed
- Minimal civil works and traffic disruption
- A rapid typical 1 to 2 km per day deployment rate

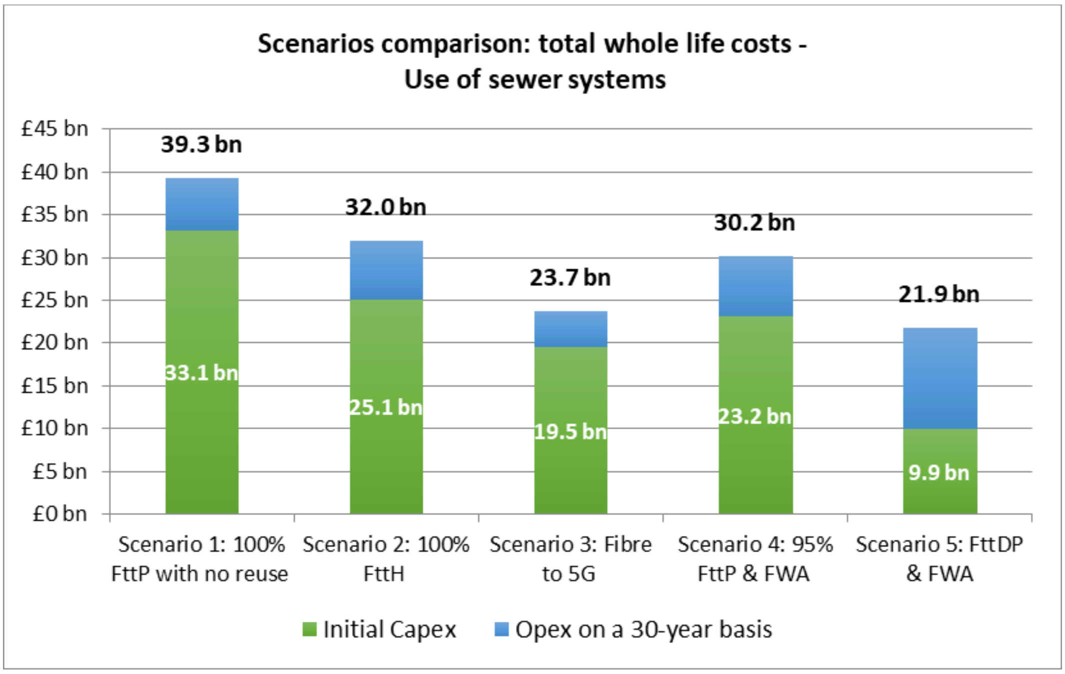


The greatest challenge to the T Series solution has been accreditation and acceptance by Water Utilities, though UK DWI Reg 31 approval is now in progress so will open the doors for its use in the UK. The good example of adoption to date has been the Catalonian Regional Government's promotion of the system with its water utility companies. Over 90km of the clean water supply is now carrying fibre for core networks. Large-scale deployments are in progress now in the USA and Eastern Europe, with many other territories in prospect. Fibre deployed in water trunk mains can also be used as a Distributed Acoustic Sensor for accurate and real-time leak detection and condition monitoring which is a significant spin-off benefit of broadband deployment.

CRALEY Group also claims to have resolved the primary issues surrounding the use of sewer pipes with its Breeze Liner system with a technique, which combines pipe re-lining/refurbishment with a fibre micro-duct integral to the liner wall.

- The Breeze Liner system (sewer pipes)
- Thermo-plastic in-situ laminated re-liner
- Fibre micro-ducts built into the wall of the liner
- Issues of poor pipe condition permanently resolved
- No ragging or blockage problems
- Minimal civil works and traffic disruption

The impact on total costs would amount to an average 4% cost reduction:



Use of Power Distribution (Poles): Depending on the height of power poles; the use of local mains voltage distribution could provide alternatives in certain cluster deployments. In Ireland and France fibre deployment is made possible by local electricity distributors under certain transparent rules. These include for example:

- The installation of fibre cable a specified minimum distance underneath power
- The use of a physical load calculator for pole load including under severe weather conditions, etc)
- General Health and Safety priorities.
- However, it should be noted that in most countries, regulation stipulates the use of either telecom OR power poles in any one deployment 'zone'- switching between poles in any one run is generally no permitted.

The benefit of using power distribution poles is a cost saving from new civil infrastructure provision where none currently exists. The general provision cost of a new pole in the UK is around £260. However, it is difficult to predict the extent that new duct or pole would be required without detailed survey. Therefore, we have not modelled any additional benefits from deploying over power poles as part of this analysis. Power poles will be used if they reduce the linear length of the network deployed.

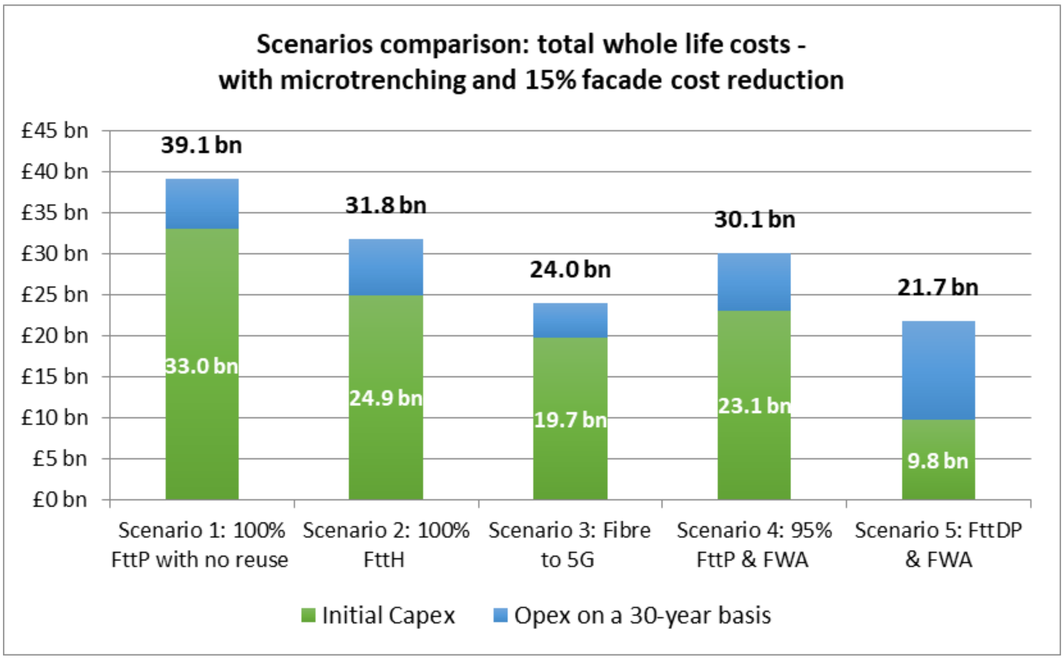
Use of Facades etc. The use of building facades is already a very common practice in certain countries; Spain and its territories being one. It is clearly a very flexible means for deploying fibre, particularly where terrain or geophysical constraints are particularly difficult. It is also used on Multi Dwelling Units, MDU's or terraced housing, or when houses are close but not touching, with the use of catenary wiring.

The cost of Façade needs to include consent costs, consenting normally requires both the resident and the landlord if different. Consenting normally takes place in the evening and weekends and in most cases, takes on average 3 visits per home to gain the correct authorisations. This cost is offset by the cost reduction in deployment, however it still ranks 3rd in the cost of deployment, after aerial and ducted vaulted deployment methods.

Nonetheless, there are significant challenges within the acquisition and retention of Wayleaves for facades; for example, one ''difficult owner' could block the deployment of a cluster of homes. This technique does not require specific tools to deploy but requires a large coordination effort in licencing and Wayleaves. Consideration of 'special measures' within revisions to the Electronic Communications Code may help alleviate this. However, as a regulatory consideration this is outside the scope of this study.

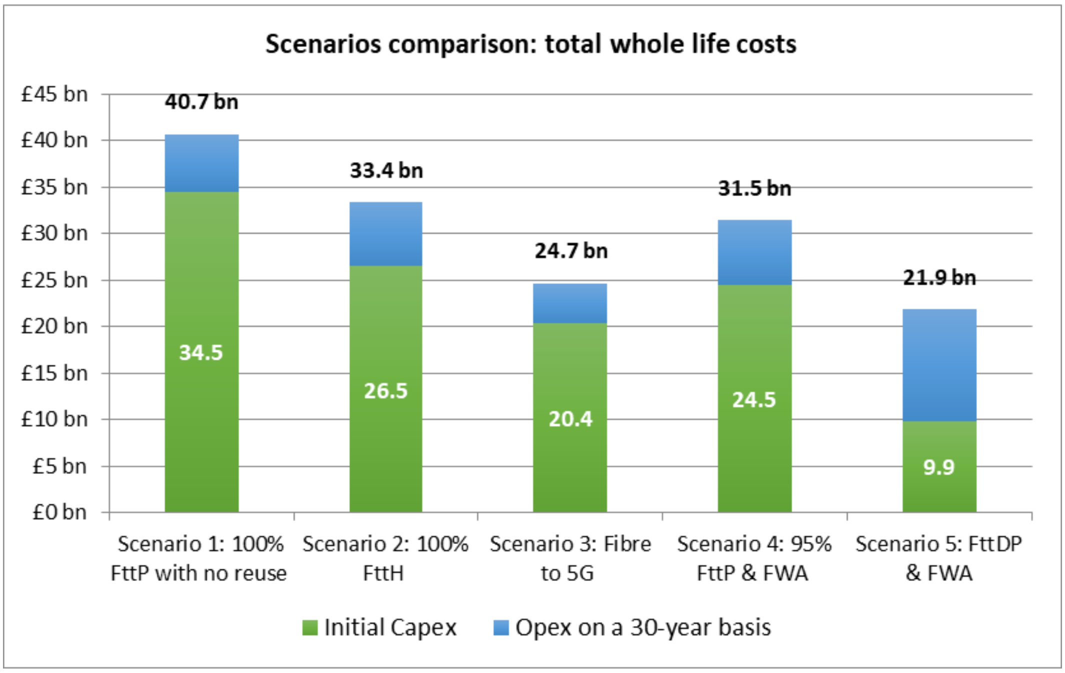
Evidence from other deployments show that the use of facades deployment can reduce up to 15% of the Capex in a chosen area in comparison with traditional FTTP deployment.

Impact of a scenario with both micro trenching and reuse of facades



The impact is therefore around a 5% global reduction on whole life cost – slightly less in scenario 5.

The graph showing the original model calculations is shown below for comparison:



5.2.2. Impact of Different Commercial Models

The scope of this study included consideration of different commercial models that could have an impact on the cost of deployment or of running new digital communications infrastructure. The scope did not include consideration of models that were:

- More attractive from a government perspective in terms of subsidy or grants
- Private initiatives to assist in the raising of investment

A high-level review was conducted across a number of sources, including:

- The EU Guide to High Speed Broadband Investment
- The FTTH Council guidance and resource materials
- General industry research.

From this review, three models were identified that met the criteria of the study. These are described below.

Community Broadband Model- **'Self-Build'**. This model has been adopted in various countries, most commonly in deep rural areas where investment and rollout by private operators is considered 'uneconomic'. The model primarily revolves around the establishment by local residents of a 'Community Interest Company' or similar legal entity, through which local investment is channelled as debt or equity. This reduces the need for external investment of difficult business cases, with longer than average payback periods and lower returns.

However, the greatest direct impact on capital and operating costs comes from 'sweat equity'. Local people are encouraged to invest their time instead of (or as well as) their money- and hence massively reduce the labour costs of build. They also offer 'free' Wayleaves or easements over their land for duct routes- thus saving significant time, effort and risk in route planning and development.

There are a number of 'landmark' case studies of this approach, including those listed below with links to the relevant case studies.

Case Study: B4RN- Broadband for the Rural North

Description:

Broadband for the Rural North (B4RN) is a professional fibre to the premises broadband network, registered as a non-profit community benefit society, and run by a dedicated local team with the support of landowners and volunteers. Basic offer is 1,000Mbps symmetrical FTTP broadband to every property in the coverage area within North West England,

Service costs are £150 connection and £30 per month. 10Gbps is also available to all properties.

Metrics:

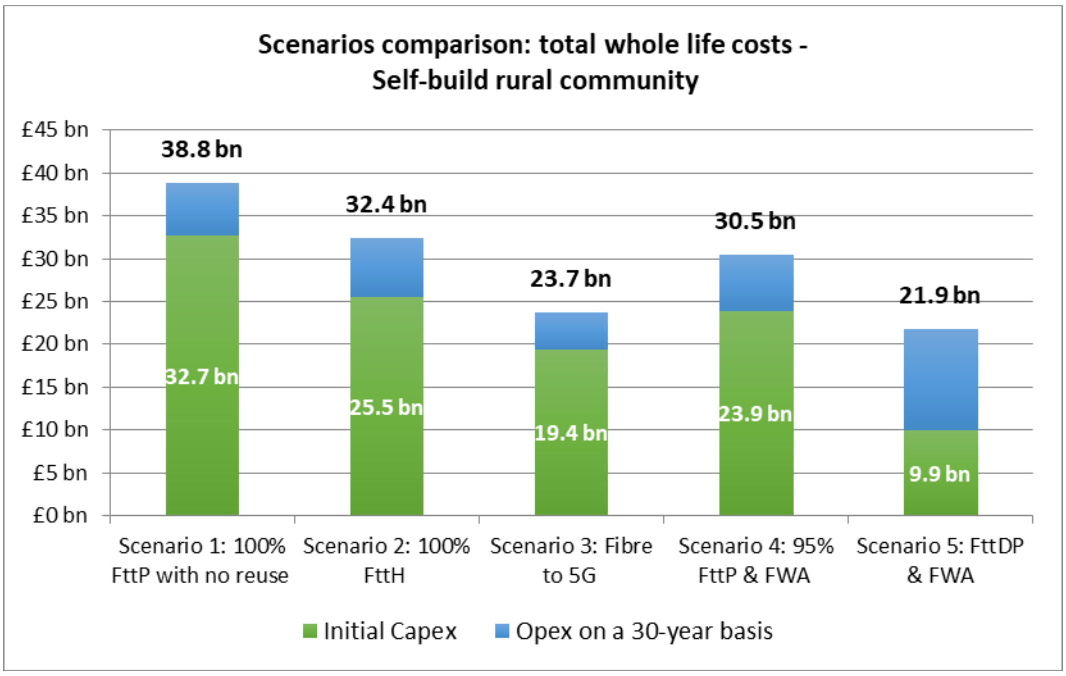
	Wave 1	Full Network
Number of premises reached	3,500	13,000
Initial Total Capex	£3.5m	£7.8m
Cost per Premise Passed	£1,000	£600

Comparison:

B4RN install fibre in new cable routes; their Premises Passed delivers a fibre pair directly at each premise, ready for short (<20m) connection. This is equivalent to the approach described in Scenario 1 including connection charges.

The Cost Model estimates an equivalent cost of £1,620.

Through 'self-build' and 'self-dig', B4RN avoids the majority of Wayleaves and construction labour. This provides the bulk of the 32-63% reductions in Capex projected. [6]



Publicly run Municipal Network Model (Publicly Owned infrastructure)

Historically, municipal authorities have played a role in designing, building, financing and operating infrastructure that provide benefit to the communities they serve. The principle is enshrined in EU Law under the principle of 'Service of General Economic Interest' (SGEI), which is a mechanism exempt from Competition and State Aid regulation.

The cost impact of this approach is that the public body takes on the responsibility and risk of the basic physical civil infrastructure and sometimes also the passive and active layers of the network. The 'intervention point' is often determined by how difficult the business case is to justify in normal commercial terms.

6 https://www.gov.uk/government/publications/community-led-broadband-schemes/case-studies#b4rn-case-study

Two examples at each end of this intervention scale can be found in the FTTH Council Case Studies Collection of 2016: [7]

- Stockholm. AB Stokab is the municipally owned company in Stockholm that owns, builds and operates communications ducts and dark fibre provision throughout the city. Total Investment- £282.5m for the backbone network and £141m for FTTP. There are no public subsidies. All funding comes from customer revenues through renting of dark fibre. Overall costs are reduced by Stokab **"digging once"** and providing common physical (duct) and passive (fibre) infrastructure, which is then used by all network and service provider on an open and equal charging basis.

- Suupohja. Suupohjan Seuterverkko Oy is a non-profit limited company owned by seven municipalities in Western Finland. The purpose of the company is to build and manage FTTP networks. It provides retail and wholesale services over its own fibre networks in the most rural areas of Finland.

Owning and operating the network has been totally separated from providing services; the municipalities provide the civil, passive and active network infrastructures, enabling connectivity for service providers. The municipalities justify the Capex through using the network infrastructure for their own public services, generating significant saving in the Opex previously paid to network operators for slower, less reliable copper leased lines.

This model is defined within the EU Guide to High Speed Broadband Investment as publicly owned infrastructure supported by public sector aggregation. The associated business model was based on an 8 to 10-year payback and Suupohjan Seuterverkko Oy is well within its target to achieve this.[8]

Privately run Municipal Network Model (Concession and Joint Venture)
This is a variant of municipal ownership. In many situations, a municipal authority or public body has physical assets, such as street lighting, ducts to support CCTV and Urban Traffic Control, rooftops of high-rise buildings, etc. However, they may not have the appetite, funding or skills and resources to develop these into a municipally owned infrastructure themselves.
Meanwhile, these are all valuable assets to operators looking to re-use or share assets to reduce the cost of implementation.

The Concession or JV approach enables the public body to retain the assets and work with a private operator to exploit them. In a Concession, this would be in return for exclusivity (an Irrevocable Right to Use- IRU) and a share in the revenues generated from networks using the assets. In a JV, the assets are more often transferred into a separate Special Purpose Vehicle in return for shares of equivalent asset value; the operator then runs the network on behalf of the JV and revenues flow into that JV.

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[7] http://www.ftthcouncil.eu/documents/CaseStudies/CaseStudy_Collection_2016.pdf

[8] https://ec.europa.eu/digital-single-market/en/news/successfully-bringing-fibre-rural-finland

Two examples of this are:
Piemonte in Italy. The municipal governments formed a private-public partnership to utilise public assets and bring together public sector demands to help develop a business case for the network infrastructure. Details can be found in the EU ENGAGE Programme Broadband Best Practice Factsheet (No.23)[9]

Bristol Bristol's key growth industries were facing challenges in terms of securing ultrafast broadband at prices that are affordable for business, residents and the public sector. This issue was becoming increasingly concerning as it was inhibiting competitiveness, growth and the kind of inter-company collaborations and supply-chain interactions that Bristol City Council believed were critical for those key sectors.

Bristol City Council therefore sought collaboration with the private sector to commercialise their existing network under a concession agreement, Bristol believed this was as the best way to solve the issues and add value to the local economy.

Following an extensive procurement process, the Council awarded a Concession Contract to a Joint Venture company formed between ITS Technology Group and Net Support UK for a 20-year exclusive concession agreement on Bristol's extensive duct infrastructure (currently 75km, with a further 58km existing but unused and a planned expansion programme to over 150km in total), for the development of Ultrafast broadband services to business and ultimately to residents.

Premises Served:

	Initially	Within 3 years	Within 5 years	Potential for expansion
Business	1328	2094	2842	19000
Residential	3000	7000	9000	437500

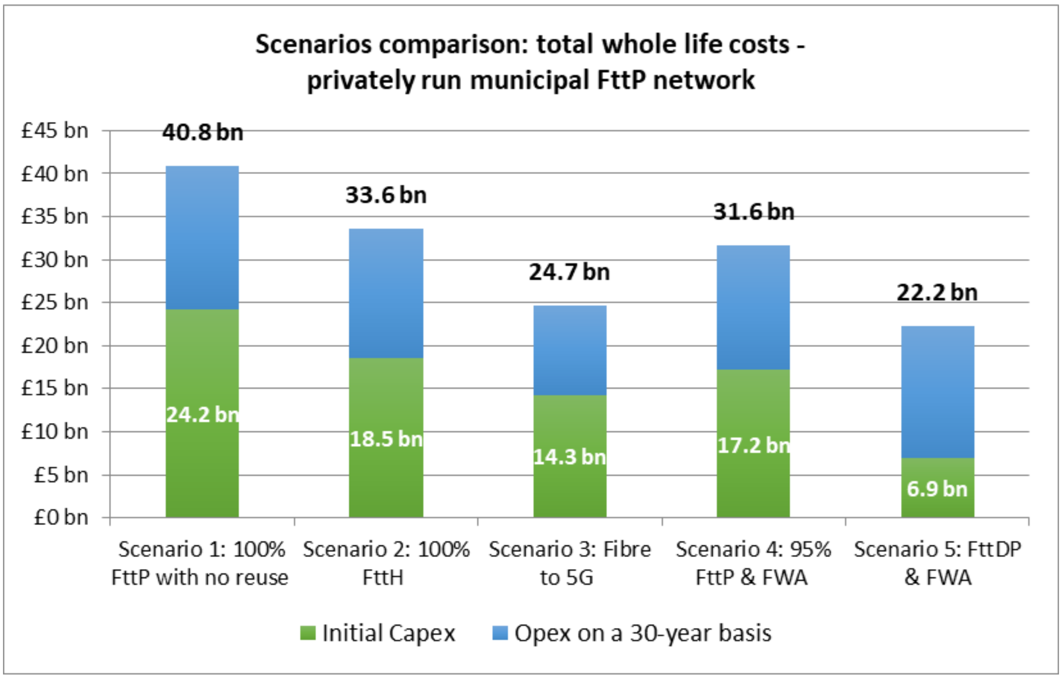
Technology Deployed:
- FTTP, Point to Point and GPON
- Core network fibre transit for other carriers
- Open access Wholesale platform
- Wireless infill

ITS Design, Build Finance and Operate the passive and active network using physical duct infrastructure provided under a 20-year Concession Agreement with Bristol City Council. The corresponding business case is based on anticipated revenues of about £144m over the total life of the contract, giving a payback period of 3 years and ROI within 2 year.

Anticipated benefits of alternative commercial models
In order to get an estimate of the associated benefits of such deployments, a typical cost optimisation would be as follows:

[9] http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?doc_id=4975

For a self-build scheme in a rural community, an initial Capex of £600 per Premise Passed for 30% of premises in clusters G1 and G2 represents a dramatic reduction in the capital required. There is also increased value in the community through retention of the assets by the community.



The comparison only shows those scenarios that are appropriate to a rural-self build scheme, i.e.

- A complete build including civil infrastructure (scenario 1)
- A complete build using other existing infrastructure (scenario 2)
- A deployment combining FTTP and FWA for longer reach premises (scenario 4)

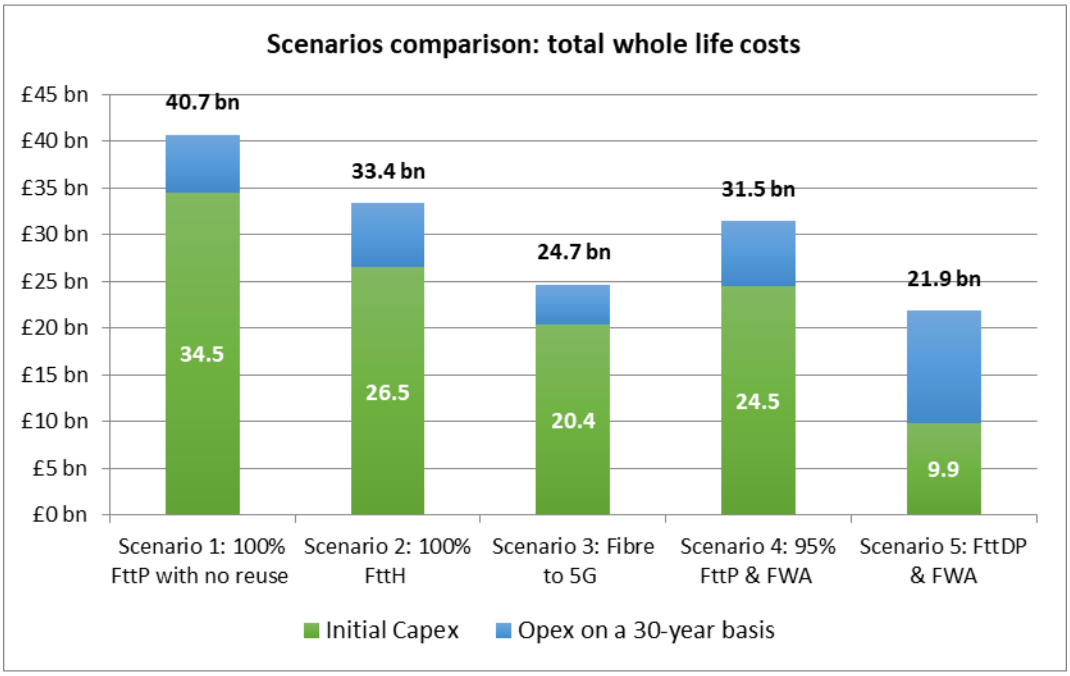
For privately-run municipal FTTP networks, a reduction of Capex of c.35% can be expected with a corresponding increase in Opex of 2% to cover Wayleaves, service or concession charges to the public-sector asset owner. This is important to avoid the use of the asset being considered as state aid under Article 105 of the Treaty for the European Union (TFEU).

The comparison only shows those scenarios that are appropriate to a privately-run municipal network, i.e.

- A complete build using existing infrastructure (scenario 2)
- A deployment combining FTTP and 5G (scenario 3)
- A deployment combining FTTP and FWA for longer reach premises (scenario 4)

Therefore, the self-build model reduces whole life cost by about 5%, while in the privately run municipal network model, there are very significant Capex reductions, which will stimulate development. However, these are likely to be offset by higher Opex in the long term.

The graph showing the original model calculations is shown below for comparison:



Scenarios comparison: total whole life costs
£45 bn
£40 bn
£35 bn
£30 bn
£25 bn
£20 bn
£15 bn
£10 bn
£5 bn
£0 bn
40.7 bn
33.4 bn
24.7 bn
31.5 bn
21.9 bn
34.5
26.5
20.4
24.5
9.9
Scenario 1: 100% FttP with no reuse
Scenario 2: 100% FttH
Scenario 3: Fibre to 5G
Scenario 4: 95% FttP & FWA
Scenario 5: FttDP & FWA
Initial Capex
Opex on a 30-year basis

6. International Benchmarks and Comparisons

This section of the report provides an overview of both UK and International cost data available through open sources and local experience and knowledge of building networks, both in the UK and internationally.
In summary, the study costs as calculated are broadly in-line with both International benchmarking and current/built networks in the UK.

6.1. Available comparisons with study geotypes

Currently across the UK, several operators are building various types of networks in addition to Openreach. The largest of these alternative network deployments is Virgin Media**'s Project** Lightning. This project involves a £3billion investment to increase the total Premises Passed by Virgin Media to c.17million (around one-third more than at present). The deployment commenced with the use of Hybrid Fibre and Coaxial (HFC) cables but has now moved to primarily FTTP. The civil construction method is exclusively micro trenching and is costing c. £600 per Premise Passed. [Note1]

Micro trenching is a common practice in Germany, Norway and Malaysia achieving on average 200 metres per day per team/vehicle. This compares with deployment using traditional duct construction techniques of c.60-80 metres per day per team.

Portugal Telecom has designed and built a large FTTP network with a reported cost of £200 per Premise Passed [Note 5]. This number is the most cost competitive figure reported by any major telecoms operator to date here in Europe (although in the industry lower figures are reported for small operators in the range of £100 per premise passed in West European apartment blocks and condominium developments). It should be noted that unlike the Virgin Media - Project Lightning choice of construction, the Portugal Telecom FTTP network deployment predominantly used a recently completed underground network of ducts. Research into the PT case studies shows that the cost of £200 per premise was achieved through a combination of duct sharing, a high volume of Multi-Dwelling Units (MDUs) and an abundance of cheap labour.

Comparing Portugal Telecom with dense urban London alternative network operators the comparable cost per Premise Passed is £320. [Note 4] This cost is based upon Multi-Dwelling Units of no more than 5 levels, using façade deployment both vertically and horizontally on the MDUs with support from the Local Authority leading up to the deployment phase. In Spain it is reported that much lower figures (<<£100) are achieved in the very dense centre of old towns also using façade mounted cabling. Façade mounted cabling is not accepted in most areas of London of course and so in other parts of central London costs can easily reach £1200 or more. In older buildings cabling inside the building can also be significant in contrast to the more usual case where street works dominates.

Across France several different networks have been or are being deployed. France has launched and continues to complete its national FTTP network rollout. Costing's per Premise Passed of c.£1,250 in rural areas equivalent to this study's geotype1 have been achieved [Note 4]. This is a relatively high number overall- but is broadly similar to this study's cost model outputs for geotype 1, considering France has a higher average metre per premise in these rural environments. In contrast, in another West European fibre on rural electricity poles project, costs were projected to be over £2000 due to a combination of low density and health and safety driven costs – the cost of using telco poles would be significantly lower. The comparison with geotypes 3 and 4 of this study (suburban and urban FTTP network rollouts) shows average costs per Premise Passed of between €300 and €600 [Note 4]. It should be noted that in France, re-use of infrastructure assets, both existing telecom aerial and duct infrastructure, along with electricity network assets, is very common. In some rural networks, the network build for FTTP is incurring less than 10% new civil build, the majority of FTTP deployment being delivered using both the low and medium voltage electricity power networks.

In geotype4, (urban with city and town), TalkTalk have a cost of circa £500 per Premise Passed [Note 2] with no or little asset reuse, and Proximus of Belgium [Note 3] have identified costs of between €600 - €1000 per Premise Passed in areas similar to geotypes 4 and 5. [Note 4]
In Spain in low density villa areas the use of micro-trenching and relatively lax restoration standards allows modest costs of £350 per premise passed in areas of 30 metre plot frontage (larger than the UK average).

Consideration of TalkTalk and Proximus costs for geotype4 alongside an asset infrastructure sharing/reuse approach, corroborates costs of c. €600 as achievable as reported in France and the Republic of Ireland [Note 4].

However, a direct like-for like comparison cannot be drawn between these figures, as the metres per Premise in each comparative geotype is not available. This is a key metric in facilitating an accurate benchmark as described below.

6.2. What conclusions can the study draw from the international benchmarking exercise?

The study has identified build costs for the UK considering both technology and geotype. These build costs do fall broadly within the international and UK benchmarking comparisons identified above. The only exception to this is the comparison of FTTP in Portugal with as reported above. The differential of £200 versus £320 per premise is based upon Multi Dwelling Units but without any asset sharing of ducts or aerial infrastructure.

Build costs are greatly influenced by a combination of factors, as listed below:

- Metres per Premise Passed
- Network topology
- Density of premises per Km2
- Technology used
- Deployment /Build/Construction choices
- Asset sharing
- Availability of skilled workforce
- Local labour rates

When comparing costs across different networks, the key parameter of Metres per Premise Passed for international benchmarking is difficult to attain. Validation of data that is available shows that in rural France the equivalent of geotype1 has an average of 20 metres per Premise Passed and the equivalent of geotype4 has between 7 – 12 metres per Premise Passed.

Without both a direct link between metres and cost per Premise Passed the international comparison can only be used for generic benchmarking.

Cost per Home Passed with reference to technology and geotype.

		£ - € **Homes Passed (Not Connected)**				
Technology	Geotype	UK	Republic Ireland	France	Belgium	Spain / Portugal
		£	**€**	**€**	**€**	**€**
100% FTTP with no infrastructure re-use (the **'theoretical case' for** baseline costing)	G1 Mainly Rural		Very little deployed network. No government intervention. National Broadband Plan delayed			
	G2 Largely Rural					
	G3 Urban with significant rural					
	G4 Urban with city & Town	£600 (Virgin Media) Note 1	*€700 - €800* Note 2		€800 - €1000 Proximus Note 3	
	G5 Urban with minor conurbation					
	G6 Urban with major conurbation	£500 (TalkTalk) £320 (MDU) Note 4				
100% FTTP with infrastructure re-use	G1 Mainly Rural		Very little deployed network. No government intervention. National Broadband Plan delayed	€1,300 + (Aerial Power Networks re-use) Note 5		
	G2 Largely Rural			€800 + (Aerial Power Networks re-use) Note 6		
	G3 Urban with significant rural					
	G4 Urban with city & Town		*€650* + (Aerial Power Networks re-use) Note 7			**€200** + significant 3rd party duct re-use) Note 8
	G5 Urban with minor conurbation					
	G6 Urban with major conurbation					

Note[1] Virgin Media 2014 Results, February 2015 (http://www.libertyglobal.com/pdf/fixed-income/Virgin-Media-Q4-2014Investor-Release-FINAL.pdf). Page 3 gives a total cost for 4m premises of between £2.9bn and £3.1bn (i.e. c. £750 / premises), of which c. 80% (£600 / premises) would be for the network and c. 20% (£150 / premises) for the purchase and installation of customer premises equipment. Note[2] TalkTalk Group Preliminary Results May 10th, 2017. Note[3] Proximus have assumed G4- G5 Type with no infrastructure sharing based upon high cost of H/P https://www.proximus.com/sites/default/files/Documents/Investors/Reports/2016/fiber/gFiber_MarketCommunication_presentation_forweb.pdf. Note[4] Generic information available and within the public domain. Note[5] Analysis Mason, FTTX forecast Report, December 2016 +

Case study projects in France and Portugal providing on techniques and associated costs are shown below. In France, the case study on Nord Pas De Calais and Heurault describes the difference made through public intervention by the French Government. In the case of the public intervention area (with a cost of €1050) the network design and build is heavily based upon asset sharing with the predominant use of aerial power networks and some use of existing telecom infrastructure ducts.

The European Council in the guidance on its Cost Reduction Directive has noted that asset sharing can achieve savings of c.12% of build cost. Within the Republic of Ireland (RoI) the majority of commercial FTTP rollouts are using existing assets, be it existing telecom assets of Eir (the incumbent operator) or the power network owned by ESB. In the case of SIRO, the Joint Venture between ESB and Vodafone, it is clear within RoI that to deliver FTTP on existing aerial or ducted vault low voltage power network assets, is the most cost-effective solution for FTTP. Physical survey outputs have shown the alternative of new civil construction can increase costs by a factor of 200%-300% depending on the length and complexity of the dig.

6.3. France FTTH Deployments Benchmarking

The deployment of FTTH was initiated in 2009, with major ISPs involvement and with a regulatory push to provide open access to Orange duct infrastructure. The real deployments started in 2011.

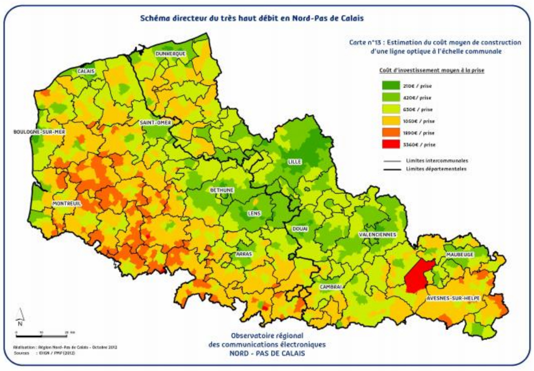
Two areas have then been defined in the country:

1. A private infrastructure investment area representing about 50% of the households with open and common infrastructure in some segments of the network. In so-called ZTD (Zone Très Denses") representing the first 140 communes, ranked in population density-order, only the vertical part in the buildings is common. As a consequence, in cities such as Paris, multiple horizontal infrastructures are being deployed by the 4 largest ISPs (Orange, Iliad/Free, Altice, Bouygues Telecom) resulting in a non-optimal capital allocation. The ZTD represents about 6 M households, or about 20% of the total French Households. The area where common infrastructure is more widely available is called “zone AMII” and represents about 30% of French households

2. A public infrastructure investment area representing about 50% of the households with a similar architecture as the ZMD. Public investment refers to the fact that in these areas, given the costs of deploying FTTH, subsidies are being granted to allow for a viable infrastructure business case. This is also because the retail price levels of ‘triple play’ services on fixed networks (unlimited voice to mobile and more than 100 countries, unlimited Internet and up to 100 free TV channels) are very aggressive.

To facilitate benchmarking, the study has taken a few examples extracted from publicly available data of the digital framework analysis conducted in various parts of France.

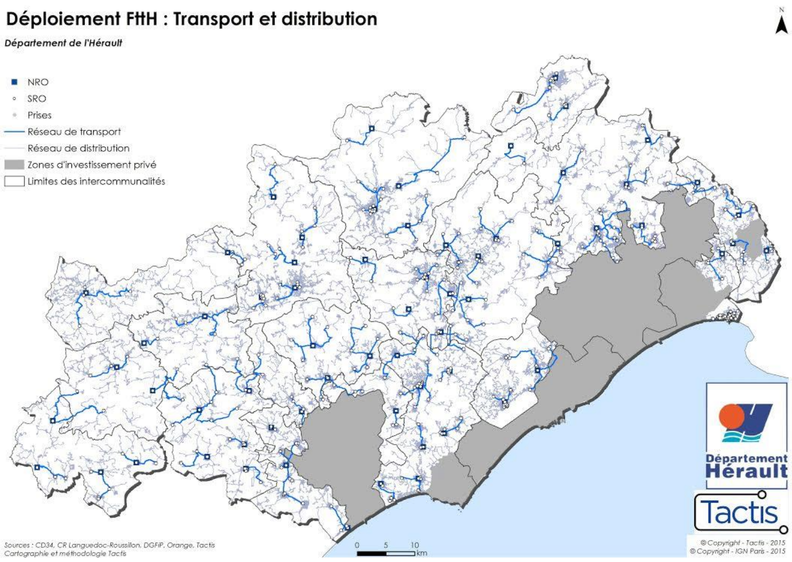
The Nord-Pas de Calais region has similarities with the population and premises density in the UK. The following map describes the expected cost level for building an FTTP infrastructure. As a public tender took place, the price level at which the deployment is happening is lower than the indicated level (roughly by 15 to 20%).



For the Nord Pas De Calais, 93% of the premises infrastructure costs less than 630€ and 98% less than 1050€. This does not include the variable final drop cost per premise.

The department of Herault (South of France), has the following coverage targeted under a typical public intervention.

For this network, the cost of deploying the infrastructure in the private investment area is about 500€ average per household. In the public investment area, the cost of deploying is on average 1150 €.



Government Intervention

French telecoms watchdog, the Autorite de Regulation des Communications Electroniques et des Postes (Arcep), has opened a public consultation on a draft proposal with regards to the technical and operational processes of sharing fibre-to-the-home (FTTH) networks. The regulator notes that the pace of shared optical local loop rollouts has increased considerably in recent years, from 810,000 additional premises passed in 2013, equivalent to a 38% year-on-year increase in eligible premises.

Going forward, Arcep seeks to establish a detailed list of all the processes (exchanging information on eligibility, ordering a line, etc.) involved in the deployment of fibre, in order to develop and implement a standardised information system between operators. Arcep believes that a lack of standardisation runs the risk of FTTH network operating costs skyrocketing over the long-term period.

6.4. Portugal FTTP Deployments Benchmarking

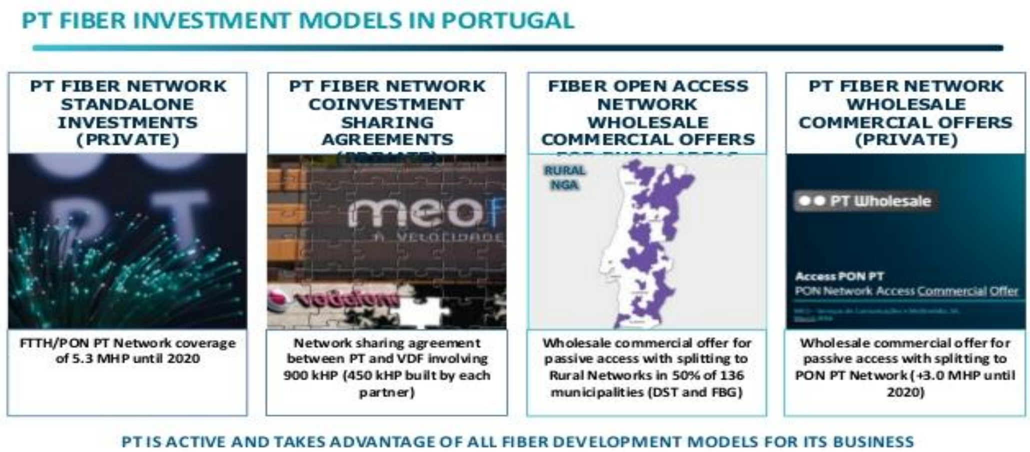
Portugal has a population of 10.8 million, of which 2.4 million are living in cities and towns.

The key attributes and differentiator of the PT rollout of FTTP are:

- Cost of Build: (€200 Per Home Passed)
- Regulatory position: Unregulated above 30Mbp/s since 2007
- Incumbent activity and alternative operators entering the market: (Incumbent launched first after seeing competition entering from TV operators)
- Sharing of existing utility assets: Mostly duct (using both telecom ducts replaced in the 1980's and the power utility ducts updated in 2008)
- Sharing of/joint build projects between operators: Vodafone and Portugal telecom entered into an agreement to share network build

PT's decision to invest in FTTP was assisted by the early adoption of next-generation access (NGA) regulation. Deployment of FTTP in urban areas started in 2008. Over a period of 12 months PT had passed 1 million homes with FTTP– the operator only considers a premise to be "passed" when fibre is available outside the customer's door, not merely just outside the building. The use of passive optical network technology relaxes the requirements for space in the central office, space in ducts, lowers energy requirements and reduces technical complexity.

By the end of PT had deployed 1.6 Million Premises passed - equivalent to 40% of primary households in Portugal and 27% of total households in Portugal.



In 2012 Analysys Mason reported that:

"Three factors have aided the roll out of PT's fibre networks, which had passed 1.6 million premises – 46% of the national total:

- Its key advantage is the availability of a particularly clean and comprehensive duct system, installed mainly in the 1980s, which is also available to competitors at an enviably low cost. PT estimates that less than 5% of its FTTH Capex is on new civil infrastructure.
- Labour costs are lower in Portugal than is typical in Western Europe.

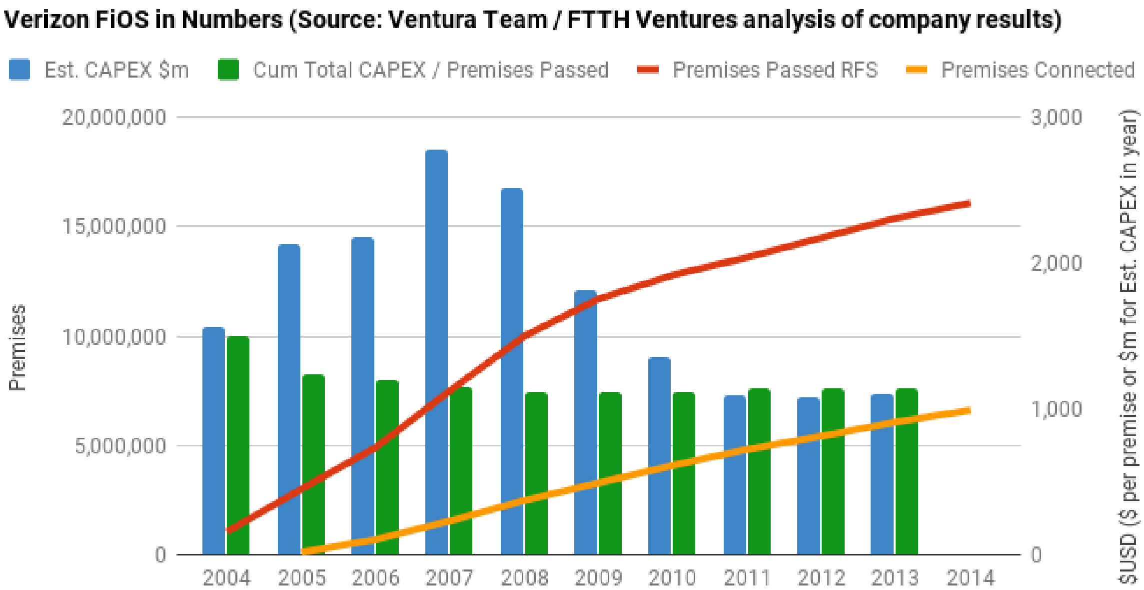
- PT has agreements for relatively easy access to MDUs. It can also re-use in-building coax plant, so its FTTH-based TV service does not generally require a separate set-top-box.

The cost per premises passed for FTTH/GPON is, PT claims, under EUR200 (the *Study's* estimate of the average for Western Europe is around EUR700–800), and the final subscriber *connection typically takes between three and four hours."*

Given the success and speed of rollout of the PT FTTP network, Vodafone quickly launched its own FTTP network, which was fast-tracked by the announcement, in 2014, that the Vodafone Group with Vodafone Portugal and Portugal Telecom had signed an agreement to deploy and share fibre networks reaching 900,000 homes in Portugal.

6.5. Verizon FiOS, USA

Verizon is a major regional telco similar in its fixed line business to BT. In 2004 Verizon carefully selected areas for 'fiberisation' partly to compete with cable TV and also to prepare for de-commissioning of the copper network (which process is now starting). As can be seen in the chart below, an average cost of $1150 per premise passed was achieved using total Capex (note: the actual 'premises passed' figure would be lower as Verizon quotes total Capex including the home drop- or premises connection). Allowing for some inflation this would be around £900 today as a ceiling. In the US the great majority of access networks are built using overhead cabling often on shared utility poles.



Source: Ventura Team / FTTH Ventures analysis

6.6. Reggefiber, Netherlands

For many years in the European fibre community, Reggefiber was the 'poster project' for Europe. Pioneered by a construction billionaire in the Netherlands, Reggefiber started widespread fibre deployment in the Netherlands initially in urban areas and later also in small towns or satellite suburbs. Most networks were buried in new dig duct systems with Reggefiber passed more than 2 million homes before it sold out to KPN (the national incumbent).

It is difficult to interpret the somewhat lumpy Capex programme but cost per premise passed ranged between £320 to £1200 per premise passed with the average being around £720.

Interestingly, before being fully acquired by the incumbent telco KPN, Reggefiber offered a choice of local or national pricing. The fibre drop rental varied according to local capital cost so for a home in capital expenditure (Capex) class €700 the charge would be €14.36 whereas for the €1,450 Capex class the monthly tariff was €18.25. Active operators could also choose a bundled national deal of €16.76 flat rate nationally.

6.7. Detailed International FTTP Geo Type G6 Oise Project, France

Appendix G contains details of the French Oise project. This project clearly shows that large scale rapid deployment of FTTP networks have been delivered in France with final network build having less than 10% new civils on a project delivering FTTP to over 150,000 Homes in Rural France.

7. Conclusions

7.1. Purpose

In this section, conclusions are drawn from comparison and consideration of the results and analysis of the study.

The intention is not to make recommendations, as that is not within the scope of the study or the roles of the authors. Any recommendations regarding the optimum future approach for UK digital communications infrastructure must consider both the demand for digital communications (which is the subject of the partner study- the Benefits Analysis) and other important externalities, including (but not exhaustively):

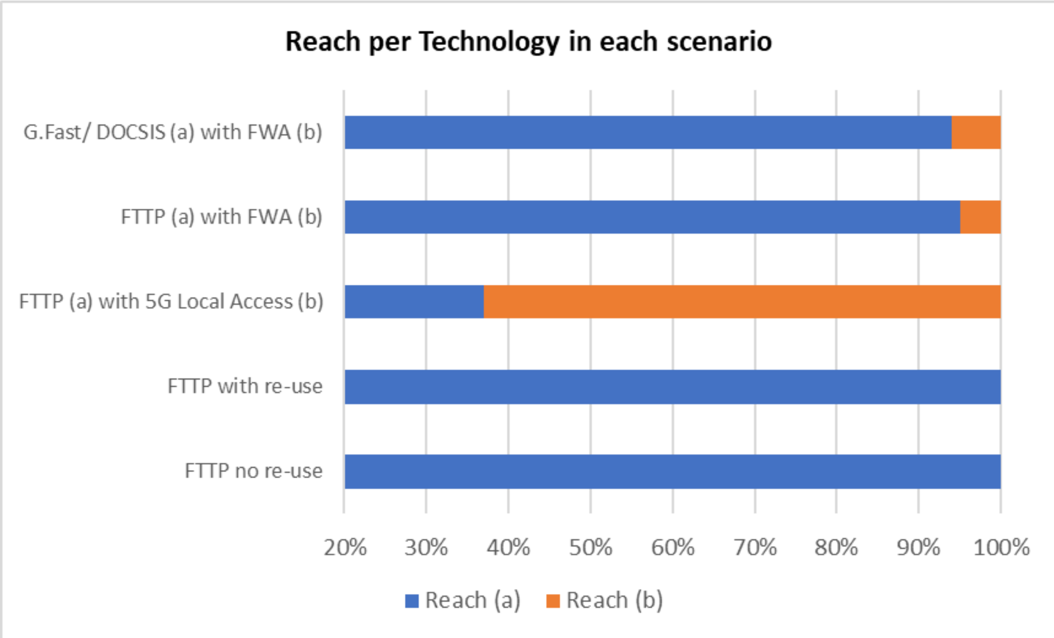
- The Regulatory environment
- The availability of Investment and appetite of investors for differing commercial approaches and markets
- Planning regulations and procedures
- Wayleaves and other consents
- Opex and support overheads accounting principles within operators' overall business structures
- Market conditions and the extent of competition

These conclusions are therefore provided solely to highlight the key findings and outcomes of this Report on the Analysis of Costs, together with any inter-linking factors that should be considered.

7.2. Anticipated Reach and Performance per Scenario

The study assumed a fundamental requirement to reach 100% of premises and the scenarios were designed to explore this using the mix of technologies agreed as being within scope.

Based on the modelling and test designs, the percentage of premises reached with each technology in the scenarios is shown here:



(NB: this assumes that all premises in geotypes 4 to 6 are served through 5G access in scenario 3)

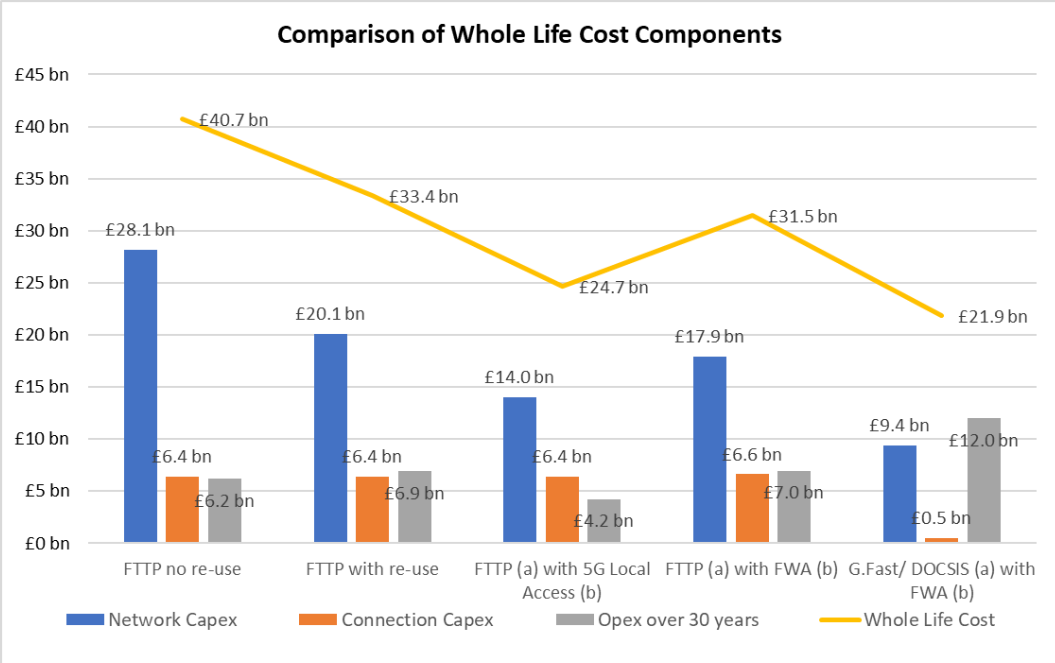
On this basis (with reference to the design and performance assumptions in Appendix A), the performance received by premises under each scenario from the technologies would be:

- In scenarios 1 and 2, 100% of premises are reached with FTTP and could receive 1GBps and beyond.
- In scenario 3, the 63% of premises with 5G access could receive up to 500Mbps and possibly more, depending on contention and transit capacity. The 37% with FTTP could receive 1GBps and beyond.
- In scenario 4 the 95% reached by FTTP could receive 1GBps and beyond. The remaining 5% of FWA premises could receive up to 100MBps at the costs and designs modelled, with the capability to expand with improvements in FWA to 'match' 5G capability.
- In scenario 5, the design maximum for the 94% (plus) of G.Fast and DOCSIS premises assumes up to 300Mbps download. The remaining 6% of FWA premises have the same characteristics and future capability as described for scenario 4 above.

7.3. Cost Results

7.3.1. Whole Life Cost Comparison between scenarios

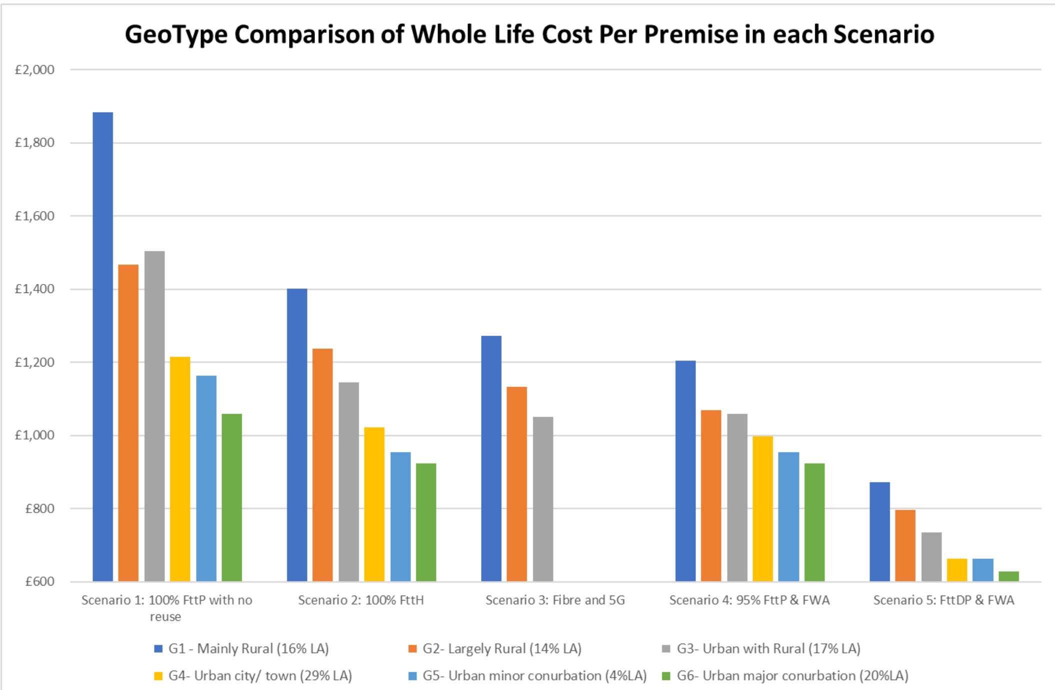
The results, whilst not surprising, are significant. The capital costs versus the whole life costs of each Scenario are shown below. Network capital costs are significantly higher for fibre solutions. However, the higher operating costs of copper and wireless significantly counter-balance this over a 30-year period:.



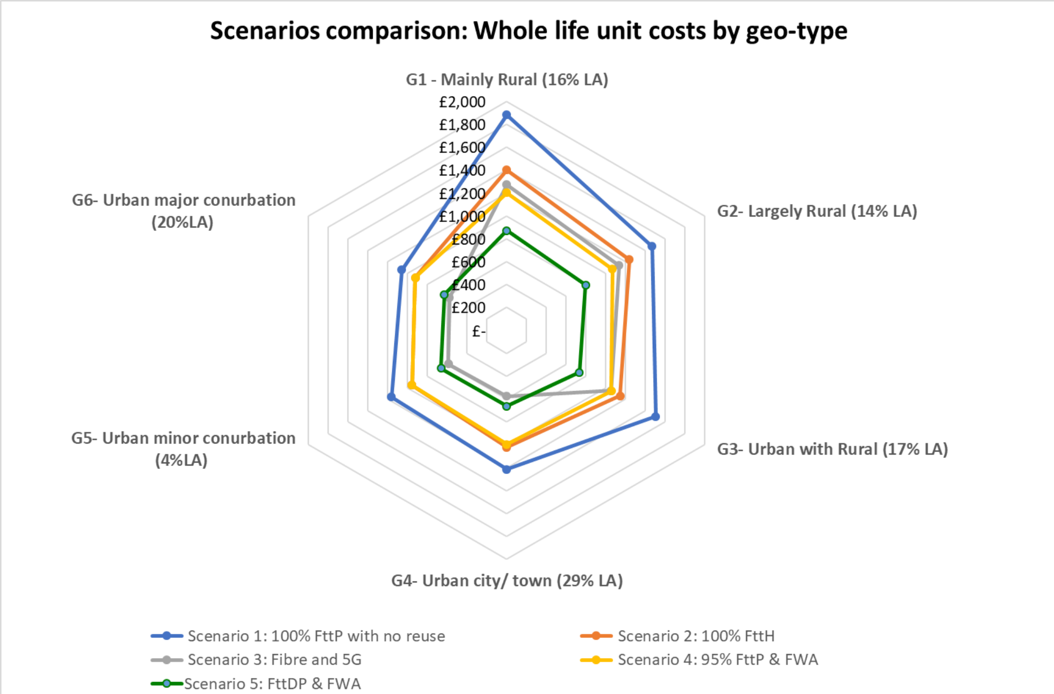
The comparisons show that there is only a difference of £11.5bn between the whole life costs of scenarios 2 to 5, with the exception of scenario 1 which includes the provision of new physical infrastructure.

7.3.2. Cost Per Premise Comparison between scenarios

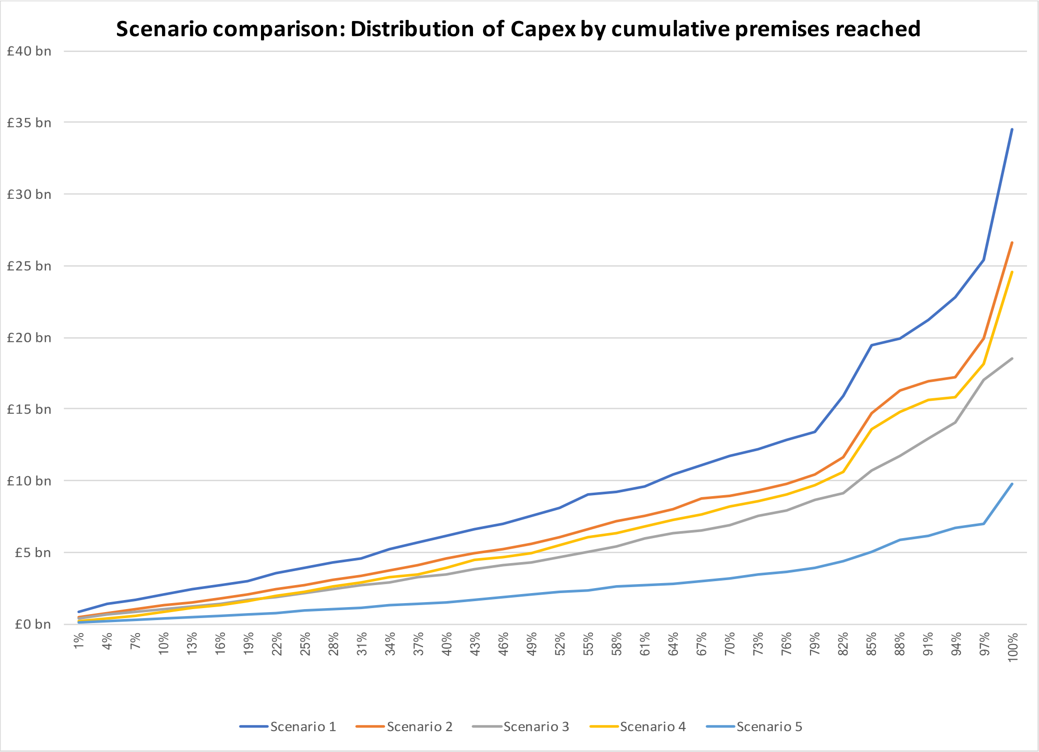
Analysis of the whole life cost Per Premises highlights the significant variation between geotypes, ranging from £1,883 in scenario 1 for geotype1 to £628 in scenario 5 for geotype 6:



This is clearly driven primarily by premises density, as shown on the geotype 'radar' diagram below. This indicates the heavy cost burden of reaching the final 4-8% of premises with any digital communications infrastructure capable of supporting speeds exceeding 100Mbps, using any fixed technology.



This translates into disproportionate costs between premises in the 'first, second and final third' of UK geotypes. Further granular analysis of the cost modelling data at OCN level reveals the full extent of this difference. The graph below shows how the Capex increases as more premises are reached, based on OCN (or PoP) deployment costs:

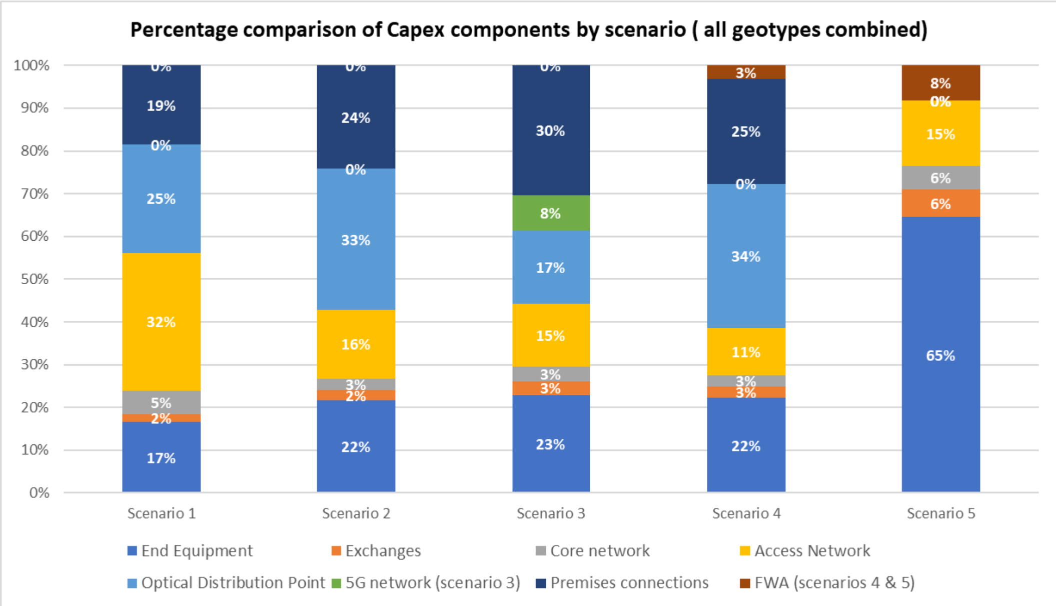


This shows a gentle climb for c.80% of premises, with Capex for the final 20% increasing exponentially to 100% coverage.

This trend is consistent across all technologies (albeit lower for scenario 5 due to there being very little premises connection Capex), as it is dependent mostly on premises density.

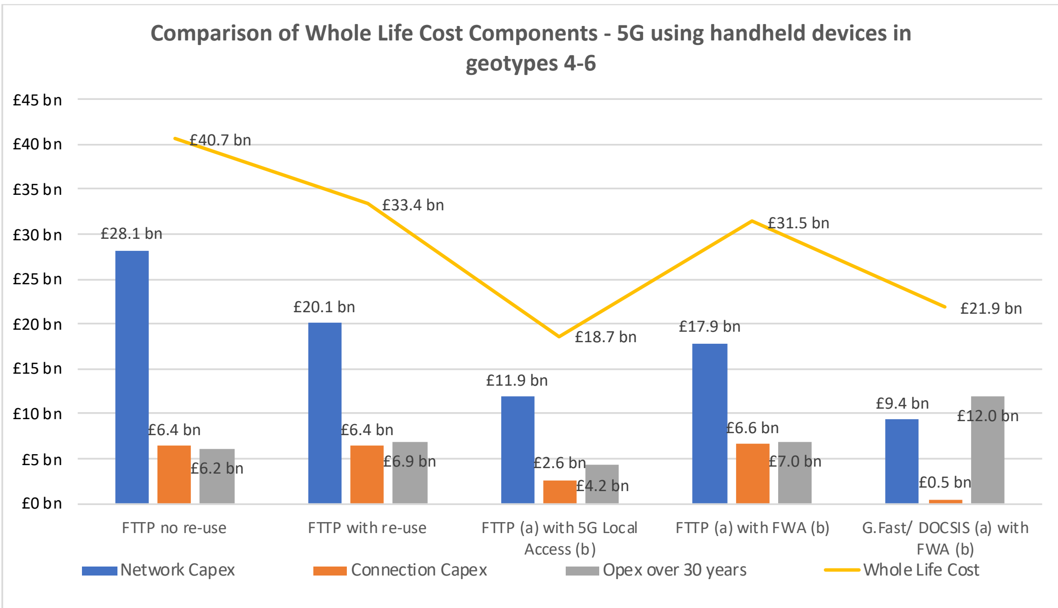
7.3.3. 5G and the impact of end equipment costs

The overall comparison at 7.3.1 above demonstrates that 5G access from a local fibre transit network offers a credible solution alongside the other technologies, primarily in urban areas. Further, this scenario deployed 53% of the total capital on premises connection costs at 30% and customer premises end equipment (CPE) at 23% as shown below. It is important to note that the diagram includes all geotypes; hence the existence of premises connection costs in scenario 3, arising only in geotypes 1 to 3. Also, CPE represents a significantly higher percentage in scenario 5 simply due to there being significantly less Capex applied to new passive infrastructure.



If connections were made directly with the small cell base stations from each 5G device- such as mobile phones and tablets- the need for premises connection equipment would be removed, leaving only replacement of dedicated equipment, such as set-top or other video streaming devices. This would reduce the overall Capex by up to £3.9bn.

The overall whole life cost of deploying Fibre to 5G in geotypes 5-6 and FTTP in geotypes 1 to 2 would then be £18.7bn, making it marginally the lowest; the comparison would then look like this:



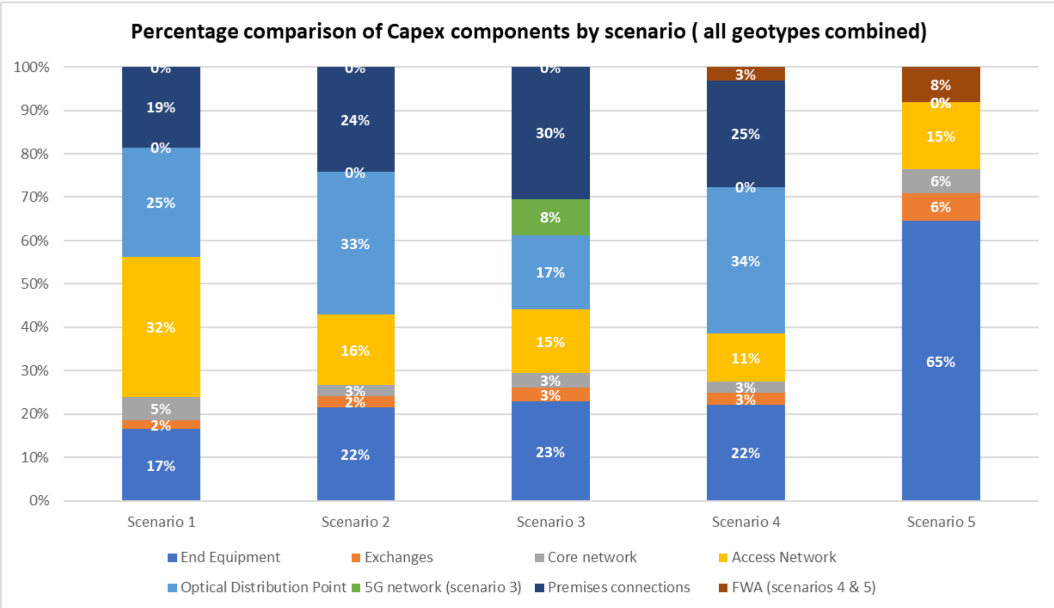
However, it is important to note that this adaptation of scenario 3 is reliant on the availability and affordability of 5G devices. This may have an unpredictable effect on managing the rollout of a Fibre to 5G infrastructure.

7.4. Key Cost Components and Variables

The analysis, supported by feedback through the survey, confirmed that the following are the components that have the biggest impact on the cost of the various technologies:

7.4.1. Distribution and Access Networks

Breakdown of the costs associated with the geotypes in every scenario highlight that the largest capital cost components of any technology are the elements concerned with implementing the access and premises distribution networks locally. The value and percentage of these elements vary across the scenarios as shown above but repeated below for ease of reference (note that premises distribution costs are the majority of the Optical Distribution Points costs category):



This highlights the importance of exploring and developing alternative means of delivering this access and distribution, as well as ways of sharing/ reducing the cost of this layer. Many of those currently identified have been considered in the 'What If' section of this report.

7.4.2. Civil construction and passive infrastructure

The comparison of scenario costs also demonstrates that the most profound impact on the cost of digital communication infrastructure is actually the related level (and nature) of the civil construction required:

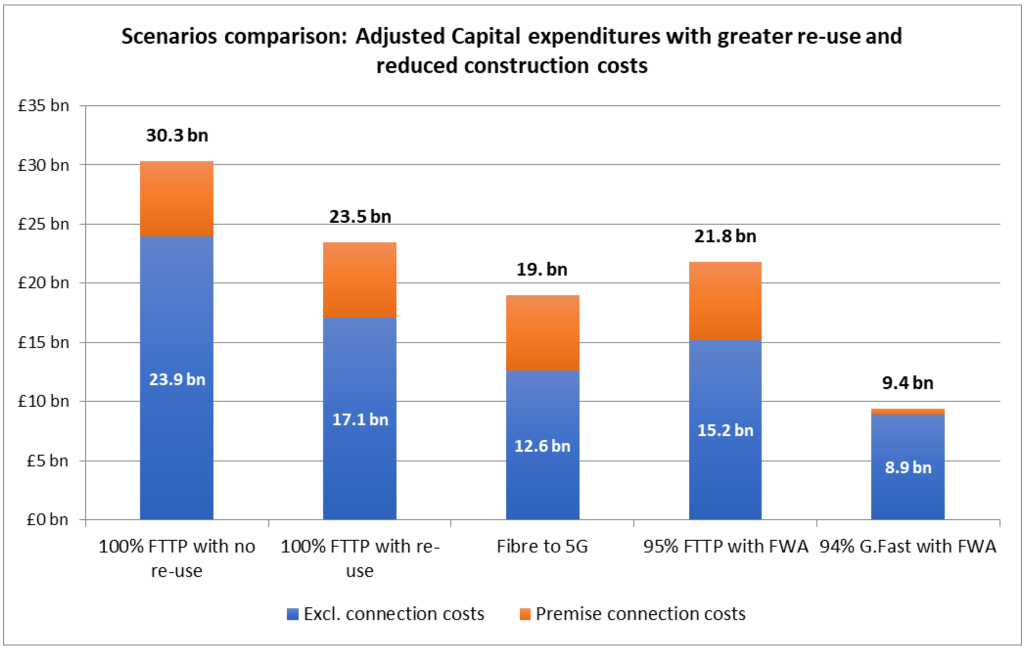
- Scenario 5 contains the lowest amount of civil construction through the most extensive re-use of cabinets, ducts and poles as well as copper and coax.

- The only difference between Scenarios 1 and 2 is the re-use of physical (civil) infrastructure; even with the modest assumptions made in this regard, there is still a 28% reduction in capital cost.

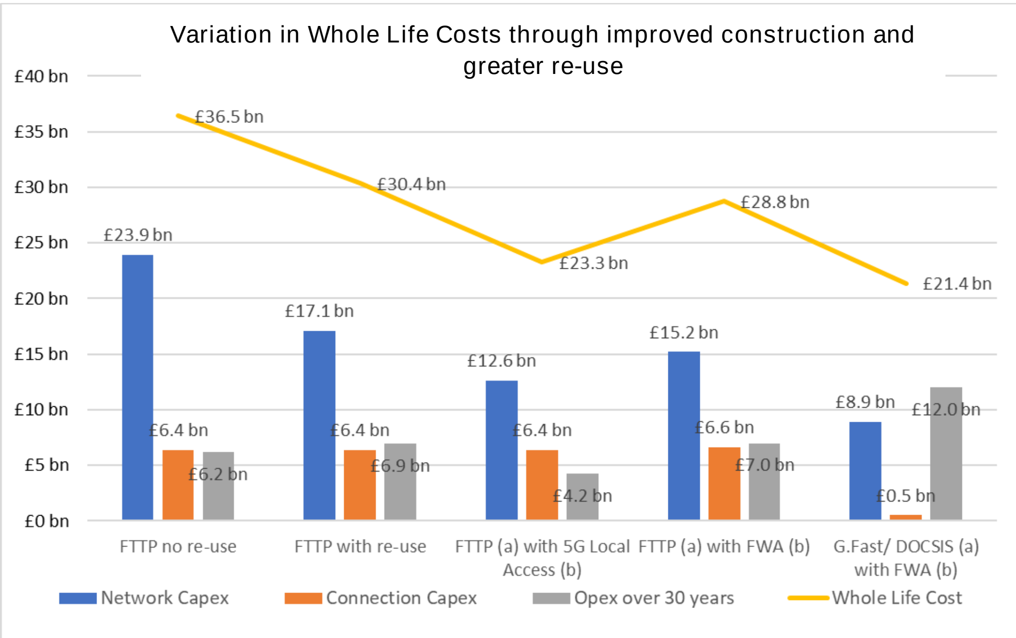
Improvement in construction techniques and the introduction of new commercial models to share/ re-use existing assets play a major part in reducing the capital burden.

The net effect of applying the principles considered in the What If section on the components identified in both paragraphs 7.4.1 and 7.4.2 is a realistic potential reduction in initial capital expenditure across the scenarios by at least 5% to 15%, depending on the level of construction and asset re-use involved.

By modelling a 15% reduction in scenarios 1, 2 and 4, 10% in scenario 3 and 5% in scenario 5, the initial Capex per scenario would reduce as follows:



This would vary the whole life cost comparison as shown:



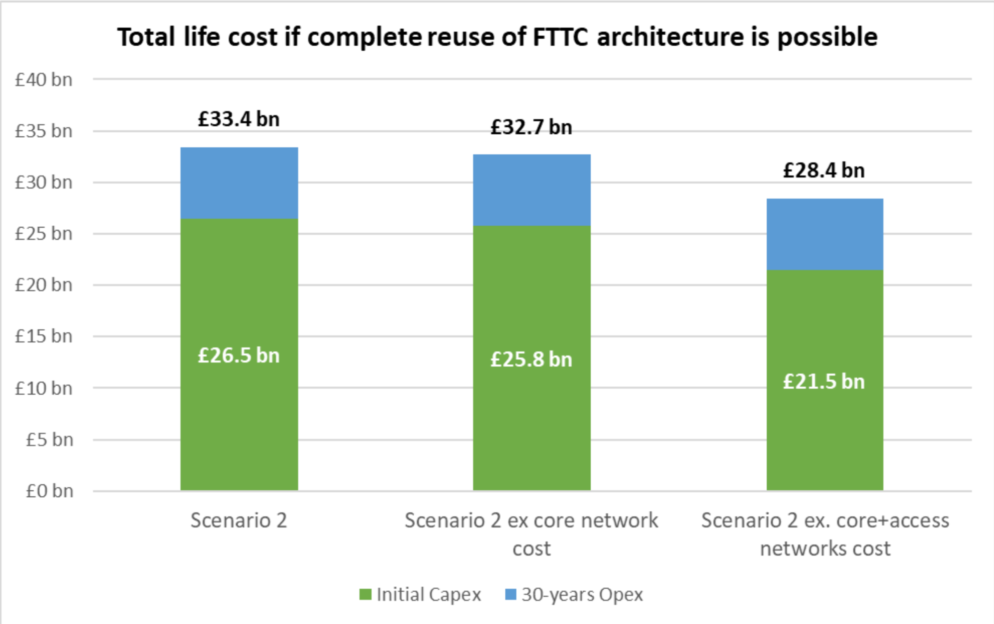
7.4.3. Rollout

The same principles regarding the impact of civil construction on the cost analysis hold true for speed of rollout.

Section 4.2.3 (and the detailed modelling in Appendix H) clearly show nearly a 20% reduction in the speed of FTTP rollout where civil infrastructure is re-used, from 15 years to 12 years. G.Fast/ FTTDp rollout takes two-thirds of the time, being modelled at 8 years (based on the stated assumptions and corroborated by Openreach statements and Swisscom experience).

7.4.4. Re-use of the FTTC Architecture

This is a key variable in the re-use cost profile as described in section 5.1.3 above. Significant investment has been made in rolling out fibre to the cabinet (FTTC) to enable premises with 'superfast' broadband using VDSL. Depending on the technical specifications applied to this rollout and the corresponding availability of sufficient fibre to PCCP 'Green Cabinet' level, there could be valuable reductions through re-use or adoption of some of this infrastructure.



The diagram also show the impact of extending the same considerations to any technical standards and specifications relating to FTTDp.

7.5. Key Findings (including from What If reviews)

7.5.1. FTTP costs approximately 30% more than G.Fast over a 30-year period

Assuming similar levels of re-use for both technologies (i.e. scenarios 2 and 5), the whole life costs of the infrastructure (i.e. excluding connection costs) are £33.4bn for FTTP and £21.9bn for FTTDp- assuming 'infill' for FTTDp of c.6% using FWA.

The key differences are:

- A Capex-heavy FTTP approach versus an Opex-heavy FTTDp one, in relative terms
- Performance levels of 1Gbps designed download versus a modelled 300Mbps (with 6% 'infill' achieving 100Mbps).

The variant scenario exploring a transition from FTTDp to FTTP indicates that whilst it offers a migratory path, it is also likely to incur in the region of £2.3bn of additional Capex and c.£550m of additional Opex over a 30-year period.

7.5.2. Alternative Construction and Commercial Models can make a significant impact

The breakdown of capital costs for each scenario in section 3 shows that access network costs are the most significant factor- and civil construction is the largest component of those costs. The impact of sharing civil infrastructure is an estimated reduction in the capital costs from around £41bn to around £33bn, as can be seen from the difference between scenarios 1 and 2. The percentage of FTTP Premises Passed can be extended further by also adopting construction techniques such as micro trenching and use of other utility infrastructure, liberating at least 5 to 15% of the build capital as modelled above.

Different commercial models as described in section 5 also reduce the capital and often operating cost of the infrastructure by utilising shared physical assets. It is difficult to project the overall cost reductions, as these would be tempered by the commercial arrangements between operators and asset owners. Nonetheless, the modelled assumptions in section 5 indicate that network build costs represent 75-85% of the total capital requirement for a FTTP network- with the civil component between 52 and 60%.

Hence even at low estimates of 15% reduction in civil capital costs (allowing for an additional transfer of 10% to Opex for rental or concession charges), this could reduce the Whole Life costs for every fixed network component by a further 5-10%.

Whilst the availability of local authority ducts may be limited and patchy throughout the UK, other utility infrastructure could be utilised in similar ways, such as water, electricity, road and rail.

7.5.3. Non-Fibre technologies provide cost-effective capability to achieve 100% coverage

G.Fast, DOCSIS and Fixed Wireless Access can provide credible access to achieve 100% coverage of premises with at least 30Mbps capability, rising to 100Mbps by 2020. These are most likely to have benefit as follows:

- G.Fast/ FTTDp for premises within 200 metres of the distribution point (DP), in both urban and rural environments. The modelled 94% premises reach of all UK premises demonstrates the capability of the technology to extend 100-300Mbps services at low capital impact, as shown in scenario 5 (£9.8bn)

- DOCSIS in urban environments can provide a further reduction on capital cost at these speeds, with end-device costs at around £100 instead of £370 for a G.Fast network device. Whilst there will be significant competitive roll-out of DOCSIS alongside G.Fast (or FTTP), its extended reach beyond 200m makes it a credible technology for extending coverage beyond the capability of G.Fast.

- FWA in rural environments can extend coverage of 30Mbps to 100Mbps services even further, effectively reaching near-100% coverage through deployment of base stations. However, this comes at a cost, as FWA Opex is high at an average of £116 per premise (across scenarios 4 and 5), due significantly to higher licencing, site rental and maintenance costs.

- 5G can serve as an alternative technology in the medium term, bringing benefit as an access option alongside its rollout for other uses and services as described in section 5. The study suggests this is most likely to take effect from around 2020 to 2025. Nonetheless, scenario 3 also signposts the whole life cost advantages of deploying hybrid fibre and wireless technologies in urban as well as rural environments.

Glossary of Terms

Term	Description
3G	Third generation of mobile systems. Provides high-speed data transmission and supports multi-media applications such as video, audio and internet access, alongside conventional voice services
4G	Fourth generation of mobile systems. It is designed to provide faster data download and upload speeds on mobile networks.
5G	Fifth generation of mobiles systems. Designed to provide faster data download and upload speeds on mobile networks offering lower latency than 4G networks.
Access Network	An electronic communications network which connects consumers to a service provider; running from the consumer's premises to a local access node (a point of aggregation in the access network) and supporting the provision of access-based services. It is sometimes referred to as the 'local loop' or the 'last mile'.
ADSL	Asymmetric Digital Subscriber Line. A digital technology that allows the use of a standard telephone line to provide high-speed data communications.
Backhaul	The part of the communications network which connects the local exchange to the ISP's core network, or the mobile cell to the core network
Base Station	The active equipment installed at a mobile transmitter site. The equipment installed determines the types of access technology that are used at that site.
BDUK	Broadband Delivery UK
Broadband	A data service or connection generally defined as being 'always on' and providing a bandwidth greater than narrowband connections
Connection Provider (CP)	A company that provides an electronic communications network or provides an electronic communications service
Core Network	The central part of any network aggregating traffic from multiple backhaul and access networks.
CPE	Customer Premises Equipment. Equipment located at a subscribers premises and connected to a telecommunication provider network.
DEFRA	Department for Environment, Food & Rural Affairs. The government department responsible for environmental protection, food production and standards, agriculture, fisheries and rural communities.
DOCSIS	Data Over Cable Service Interface Specification. It is a standard for the high-speed transmission of data over cable networks.
DSL	

	Digital Subscriber Line. A family of technologies generally referred to as DSL, or xDSL, capable of transforming ordinary phone lines (also known as ‘twisted copper pairs’) into high- speed digital lines, capable of supporting advanced services such as fast internet access and video on demand. ADSL and VDSL (very high speed digital subscriber line) are variants.
Ducts	Underground pipes which hold copper and fibre lines.
Duct Access	A wholesale access service allowing a CP to make use of the underground duct network of another CP.
Ethernet	A packet-based technology originally developed for and still widely used in Local Area Networks.
Femtocell	A small base station, typically installed indoors to improve indoor mobile coverage. A residential femtocell uses the consumer’s broadband connection to offload the mobile data onto the fixed network.
FTTC	Fibre to the Cabinet. Access network consisting of optical fibre extending from the access node to the street cabinet. The street cabinet is usually located only a few hundred metres from the subscribers’ premises. The remaining segment of the access network from the cabinet to the customer is usually a copper pair (see DSL).
FTTDp	Fibre to the Distribution Point. Access network consisting of optical fibre extended from the access node to distribution point. The distribution point is typically less than 100m from the subscribers’ premises. The remaining segment of the access network from the DP to the customer is usually a copper pair (see DSL)
FWA	Fixed Wireless Access is the process of accessing a communicating network or internet on fixed wireless networks
G.Fast	A broadband transmission standard that further increases the access speeds possible on copper lines
Geotype	Geographical Types. Specific Geotype affected by terrain type, physical factors and the environment
GPON	Gigabit Passive Optical Network. A passive optical network is a telecommunication technology used to provide fibre to the end consumer, both domestic and commercial.
ISP	Internet Service Provider. A company that provides access to the internet.
Leased Lines	A transmission facility which is leased by a consumer from a public carrier

LLU	Local Loop Unbundling. LLU is the process where incumbent operators (in the UK this is BT and KCom) make their local network (the lines that run from the customers' premises to the telephone exchange) available to other communications providers. The process requires the competitor to deploy its own equipment in the incumbent's local exchange and to establish a backhaul connection between this equipment and its core network
LTE	Long Term Evolution. This is a 4G technology which is designed to provide faster upload and download speeds for data on mobile networks
Mbps	Megabits per second (1 Megabit = 1 million bits). A measure of bandwidth in a digital system.
MNO	Mobile Network Operator, a provider who owns a mobile network
Mobile Broadband	Various types of wireless, high-speed internet access through a mobile telephone or a mobile data dongle.
MPF	The provision of access to the copper wires from the customer premises to a BT MDF that covers the full available frequency range, including both narrowband and broadband channels, allowing a competing provider to provide the customer with both voice and/or data services over such copper wires
NGA	Wired access networks that are capable of delivering broadband access services with enhanced characteristics (such as higher throughput) as compared to those provided over already existing copper networks
OCN / POP	Optical Connection Point / Point of Presence. A demarcation point between communicating entities
OFCOM	The Office of Communications is the government approved regulatory and competition authority for the broadcasting, telecommunications and postal industries of the United Kingdom.
OSC	Optical Sub Loop Connection. A network termination point that provides deeper fibre access to the local network.
Physical Infrastructure Access (PIA)	A regulatory obligation under which BT is required to allow CPs to deploy NGA networks in the physical infrastructure of its access network.
PSTN	Public Switched Telephone Network. The network that manages traditional fixed-line telephone systems
SMPF	The provision of access to the copper wires from the customer's premises to a BT MDF that allows a competing provider to provide the customer with broadband services, while another provider continues to provide the customer with conventional narrowband communications.
Superfast Broadband	The next generation of faster broadband services, which delivers headline download speeds greater than 30 Mbit/s.
VDSL	Very High Speed DSL. A high-speed variant of DSL technology, which provides a high headline speed through reducing the length of the access copper line by connecting to fibre at the cabinet.

Wi-Fi	A short range wireless access technology that allows devices to connect to the internet. These technologies allow an over-the-air connection between a wireless client and a base station or between two wireless clients.

Costs for Digital Communications Infrastructures

A Cost Analysis of the UK's Digital Communications Infrastructure options 2017- 2050

Commissioned By

NATIONAL
INFRASTRUCTURE
COMMISSION

FINAL REPORT APPENDICES

Appendices

A. Service Specifications and Performance Assumptions

Technical Specifications

Applicable General Standards

1) In terms of active equipment (both on the network side as well as on the CPE side), we will refer to ITU specifications for fixed technology and 3GPP standards for FWA type of technologies

2) With regards to fixed technologies, here is the list of proposed standards :
   - FTTH GPON : G.984 and G.987
   - FTTH P2P : G.986
   - DOCSIS 3.1 : is a standard per se
   - G-Fast : G.9700

3) With regards to FWA technologies, reference should be made to 3GPP standards and potentially 5G evolutions starting with release 15 onwards. As far as frequencies are concerned, options either in the 3,6 to 3.8 Ghz, 3.8 to 4.2 GHz or 5.5 to 5.7 Ghz lightly licenced bands or in the 26 GHz band could be candidates for deployment. For the purpose of our study, our proposal is to concentrate on the 3.6 to 3.8 GHz band and also use 5.5 to 5.6 Ghz for the test designs, as a commonly used band for existing FWA operators.

Fixed Technology Specifics

Node Definiitons

4) A few nodes are to be defined in the network in order to propose standardised architectures that could accommodate the progress of the optical technologies from a speed/reach perspective

5) Therefore we would propose the following definitions :
   - Optical Connection Node (or Point of Presence-PoP): the highest point in the optical access network, where OLT (Optical Line Termination), Optical DDFs and some passive couplers can be installed. This node will connect to available transport networks
   - Optical Sub-Loop cabinet OSC): an intermediary point between the Optical Connection Node and the customer premises. Typically in a GPON architecture, such a cabinet or chamber can host passive couplers. For the sake of our study, we assume that this cabinet/ chamber is passive and that connections between this Node and the Optical Connection Point (see below) are entirely a point-to-point architecture
   - Optical Connection Point (OCP): the last passive connection point before entering the customer property
   - Optical Termination Point: the last optical connection installed in the customer premises

Network Dimensioning

6) In terms of dimensioning, our recommendation will be as follows:
   - Optical Connection Node: a minimum size of 1000 customer premises to accommodate sufficient granularity for letting multiple ISPs get an economic return by installing their OLTs. The size of 1000 should also be compatible with the current optical link budget.

- Link budget/max distance between OLT and CPE: a typical link budget of 28dB shall be applied; given current technologies and with 1>64 split ratio (in the case of GPON) a 16km distance would be achievable
- Optical Sub-Loop cabinet: 2x28U of inside connection capabilities (600 customers) or a variant of 2X40U of it (800 customers)
- Optical Connection Point: two fibres going to the Optical Termination point

7) As far as cables are concerned, the following is a minimal set of recommendations:
   - Optical Connection Node to Optical Sub-Loop: a minimum of 48 fibres
   - Optical Sub-Loop: two fibres dedicated to each customer premise plus a reserve (at 20% of the capacity) to accommodate for future growth and repair needs

Construction Techniques

8) We will assume use of the construction technique that is most applicable to the terrain, land use and any other geo-physical consideration from the list below:
   - Traditional trenches
   - Micro or Slot trenching
   - Directional drilling
   - Impact or vibration Mole ploughing
   - Standard telecommunications poles with catenary transport

9) The following excavation depths will be assumed:

Ground Material/Surface	Minimum Depth
Pavement and Grassed areas	350mm
Highways and Roads	600mm
Arable Land	600mm
Motorway and other Trunk Roads	800mm
Railways	1000mm

10) We will assume levels and competencies of construction resources to ensure adherence to HAUC and NRSWA obligations.

11) We will assume cables will be provided in ducts and not directly buried. The specification of ducts will be confirmed in terms of:
   - Material type, e.g. Polyvinylchloride or High density polyethylene, etc.
   - Diameter range, resistance to crushing, resistance to stretching
   - Micro-ducting or sub-duct structure
   - Resistance to air or to water pressure

12) Standard telecommunication duct dimensions shall be used:
   - 100mm diameter for local area core networks
   - 38mm diameter for premises access

13) Standard specifications of chambers will be assumed, e.g. FW2, FW4 etc. and will assume deployment of standard 'Quad Box' sections of 1310x 610 by 150mm.

The preferred chamber will be a preformed stackable lightweight type as shown, using GPS or HDPE material of 1310x610x450 depth to enable fibre joints to be positioned:

14) All fibres will adhere to Fibre optic specifications G657 A2/Bx

15) Cable specifications will be applied as relevant to:

- Installation in telecommunications ducts as defined above
- Installation on poles including electricity distribution poles

16) The following connector specifications will be applied as appropriate:

- Standard SC
- Standard LC
- Fusion splices
- Mechanical splices

Wireless Technologiy specifics

The following design considerations will be applied to defining wireless deployment and coverage:

17) Signal path compliance to NGA specifications for 30Mb/s download and 50Mb/s download services, as defined in the EU DG CONNECT Technical Guidance Notes in terms of:

- Headline download and upload speeds
- Maximum download and upload speeds
- Latency
- Jitter

18) Typical output power of base stations : 30 dBm

19) Typical receiver sensitivity in 20 MHz band : -105 dBm

20) MIMO/diversity transmission adding additional gain in link budget

21) Typical cell edge size for outdoor reception:

- in rural environments - 1km
- In semi-urban and urban environments - 500m

Performance Assumptions

22) We have made the following assumptions on the bandwidth performance of the various technologies. These are shown in the table below:

	Upload		Download		Comments
	'Design Maximum'	Average	'Design Maximum'	Average	
Baseline UK Performance (Ofcom Report 2017)	15.6	4.3	39.1	36.2	
FTTP	200	100	1,000	500	
Fibre to 5G i.e. local core network to 'lampposts' with 5G access	100	20	500	100	Average assumes cell edge speed.
G. Fast/ DOCSIS	60	20	300	100	Based on Swisscom experience. Also, early results from BT trials.
FWA/LRVDSL	20	10	100	30	Based on FWA, as LRVDSL likely to be the 'last resort' technology

All Speeds stated as Mbps

23) These figures are currently design estimates; whilst the access architectures for FTTP and 5G can support significantly higher download and upload bandwidths, providers will limit this through contention ratios and the transit/ backhaul capacity delivered to serving area Points of Presence. Using these assumptions allows for growth both in premises and capacity to meet demand.

24) Download speeds are generally set by network operators against the dimensioning of the network infrastructure and architecture

26) The Upload speeds within a given network architecture are calculated by consideration of the levels of aggregation designed within the architecture and by application of Shannon's capacity theorem. These are then set as design parameters.
Typically in the UK, a 1:8 ratio is used. We have assumed this improves as more transit and backhaul capacity is made available and usage profiles change. Hence, we have generally applied a 1:5 ratio in the table above.

25) Through improvements in network capacity and technology upgrades, the 'design maximum' figures can be assumed to become likely 'averages' during the time horizon of the study.

B. Infrastructure Re-Use Assumptions

1. Principles behind the assumptions

The scope of the Cost Analysis exercise was determined to generate a comparison that was as 'pure' as possible between certain technologies and the way that they may be deployed across an agreed set of geotypes, A 10% sample of these geotypes (weighted as appropriate to be representative of the overall UK population.) was then used to model the capex, opex and whole life costs of five scenarios:

1) 100% FTTP premises coverage with no re-use of existing infrastructure (the 'theoretical case' for baseline costing)

2) 100% FTTP premises coverage with re-use of physical infrastructure

3) Fibre to 5G premises access nodes- e.g. on lamp-posts (the adoption of 'disruptive' technology)

4) FTTP with FWA/ Long-Range VDSL in rural areas (consideraton of economic constraints on FTTP)

5) Mixed Technology Deployment (to upgrade the UK's existing infrastructure), such as G.Fast over FTTDp and DOCSIS 3.1 over co-axial cable.

Scenario 1 was designed to be a 'baseline' analysis, in which no assumptions or use was made of existing infrastructure.
Scenario 2 however, assumed a more realistic position; that a proportion of the existing physical infrastructure of ducts, poles, etc could be utilised to save both time and capex in the deployment of a new FTTP infrastructure.
Scenario 3 adopted the same principle as scenario 2- but further assumed that fibre was only deployed in the local 'core' network, with premises access being delivered via 5G local small cells on street furniture.
Scenario 4 also built on scenario 2, adding a further pragmatic dimension of limiting FTTP to 95% of premises on the basis of economic effectiveness. The remaining 5% were then modelled as being served by FWA
Finally, scenario 5 assumed that G.fast using FTTDp and DOCSIS3.1 on cable coax networks are utlised as an alternative to FTTP, with FWA being deployed to remaining premises as in scenario 4.

On the basis of these technical models, various assumptions were made on the extent of infrastructure re-use. These varied by the nature of the infrastructure and the geotype concerned. These base assumptions are shown in the following section and were applied equally to scenarios 2 to 5.
Additional overall assumptions were made regarding re-use:

a) No fibre is shared; only physical infrastructure assets such as ducts and poles.

b) Only passive infrastructure owned and managed by Openreach is available for re-use. Given the requirements of the Civil Infrastructure Directive, assets managed by other utilities should be considered and would have a beneficial effect on the level of re-use. However, as at the date of this report considerations and negotiations over their use were not sufficiently developed to enable a robust level of inclusion to be determined. NIC could be a valuable contributor in developing this aspect.

c) Congested and collapsed ducts are not rectified so as to be made available for re-use. Whilst current regulated products from Openreach for shared use (PIA) make provision for clearing ducts, accurate assessment of the impact of this would require significantly more granular design and analysis than permissible within the scope of this report. Instead, the proportion of re-use is set to assume only ducts that are 'fit for purpose' are used

d) No separate consideration is made regarding special environmental conditions. Such conditions would include Sites of Special Scientific Interest (SSSIs), Conservation Areas, etc. Instead a pragmatic level of re-use has been applied as shown below, that allows for greater 'new build' distances per geotype to accommodate longer runs to circumvent these situations.

2. Re-use assumptions per geotype

The level of existing infrastructure estimated as re-usable was considered separately for each geotype. Different ratios were also assumed for the following criteria as shown.

- The percentage of reusable infrastructure versus non-existing was assumed to vary between core network (from the Optical Connection Node to the Optical Subloop Cabinet) and access network (from the OSC to the Optical Distribution Point).

- The ability to re-use duct was considered differently for routes requiring larger underground cables (carrying more than 144 fibres), smaller underground cables and aerial poles.

Geotype 1: Mainly rural

Core network: share of...	Total	< 144 fibres	Above 144 fibres
Aerial	35%	35%	0%
Underground - existing duct	56%	54%	2%
Underground - non existing duct	9%	8%	1%

Access network: share of...	Total	< 72 fibres	Above 72 fibres
Aerial	65%	65%	0%
Underground - existing duct	30%	29%	1%
Underground - non existing duct	5%	5%	0%

Geotype 2: Largely rural

Core network: share of...	Total	< 144 fibres	Above 144 fibres

Aerial	30%	30%	0%
Underground - existing duct	60%	58%	2%
Underground - non existing duct	10%	9%	1%

Access network: share of…	Total	< 72 fibres	Above 72 fibres
Aerial	60%	60%	0%
Underground - existing duct	35%	33%	2%
Underground - non existing duct	5%	5%	0%

Geotype 3: Urban with significant rural

Core network: share of…	Total	< 144 fibres	Above 144 fibres
Aerial	25%	25%	0%
Underground - existing duct	65%	63%	2%
Underground - non existing duct	10%	9%	1%

Access network: share of…	Total	< 72 fibres	Above 72 fibres
Aerial	40%	40%	0%
Underground - existing duct	52%	50%	2%
Underground - non existing duct	8%	7,5%	0,5%

Geotype 4: Urban with city and town

Core network: share of…	Total	< 144 fibres	Above 144 fibres
Aerial	10%	10%	0%
Underground - existing duct	66%	63%	3%
Underground - non existing duct	24%	22%	2%

Access network: share of…	Total	< 72 fibres	Above 72 fibres
Aerial	20%	20%	0%
Underground - existing duct	70%	65%	5%
Underground - non existing duct	10%	9,0%	1,0%

Geotype 5: Urban with minor conurbation

Core network: share of...	Total	< 144 fibres	Above 144 fibres
Aerial	0%	0%	0%
Underground - existing duct	68%	60%	8%
Underground - non existing duct	32%	30%	2%

Access network: share of...	Total	< 72 fibres	Above 72 fibres
Aerial	10%	10%	0%
Underground - existing duct	78%	70%	8%
Underground - non existing duct	12%	10%	2%

Geotype 6: Urban with major conurbation

Core network: share of...	Total	=< 144 fibres	Above 144 fibres
Aerial	0%	0%	0%
Underground - existing duct	60%	25%	35%
Underground - non existing duct	40%	17%	23%

Access network: share of...	Total	=< 72 fibres	Above 72 fibres
Aerial	0%	0%	0%
Underground - existing duct	80%	50%	30%
Underground - non existing duct	20%	15%	5%

C. Operating Expenditure Assumptions

1. Purpose and Overall Methodology

The purpose of this document is to detail every cost assumption regarding Opex in the model used in the study.

While designing scenarios and identifying cost items, expenditures were divided in two categories:

- Capex (capital expenditures) refer to initial capital requirement for building network and equipment, that have to be paid once
- Opex (operating expenditures) are periodic payments required to keep the network running, e.g. rental costs, energy costs, etc …

Architectures were designed for each technology deployed in the scenarios. These are shown below. The capex and opex requirements of each component were then considered and included in the cost models. In addition, any operational cost overheads were also considered; those considered relevant were then included in the opex calculations. For example:

- A fixed overhead covering all support costs not directly attributable on a core network component basis or to premises connection
- A fixed overhead covering all support costs for infrastructure information systems

Opex items are listed below for each technology. Please note that all costs relate to the annual charge for each component.

The cost models were then populated with input/ unit data using the following approach:

1. Existing figures in the cost models from modelling French network designs were checked and validated before being adopted as the 'baseline'.

2. These baseline figures were then tested against UK comparators from previous and existing projects and amended accordingly.

3. Finally, other international comparisons were used to 'sense test' the revised figures

Whenever an item aggregates several cost components, they are compiled 'bottom-up', i.e. all cost items were taken into account and summed to obtain a single result. For instance, regarding maintenance, we multiplied the cost of an engineer to the assumed number of operations required per year.

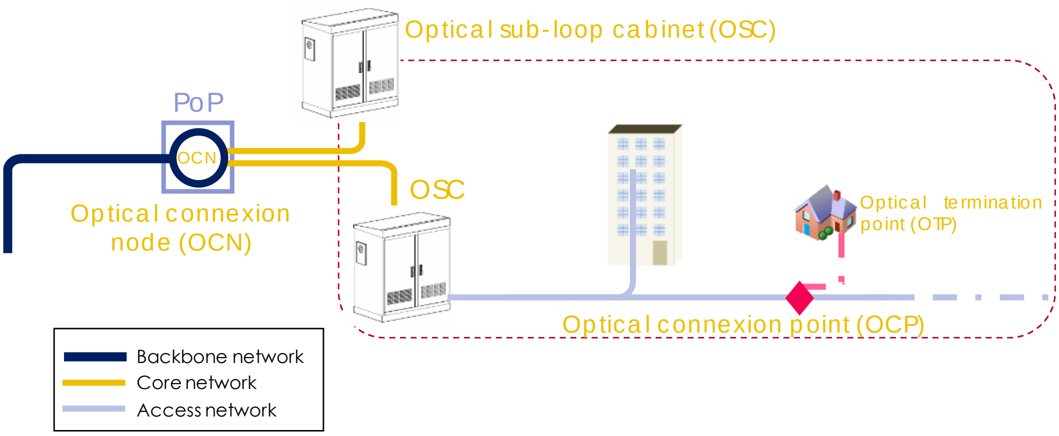
All opex unit costs relate only to the incremental maintenance costs of FTTP and FTTDp. For example, the existence of a copper network for other technologies and services to premises is recognised- and the related costs of the support of this is <u>not included</u> in the model. However, the incremental costs of running a G.Fast solution over FTTDp are included.

From our discussion with companies maintaining both copper and fibre networks (giving us a real “field” view) and operators, we have been able to model the respective cost of maintenance of FTTP and FTTDp. All have stated that in the long run, maintaining a full passive infrastructure (FTTP) is cheaper than maintaining FTTDp with lots of transient faults
generating tickets and interventions.
Therefore, in increase in the support cost of copper from the DP to premise has been included.

Capex refresh and whole life cost calculation are explained below, along with detailed Opex incurred by each technology used.

2. Opex by Technology

2.1. FTTP



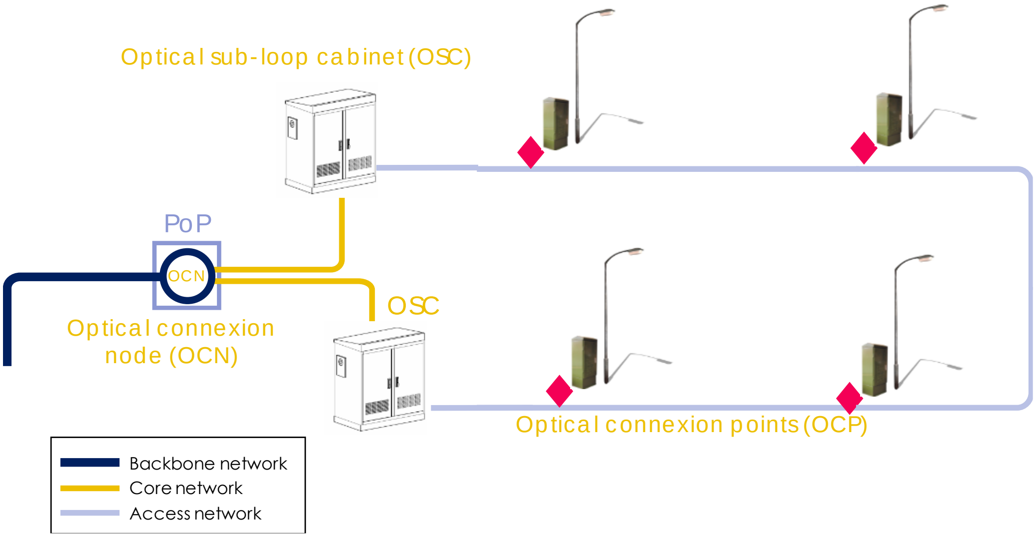
The following table lists Opex items carried by FTTP technology per year. Fibre-to-the-Lamppost Opex are similar. The technology is used in scenarios 1 to 4.

Item	Unit	Unit cost (£)	Comments
Duct rental	£ per metre	£0.26	Assumed average cost from variable figures according to areas
FTTP lines maintenance			
Fixed overhead (hotline, material, legal & paperwork)	Fixed cost	£9,000,000	Accounts for all of UK as a single overhead figure (assumes a workforce per region of c.250 including 10% management at an employee cost of £30k per year and a £90k per management head)
Support and maintenance unit cost	Per premise	£11.52	Preventive and reactive maintenance fee per FTTP deployed (infrastructure and premises)- see Note 1 essentially reactive maintenance at a cost of £50 per hour for technician time
Optical Connection Node unit cost	Per unit	£1,382.49	Yearly maintenance fee for OCN passive (buildings +Optical Distribution Frame) + optical equipment typical cost from supplier's interaction (Nokia, Huawei)
Optical Subloop Cabinet unit cost	Per unit	£460.83	Yearly maintenance fee for OSC passive equipment (refer to number of OSC per sample simulated) essentially a 4 hour visit each year per technician in preventive mode
FTTP Information System maintenance			
Fixed part	Fixed cost	£2,700,000	Accounts for all of UK as a single overhead figure. This comprises: Licence costs for Asset Management, GIS, Planning and Scheduling software; associated support and development costs.
Support and maintenance unit cost	Per premise	£0.92	IT management system cost per connected line (for inventory, maintenance workflow and wholesale) Coming from reference discussions with FTTP operators in France (SFR)
Energy cost			
Cost per Optical connection node	Per OCN	£691.25	Based on OLT typical benchmarks and a £0.15/kWh
Cost per connected premise	Per premise	£0.70	Assumes a power consumption of a 2W ONT at £0.15 /kWh

Note 1: The support and maintenance unit cost contains the following components:

- Direct costs for support and maintenance of the NTE and CPE at customer premises
- Direct costs for support and maintenance of the point to point fibre connection from the premises to the OSC
- An apportionment of the support and maintenance of the GPON fibre connections from the OSC back to the OCN

2.2. 5G Access from lampposts



The following table lists Opex items carried by 5G technology per year. 5G technology is used in scenario 3.

Item	Unit	Unit cost (£)	Comments
Fixed overhead (hotline, material, legal & paperwork)	Fixed cost	£3,600,000	Accounts for all of UK as a single overhead figure (assumes a workforce per region of c.100 including 10% management at an employee cost of £30k per year and a £90k per management head)
Power for the base station	per base station	£150	Based on typical output power of 30 dBm and £0.15/kWh (assumes 20 W per base station and 5000 h of full power operation per year)
Wayleave and license costs per base station, dependent on whether council (or other) owned street furniture is used vs separate monopoles:	per base station	£1,000	Based on assumptions made within the business models for 5G trials (Arqiva)- See note 2 below.
FTTP Information System maintenance	Fixed cost	£1,100,000	Accounts for all of UK as a single overhead figure. This comprises: Licence costs for Asset Management, GIS, Planning and Scheduling software; associated support and development costs.
Support and maintenance unit costs	Per base station or per premise	£1000	Based on actual benchmarks for macro base stations

Note 2: The wayleave and licence cost for street furniture such as lamp-posts can vary significantly. Annual rental charges in major metropolitan areas (e.g. Paris) can be as high as £3,000 per annum. This would have a profound effect on the whole life costs of a 5G small cell deployment.

2.3. Fixed Wireless Access (FWA)

The following table lists Opex items carried by FWA technology per year. This technology is used in scenarios 4 and 5.

Item	Unit	Unit cost (£)	Comments
Licencing and administration cost per premise	Per premise	£1.00	
FTTP Information System maintenance	Fixed cost	£1,100,000	Accounts for all of UK as a single overhead figure. This comprises: Licence costs for Asset Management, GIS, Planning and Scheduling software; associated support and development costs.
Support & Maintenance	per premise	£53	Based on 12% of premises capex costs. A 12% apportionment of initial capital is a consistent financial provision within the industry.

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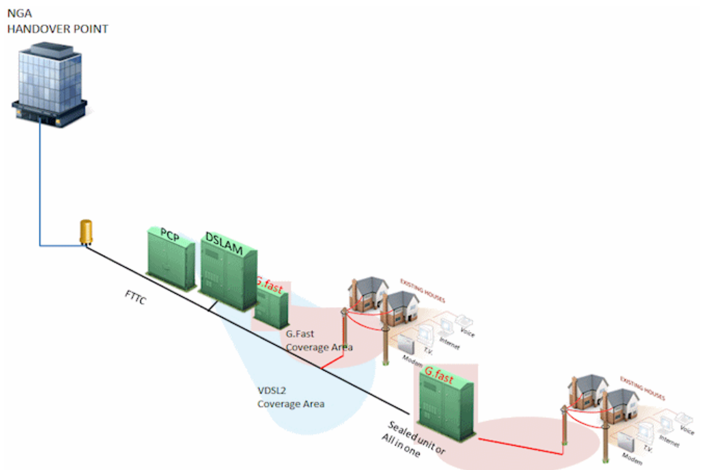
2.4. FTTDP



The following table lists Opex items carried by FWA technology per year. This technology is used in scenario 5.

Item	Unit	Unit cost (£)	Comments
Duct rental	per metre	£0.26	Assumed average cost from variable figures according to areas
Fibre lines maintenance			
Fixed overhead (hotline, material, legal & paperwork)	Fixed cost	£9,000,000	Accounts for all of UK as a single overhead figure (assumes a workforce per region of c.250 including 10% management at an employee cost of £30k per year and a £90k per management head)

Support and maintenance unit cost	Per premise	£13	Preventive and reactive premise deployed (infrastructure and premises)- see Note 3 our discussion with Swisscom assumes that because of the high frequencies being used, micro-cuts will lead to more notifications and more interventions in the field. A 2.3% intervention rate on copper is typically what SFR and Bouygues Telecom have reported to ARCEP and their subcontractors
Optical Connection Node unit cost	Per unit	£1,382.49	Yearly maintenance fee for OCN passive (buildings +Optical Distribution Frame) + optical equipment
Optical Subloop Cabinet unit cost	Per unit	£460.83	Yearly maintenance fee for OSC passive equipment (refer to number of OSC per sample simulated)
Distribution Point (G.Fast) unit cost	Per unit	£200	Yearly maintenance fee for DP active equipment (for 40 ports). Based on one intervention per DP per year lasting two hours will possibly two technicians. It doesn't assume pole mounted equipment which would require the use of an aerial bucket truck
FTTDP Information System maintenance			
Fixed part	Fixed cost	£2,700,000	Accounts for all of UK as a single overhead figure. This comprises: Licence costs for Asset Management, GIS, Planning and Scheduling software; associated support and development costs.
Support and maintenance unit cost	Per premise	£0.92	IT management system cost per connected line (for inventory, maintenance workflow and wholesale)
Energy cost			
Cost per Optical connection node	Per OCN	£691.25	Based on OLT typical benchmarks and a £0.15/kWh
Cost per G.Fast Distribution Point (48 ports)	Per unit	£187.5	Assuming powering from the CO and a £0.15/kWh
Cost per connected premise	Per premise	£0.70	Assumes a power consumption of a 2W ONT at £0.15/kWh

Note 3: The support and maintenance unit cost contains the following components:

- Direct costs for support and maintenance of the NTE and CPE at customer premises
- Direct costs for support and maintenance of the existing copper connection from the premises to the DP

- An apportionment of the support and maintenance of the point to point fibre connections from the DP back to the OSC
- An apportionment of the support and maintenance of the GPON fibre connections from the OSC back to the OCN

Based on the table, unit Opex both per premise and per geotype could be calculated and then used to compute the Whole life cost.

3. Capex refresh

This item accounts for replacement of infrastructure equipment, which is assumed to be necessary every 8 years. The items below require a Capex refresh. When not mentioned otherwise, the replacement unit costs are equal to the initial capital expenditures.

Items to be renewed	Unit cost	Comments
Fibre network		
Customer Premises Equipment	£46	
Set-top box (for TV)	£138	
PoP (Optical Connection Node)	£25,000	The unit cost of building it ranged from £32,000 (new PoP) to £69,000 (existing PoP)
Specific to FTTP:		
Active equipment in Optical subloop cabinet	£28	
Specific to FTTDP:		
Active equipment in G.Fast device	£370	
Active equipment in DOCSIS device	£92	
5G Network		
Small cell	£4,000	
FWA network		
Replacement of half of 15m poles	£15,000	The replacement costs are identical to the ones indicated on the Capex table because half of poles were assumed to be already built.
Replacement of half of 25m masts	£25,000	
FWA cabinet on pole	£1,200	
Cambium 450 sector	£5,000	4 per pole
Consumables	£250	Per pole
Radio transceiver	£250	Per premise
Home router	£50	Per premise

4. Whole life cost calculation

Whole life costs were calculated by adding up discounted yearly Opex.
A single discount rate was picked in all scenarios: 9.3% which is based on the WACC used for regulated products[1].

Deployment time influences Opex as a faster deployment generates more 'absolute' opex cost, without necessarily generating revenue at the same rate. Many operators build speculatively to manage carefully the cash-flow implications of this.
However, this study focuses specifically on the cost and not demand elements of the infrastructure. To accommodate this, the model assumes that the infrastructure is assumed to be deployed at a uniform rate.

Deployment times were assumed to be the following, based on international comparison and on typical deployment rates when the industry has made the necessary investments to move forward:

- FTTP with no infrastructure reuse (scenario 1): 15 years
- FTTP with infrastructure reuse (scenario 2 to 4 – the use of other technologies in scenarios 3 and 4 should not cause any sizeable change): 12 years
- FTTDP (scenario 5): 7.5 years

5. Commentary

As shown by the details above, the technology that carries highest Opex is FTTDp,, This is based on the assumption in our modelling that the cost of FWA backhaul is reflected in the capex for building a fibre infrastructure to the main points of presence and beyond to the broadcast locations.
In a 'real world' context', this will likely be undertaken by a major carrier, who will rent services over this to FWA operators. However, the comparison between scenarios is more consistent with this cost being considered as capex.

Taking this into account, the opex for both wireless technologies (5G and FWA) is lower than fixed. The primary reason for this is the removal of the costs for support and management of the final fixed component of the infrastructure.

The opex for FTTDp is higher than those of FTTP because of many reasons, particularly:

- Copper maintenance per premise is more expensive than fibre maintenance. This is based on empirical evidence from a number of operators with experience in G.Fast over FTTDp. For example, from one operator (Swisscom) we understood that there can be significant due to a large number of micro-cut effects on FTTDP/G-Fast when deployed in aerial environments. Also, from our experience working for operators and dealing with copper maintenance issues, using higher frequencies will lead to more notifications from customers which will materially lead to more interventions in the field and therefore more costs (even though at the end of the day the fault may not be there). These are classified as "transient faults"

[1] https://www.ofcom.org.uk/__data/assets/pdf_file/0019/50635/bt_annex_j.pdf and http://www.ukrn.org.uk/wp-content/uploads/2017/05/20170503-UKRN-Annual-WACC-Comparison-Report_FINAL.pdf

- FTTDp also requires the deployment of additional active equipment: a DOCSIS or G.Fast device. These incur extra costs of maintenance for more active equipment in the field and energy to remote power the device from a central location.
- Replacement costs of DP cabinets also occur during the life time of the project given the obsolescence of electronics.
- We have assumed in the model that there are long term implications on equipment replacement/ upgrade for FTTDp/G.Fast especially if a new generation of chipsets were to be installed every 8/10 years to accommodate for more bandwidth

Our experience working and interacting with operators shows that FTTP may bear more initial interventions in the initial phases of deployments especially if the infrastructure is shared and multiple interventions take place on the OCN, OSC and customer premises from different ISPs. For example, French networks on shared infrastructure suffer a higher number of implementation-generated faults (a new connection from ISP1 breaking an existing connection of ISP2)   If only one company is handling the maintenance of the infrastructure- and particularly where only one provides customer connections for FTTP (such as the model that prevails in the UK for DSL, with Openreach performing most of the works on behalf of other ISPs) then the probability of seeing a surge of defects in the early deployment of FTTP is limited.

From the level seen in the field after 5 years of deployment, the level of intervention on fibre is about half the level of DSL (installed into central offices)[2]. This is partly due to FTTP making use of passive components in the outside plant, structurally leading to less intervention and no remote powering from the central office.

FTTP also has a lower capex refresh level than FTTDp. download capacity of 2.5 Gbit/s shared bandwidth is available now on FTTP, with 10 Gbit/s shared download capacity already available from some vendors. A next generation (DWDM-PON using multiple wavelengths) is also under development and can be deployed re-using all the deployed infrastructure. These developments incur lower capex refresh cost at the infrastructure level than the equivalent development upgrades in FTTDp.

There is also operator field data indicating that the Opex of FTTP may become closer to that of FTTDp. The principle reasons for this are that:

1. Most network faults requiring intervention are due to physical causes such as weather, 3rd party damage, crime, fire and working party faults. These would apply equally to fibre and copper networks. Copper can corrode or suffer from dampness, which does not affect fibre, but as a proportion of network faults this is small. Similarly, fibre can suffer from bend radius issues, component brittleness and mechanical misalignment/dirt issues, which copper does not.

2. Fibre deployment generally requires a higher skilled workforce, more expensive equipment and occasionally two person working where copper technology can be done with a single person. Fibre is also significantly more expensive to repair when damaged due to the nature of alignment and jointing of fibres and the requirement of maintaining a bend radius.

[2] Based on field reports from SFR and Bouygues Telecom.

3. Fibre components made of plastic or nylon turn brittle or fail over time and current experience with 15+ year fibre in the network is that terminations often have to be repaired or replaced.

Collation of field data from various operators over a period of time for FTTP infrastructure using the latest techniques and components will assist in improving the accuracy of these figures.

Finally, our FTTP design has also assumed additional costs since we have designed an open access infrastructure (based on the deployment of OSCs) to allow for multiple ISPs to deploy their services over a common infrastructure. If an infrastructure with no-unbundling capability be deployed, there would be further reductions in the number of fibres used (which will have a similar architecture to G.Fast/ FTTDp).There would hence be a corresponding slight reduction in FTTP Opex.

D. GIS Database for Cluster Models

5.1. Principles of Linear Modelling Applied

The FTTP and FTTDP networks were modeled in the sampled districts via an algorithm method. The following datasets were gathered:

- The road network in GB from Ordnance Survey
- The location of all premises in GB from Ordnance Survey
- The location of all Points of Presence from Samknows
- The location of all street cabinets from BT

The existing PoP and street cabinets are likely to be used as location for OCNs and OSCs. That is why their locations were placed on the map to model OCNs and OSCs.

The cable network was modeled always to follow the road network, because of a lack of an actual copper or electrical network map at our disposal. Though it might result in some inaccuracies, the road network is known to be highly helpful information to model other networks.

A shortest path search algorithm was then applied to the map. It delivered the network displayed on the maps and assumed in the model.

A full version of the GIS Database is provided on the CD submitted to The National Infrastructure Commission with this Final Report for internal use only, due to NDA considerations.

E. Consideration of Weighted Average Cost of Capital (WACC)

WACC estimation

In the first drafts of the report, we kept any WACC calculation aside since the WACC of each market operator will be by nature different (different equity/debt ratio, risk profile, current debt to EBITDA ratio, regulatory decisions regarding FTTP and alternative technologies, current trends in copper wholesale prices, etc.).

As it is likely that the infrastructure considered in this report will be delivered and operated by several providers, it was felt that the application of WACC at this stage might be counter-productive in the transparency of the figures.

However, we can benchmark some current WACC applied to Openreach activities. For instance, in the report from 2015 about the WACC applied to leased line, we find the following elements about BT and Openreach WACC levels

Table 1: Revised estimates of WACC

	BT Group (base case)	Openreach	RoBT
Real risk free rate	1.0%	1.0%	1.0%
Inflation assumption	3.2%	3.2%	3.2%
Nominal risk free rate	4.2%	4.2%	4.2%
Equity beta	0.95		
Asset beta	0.73	0.60	0.79
Equity beta @ 30% gearing	1.00	0.81	1.09
ERP	5.4%	5.4%	5.4%
Gearing	30.0%	30.0%	30.0%
Debt premium	2.1%	1.9%	2.2%
Debt beta	0.1	0.1	0.1
Tax rate	19.3%	19.3%	19.3%
Pre-tax nominal WACC	10.2%	9.3%	10.6%

A recent review by ARCEP in France about the WACC of regulated activities of Orange concluded to a level of 8,7% for the years 2016 and 2017.

WACC for FTTP projects should be higher than the above-mentioned levels, possibly in the 12 to 13% range. However, the wholesale price levels should mitigate this, and they are also linked to the retail price levels in the country.

In the Draft 3 of the report, we have refined the NPV calculations based on our best estimate of the associated OPEX costs in the U.K. Therefore, the following discount rates have been applied to the model:

- 9.3% discount rate has been applied to the capex for refresh of active equipment
- 9.3% to all opex

F. Operator Survey Results and Analysis

5.2. Summary Findings

Full results of the survey can be found in the Anonymised and Compiled Results Analysis in the pdf attached to this Appendix titled:

[Appendix E- NIC Operator Survey- Anonymised and Compiled Results (Final)]

In summary, the outputs and findings from each Part are as follows.

5.2.1. Validity of Respondents

All respondents, both those invited and those requesting to participate were validated as having legitimate and current experience in the broadband market hence they were eligible to provide useful contributions to the survey and analysis.

The 15 responses were all checked as valid and qualified; this represents a response rate of 44% which is encouraging.

5.2.2. **Part A: Respondents' Scale and Span of Experience.**

The respondents (they) provide digital communications infrastructure across the UK. At least 2 provide networks in all the regions listed, with the exception of Scotland (1), Wales (1) and Northern Ireland (0). This is to be expected given the challenges of delivering infrastructure in these regions.

In terms of the technologies they have experience of:

- 60% provide FTTP either as Point to Point or GPON
- 33% provided FTTB
- 2 used FTTP/ LLU to deliver connectivity
- 5 deployed Wireless solutions, using PtP. PtMP architectures, over a combination of licenced, lightly licenced and unlicensed spectrum.
- None stated experience with G. Fast, Fibre to the Node/ SLU or DOCSIS over coax. This is to be expected as only Openreach and Virgin Media have experience in the first two - and a very small number of other operators (2 or 3) have experience of SLU.
- Hence with the final caveat, the results cover the broad range of key technologies within the scope of the study.
- They claim between them 10m premises passed with the technologies above. Growth intentions are unclear, as the number responding to future plans (by 2018- 202-2030) varied, therefore it was not possible to plot a trend.

Similarly, take up rates could not be calculated as 9 of the 15 exercised their right to commercial confidentiality and did not provide end-user numbers. However, 80% confirmed they served both residential and business premises.

The experience captured through the participating respondents is therefore broad enough to cover the scope of the survey.

5.2.3. Part B: Design and Cost Referencing - City

50% of the respondents reviewed and commented on the FTTP solution for an urban area in Geotype 6, with 2 providing feedback on the FWA solution.

FTTP

Capex: The 6 responses 'normalised' on the Capex quoted in the design (o% variance). However, this was due to a counter-balancing of some wide variance (range from 80% under to 80% over estimates). The comments indicate that the variances related mainly to the extent of new build versus re-use of infrastructure - this was a recurring theme in the underlying trends regarding cost reductions.

Premises Connections Costs were generally between £100 and £300, with some in the thousands (apparently for high-end business circuits).

Opex was intimated at being under-estimated by (on average) 24%. However, they felt this depended on what was involved and what the SLA offered to the end user (again a business grade issue)

Backhaul was provided equally over their own network and by third parties. Provision costs therefore varied accordingly, with the average being £7.4k. Opex was around £1,100 with little variance.

FWA

Capex: was considered to be over-estimated by around 10%.

Premises Connections Costs varied between £50 and £320, again probably due to a differential between residential and business.

Opex generated some debate; with one response suggesting a 20% over-estimate and another claiming significantly lower costs (100%) than stated.

Backhaul for FWA also was provided equally over their own network and by third parties. Provision costs therefore varied here accordingly, with the average being £19.3k. Opex was around £2-3k with little variance for a rented service.

5.2.4. Part B: Design and Cost Referencing - Town

47% reviewed and commented on the FTTP solution for a market town in Geotype 1, with 2 providing feedback on the FWA solution and 1 reviewing FTTC (with no corresponding feedback left)

FTTP

Capex: The 5 responses indicated an average 14% over-estimate, again with a counter-balancing of some wide variance for the same reasons as in the City design.

Premises Connections Costs showed noticeable variance between £150 and £700, with some in the thousands (apparently for high-end business circuits). There could also be an effect due to line length.

Opex was intimated at being over-estimated by (on average) 17%, with the same caveats as for the City example.

Backhaul was provided equally over their own network and by third parties. Provision costs therefore varied here accordingly, with the average being £9k. Opex varied between £1 and 3k with little variance for a rented service but noticeable difference for 'own provided'.

FWA
Capex: was considered to be over-estimated by around 25%. One FWA provider felt the design was poor, leading to this over-estimate.

Premises Connections Costs varied between £320 and £600, again probably due to a differential between residential and business.

Opex 10% under-estimate.

Backhaul for FWA also was provided equally over their own network and by third parties. Provision costs therefore varied accordingly, with the average remaining at £9k. Opex was around £1.5k with little variance for a rented service.

5.2.5. Part B: Design and Cost Referencing - Rural

31% reviewed and commented on the FTTP solution for a rural area in Geotype 3, with 23% providing feedback on the FWA solution.

FTTP
Capex: The 4 responses indicated an average 70% over-estimate, again for the same reasons as in the previous designs.

Premises Connections Costs showed noticeable variance between £275 to £900, again for business vs residential.

Opex was intimated at being over-estimated by (on average) 53%, with the same caveats as for the City example.

Backhaul was provided by third parties. Provision costs averaged at £6k but only due to an outlying response at £15k with two other at £1-2k. This could be due to the bandwidth anticipated for a network of this size. Opex was around £1.3k with variance from £1.5k to £2.5k - again probably due to the bandwidth assumptions.

FWA
Capex: was considered to be over-estimated by around 5% with the same considerations as before regarding design.

Premises Connections Costs varied between £330 and £450.

Opex was not commented on.

Backhaul for FWA also was provided equally over their own network and by third parties. Provision costs therefore varied here accordingly, with the average being £11k. Opex was stated at £1.5k from one response.

5.2.6. Part C: Impacts and Plans - Technology Roadmaps

All respondents provided an indication of their roadmaps.

FTTP
89% stated they are deploying FTTP or a variant now and would continue to do so over the next 10 years in Urban and in Rural (there was an anomalous figure against Rural FTTP in 3 years, which was discounted).

FWA
67% are deploying FWA in Cities and Rural now. Over the next 10 years, rural use may increase, with city use remaining relatively constant.

5G
Adoption showed significant inconsistency - probably due to a continued lack of clarity in the operator market. One respondent claimed to be deploying now in cities and rural (who could be involved in a pilot), with 80% anticipating deployment in 3 years within urban areas. Rural showed a predictably slower curve, with 50% adopting in 3 years and 75% by year 10.

5.2.7. Part C: Impacts and Plans - Cost impact of Re-use/ Sharing

Openreach PIA
Contributions were high to this question, resulting in an average of 33% anticipated reduction from PIA in cities. However, this was driven by an outlying response of 90% and another at 70% - the mode was 20%.
The same opinion held for PIA in towns, with an average of 33% still - but the mode was a little higher at c.30%.
There was greater confidence in savings from PIA in rural; the average was 43%, with 4 responses ranging from 50% to 80%.

Municipals and Utilities
Less reductions were anticipated from re-use and sharing of these assets, with an average of 32% saving in urban and 35% in rural, with less responses in the 60-80% range than for PIA.

5.2.8. Part C: Impacts and Plans - Cost impact of Micro-Trenching

The response was very strong and consistent at between 30 and 40% saving over normal construction costs.

5.2.9. Part C: Impacts and Plans - Licences and Wayleaves

Cost savings from better mast sharing arrangements varied between 10% and 50%, with an average of 30% saving.

They reported that street works licences and other consents constituted between 10% and 30% of project costs (average 17%). This is therefore a significant factor in build costs.

5.2.10. Part C: Impacts and Plans - 5G

Opinion on how much of an impact 5G would have as an alternative access technology was relatively consistent, with around 50% of respondents feeling it would have moderate impact in the next 5years in urban (2.82/5) – and virtually no impact in rural over the same timeframe (1.9/5).

There was little consistency around the impact on 5G access costs; with opinion on Capex ranging from a 60% reduction to a 30% increase and Opex increasing between 10% and 40%.

60% believed 5G access would be a temporary solution, with only 20% believing it would be permanent.

All believed 5G would have little to no impact within the next 3 years and 5 years in rural. Its impact would increase steadily to 'moderate' in urban over the next 25-30 years. In rural there would be a gradual climb to 'minimal impact' between years 10 and 30.

5.2.11. Part C: Closing General Comments

Open comments were invited at the end of the survey. Only four respondents took up the offer.
Their comments are reported here verbatim:

"New commercial models - such as concession contracts for ducts, co-operative organisations for civil and fibre assets, JVs for council assets - all significantly reduce the capital costs of building infrastructure. These need to be encouraged more by policy. "

"As commented, more standardisation on global best practices for design, installation and material technologies, within fibre optic systems. It's no surprise that leaders like Japan, Korea and several northern and eastern European countries have been going full fibre (even Jersey) for decades. "

"The impact of 5G will rely on modifying spectrum policy, so the rollout is not sacrificed by the spectrum fees."

"5G should be considered as complementary to FTTP rather than a replacement. Neutral host models will be important - both FTTP and 5G."

5.3. Survey Content

A Link to the Operator Survey can be found below:

https://www.surveymonkey.co.uk/r/VHMRYT9

In addition, Copies of the Design Documents used as the Reference documents in the survey can be found via the links in the Survey using the URL above.

G. International Projects for the deployment of FTTH

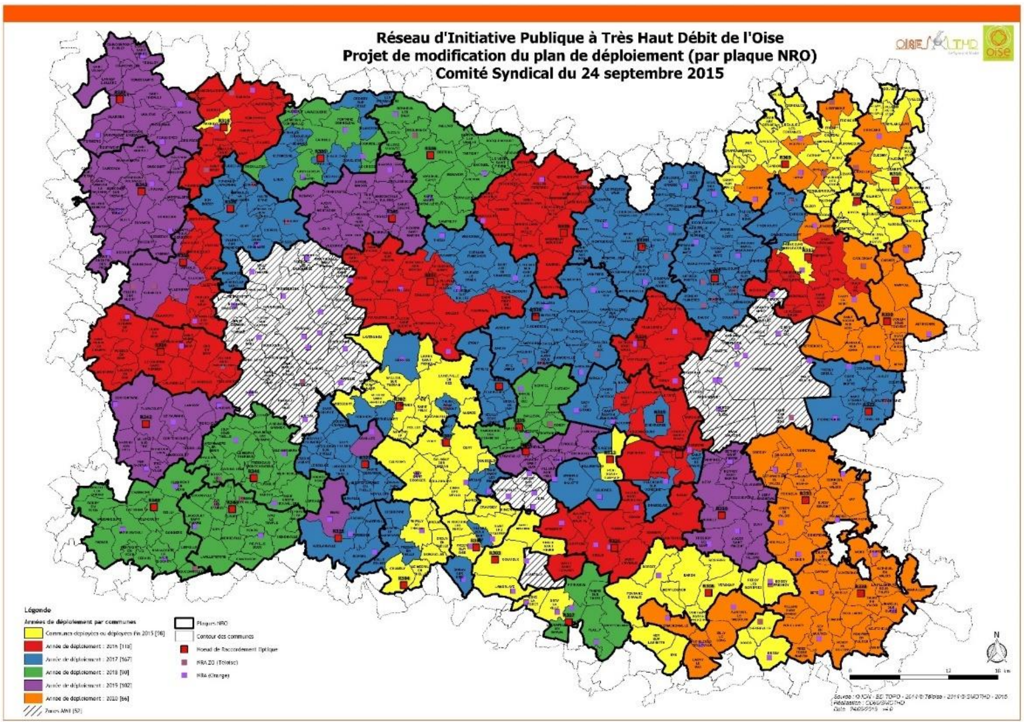
1. Oise PIN (Public Initiative Network)

1.1. Summary Information

Project Name: Oise Public Initiative Network
Name of Customer: SMOTHD (Syndicat Mixte Oise Très haut Débit)

5.4. End Customer profile

Oise is a region North of Paris and consists of 641 local areas each with individual local government in the form of an elected mayor. These 641 semi-rural and rural areas are being connected with fibre to every home and building across the region. The area has an average density of 135 persons per square Kilometer. The area in total is 6000 square Kilometers.



It is worth noting the deployment is driven by 'area completeness': municipalities have their rollout realized in one single batch, preferably within less than one year. The design and installation crews have their activity optimized, and the commercial base that is commissioned becomes more attractive for a Communication Provider, because it will have access to a consistent and large population. (Other less effective solutions tend to be starting works in almost every municipality, but delaying the complete commissioning over several phases along the contract duration).
The structure of the participants is as detailed in the chart below, with The Contractor having the Design and Build and NOT the Operations and exploitation of the network - that responsibility is with a major national operator in France. Where is the chart?

5.5. Contract Description

Public initiative Networks (PIN) are networks where the French Government has instigated an Intervention Strategy that allows public money alongside European subsidy to provide broadband services to the areas not currently being served by a commercial operator, and unlikely to be served in the foreseeable future. The Contractor bid for this contract under competition using the OJEU procurement procedure.
The Contractor will Design, Build 136 000 Homes Passed (HP) from 2014 to 2016 for the initial phase 1 of the contract.

5.6. Project Overview

The network has been designed to “pass” 136 000 premises.

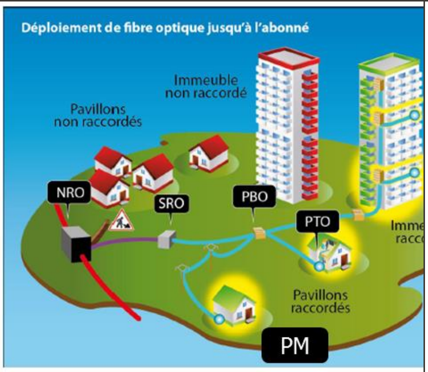
5.7. Financing, Shareholders Special Purpose Vehicle description

The project is NOT financed by 3rd party banks for debt or equity partners.

5.8. Scope of Supply

5.8.1. Design & Build

On award of the contract, The Contractor set up a dedicated project team within 3 months consisting of 25 personnel located in the local city in the region of Oise. This team has responsibility for the design and works locally, a further 20 design engineers in Malakoff Paris (60km away) and then a further 180 production personnel actually rolling out the network made up of both internal (30%) and external resources from local companies (70%)



Deployment to date:

- 4 200 km of cable
- 36 000 splice enclosures and Distribution Points (DP)
- 37 000 telecom and Power poles used.
- 8% of new civil works only

The design engineers are based in Paris, 60KM from the project office in Oise. The Design office is providing the following services to the project team:

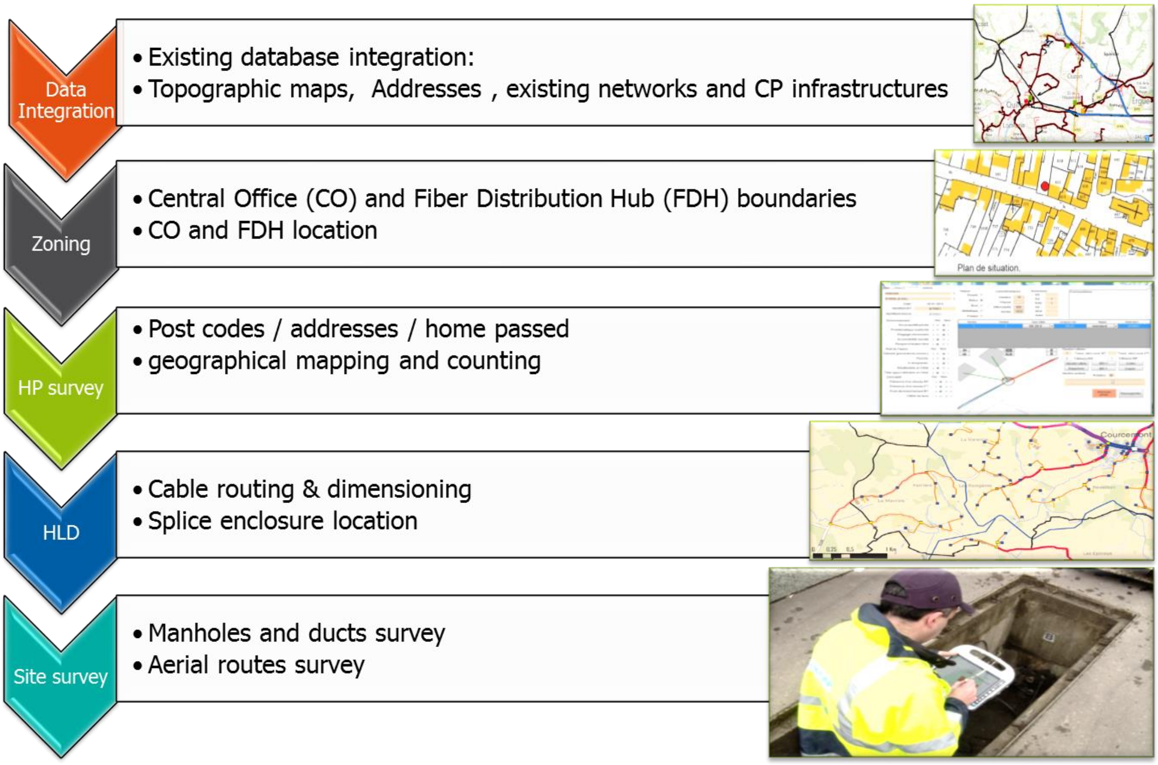
- HP detailed survey (this site survey is done by local resources using dedicated ‘in house’ software on tablet and managed by the Design Manager)
- Research and review of ALL known assets in region that can be used to facilitate the overall design (this site survey is done by local resources equipped with appropriate tablets)
- Design of network topology, from PoP boundary up to detailed design of each DP
- Engineering drawings for civil works, including rectification of existing assets, new asset deployments like electrical poles, street cabinets and chambers

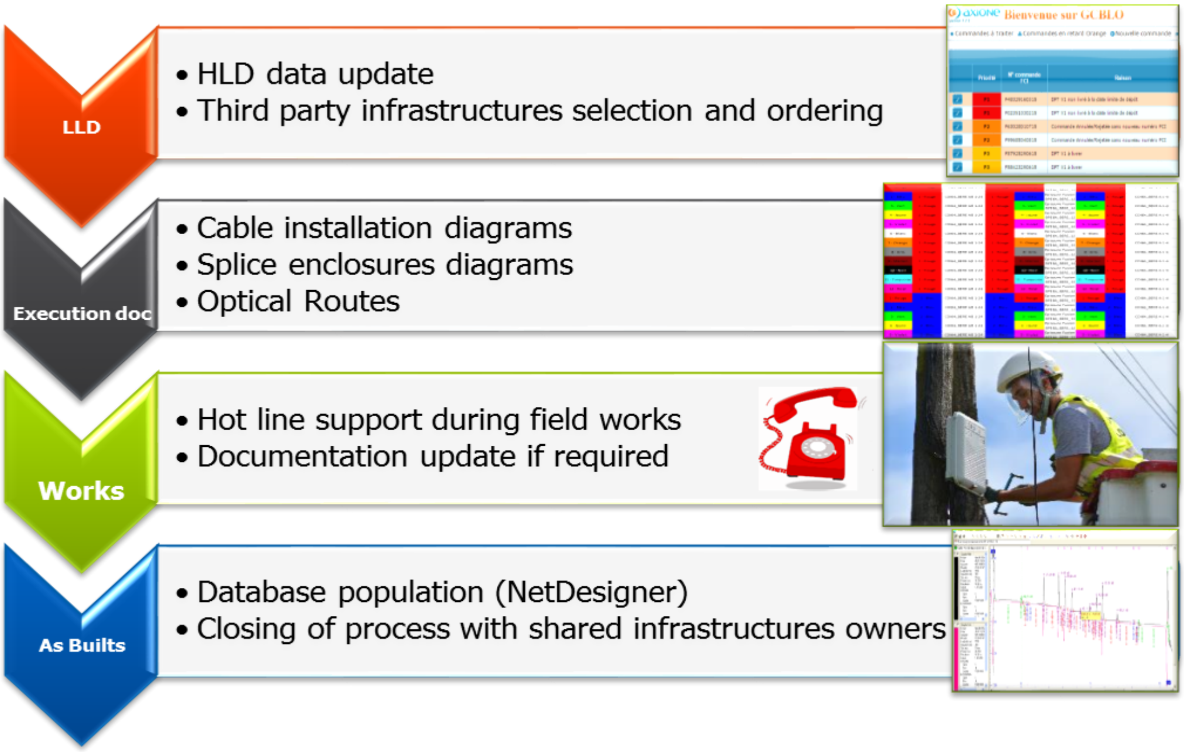
- Design and data sheets for applications of use to 3rd parties
- Cost management and design to cost analysis
- Data population for O&M activities, directly put in the OPERATOR Asset Inventory and GIS database

5.9. Design Methodology

Below is the generic flowchart of the design process. Depending on the scope of works, intermediate validation steps are requested by the Local authority; as a default, control points are generally necessary for the following deliverables:

- High Level Design (HLD) (validation of Central Offices / Cabinets initial sizes and locations)
- Homes Passed (HP) survey (validation of network size and geographical distribution)
- Low Level Design (LLD) (validation of detailed quantities and forecasted work schedule, as well as Rights Of Ways completion)
- As Built (commissioning data completion and format, for further data population in O&M GIS tool)





Point to Point access links designed and built during FTTO activities are generally simpler, although the same process is rolled out, in order to maintain an industrial and exhaustive methodology that will guarantee overall deliverable consistency.

5.10. The Contractor innovations in the Design and Build phase.

The Contractor is maintaining a team of GIS and IT experts that are continuously adapting and improving the various tools in use during the Design stage. This group of experts is also in charge of identifying new solutions that will enhance the overall rollout efficiency and quality. The example below presents one of these innovations.

5.10.1. 3D Immersive Views.

Rural areas are often poor in up-to-date and exhaustive 3D images of street views. The Contractor is compiling a comprehensive site survey with special cameras linked to software, building a 3D view of all the streets and pathways within a given area.

This reliable inventory allows us instantly to identify location, type and state of poles or manholes along the roads. All buildings visible from the streets are also captured. This ‘virtual 3D’ database provides a new tool to check quickly any place in the area without having to send someone on site, 24/7.

In addition, the design of the cables and ducts can be embedded in the images and updated as many times as requested: A web-based application offers the possibility to see the forecasted itinerary and provides some useful data as the works progress, just by clicking on the green line that represents the network (dates of completion, type of duct or cable, etc.)

Camera installed on a vehicle

5.10.2. Manhole Poles and Site -Surveys

Instead of sending surveyors on site with only paper documents, The Contractor has developed a set of 'site survey tools' that allow him/her to:

- Provide the latest updated topographic map and network information on a ruggedized tablet to each surveyor
- Simplify and control the data collection (with the ability to take pictures and update the maps)
- Send a daily update to the central office for consistency control

Data is created on site, is time stamped and can be dispatched to further processes with confidence.

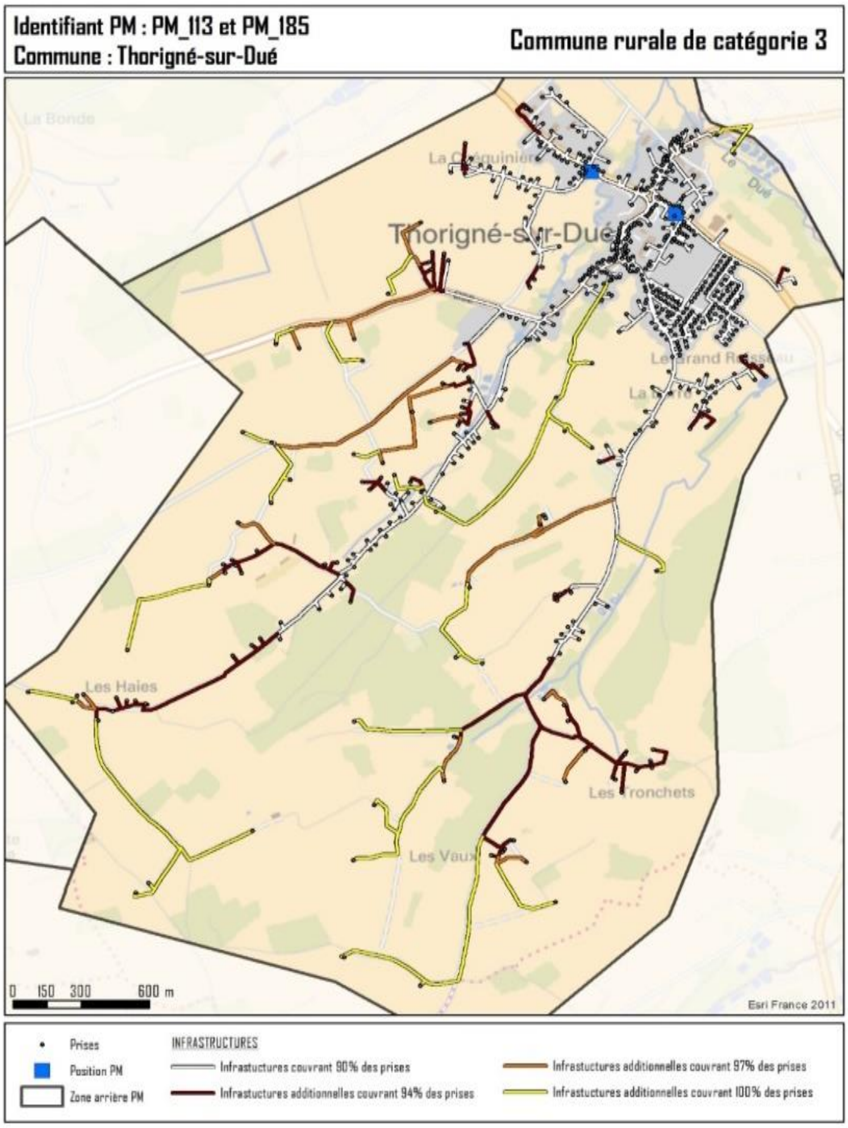
Site survey of manhole, with tablet

It is worth noting that ducts are tested together with manhole site surveys: a rope is pulled and tied, permitting a 100% successful cable installation as soon as the infrastructure owner has validated the reservation form. Thus, schedule and cost of deployment are maintained and always under control. Once the work is carried out, the database will be updated and a copy provided to the existing infrastructure owner.

5.10.3. Optimised Network Roll Out.

A successful access network design should allow the investor to identify some premises that may not be rolled out at initial stage. The reasons for this 'deferred deployment' are numerous: existing DSL broadband coverage, usage of the premises (semi-permanent, recreational) as well as 'cost of connection'.

The Contractor has developed a unique in-house tool that calculates the deployment cost of each and any DP, providing the local authority with one of the most difficult inputs to evaluate, for them to make their final decision ?? (Jim – I don't understand this sentence). The result is not only presented as a financial spreadsheet, but also as a comprehensive map that shows, in different colors, what could be the roll-out at various coverage thresholds (for instance 90, 95 and 98 % of coverage), cost driven:



Coverage map, with ‘cost driven’ thresholds.

5.11. Scope of Construction Works

The below design is a typical (The Contractor) design department output, after careful consideration of assets, distances, and existing geographical data, combined with site survey results which will generate a network design to be issued to the project office. The Project office team will then allocate work, subject to way-leaves and other rollout permissions. The Contractor engineers themselves, or 3rd party contactors managed by The Contractor will carry out this work.

The project office, alongside the design office, will have used all available assets - this design philosophy of “only building when you absolutely need to” has enabled the Oise project to have a minimal civil works program, consisting of less than 8% of the total works to date.

The main design ethos has focused on the use of Low and Medium Voltage power assets across the region. The Contractor, alongside ERDF (the Power distribution network operator), in the region have developed a set of procedures and protocols that allow The Contractor to work on “live” power networks.

The Contractor (The Contractor Energies and Services)

Deployment team are deploying fibre cable

The fitting of the fibre cable is deployed using an The Contractor bracket 1 Metre below the powered

As the cable is deployed from one pylon to another, on some pylons are able to be use, in this case when the electricity cables are routed down the pylon and therefore

In this case The Contractor have deployed a new pylon for the deploym

5.12. Street furniture and Civil Works

The street furniture deployed by The Contractor is typical of telecom deployments, in this case this has been situated in agreement with the local council and a new chamber has been deployed street level in Oise

This is a typical cabinet deployed across

This is a typical deployed chamber it links with an existing chamber further up the pavement. It is the break-out point for the Oise network. Each chamber is clearly marked

Shield to allow working on electrical pole , 'voltage on' (Internal Patent)

DP installed on Pole

Cable Coil for defered DP installation

Installation team in action

The pictures above show the actual deployment across the Oise region of France, each team leader is managing 10 separate two-man teams per day.

At each site survey the activities carried out are maximised. For example, a site survey as part of the design review will include a site engineer to photograph a 3rd party operator's chamber, identify the duct for selection as part of The Contractor deployed network, then the duct will be "rodded" and, if clear, a rope will be inserted into the chamber and clearly marked. The engineer will complete his report with photographs and will certify the chamber is clear and ready for deployment.

The design office will submit a request for use of the duct to the existing operator with detailed plans and photographs. On acceptance by the operator a detailed design and implementation documentation will be developed by the project office and handed on as part of the requirement to the installation team.

5.13. Delivery of Bandwidth and Specifications.

The Contractor is not in charge of the active part of the FTTH network. Only the link budget is controlled. Due to the architecture proposed in this rollout, the maximum optical length allowed from Central Office to Optical Telecom Outlet in each premises is 16,5 km.

Keeping in mind the overall architecture (including the maximum number of connectors and splices of the optical circuit), this distance guarantees that the link budget will remain below 29 dB if a GPON architecture with an 1:64 split ratio and class B+ SFP is used, or less than 10 dB in a ‘Point to Point’ situation. (ISP have the possibility to choose the technology they prefer). This means that the commercial offer to the end customer is 1Gb/s with this deployment.

The corresponding theoretical Optical Budget is calculated per Fibre link. This maximum attenuation is checked during the commissioning phase, for all the fibres that are measured.

The network, being a pure FTTP network, will be able to offer services above the DCENR requirements (100 Mbit/s download and 50 Mbit/s upload).

5.14. Construction approach and 3rd Party Contractors

The Contractor has adopted the strategy of in-house delivery supplemented by 3rd party companies. Localisation of resource is paramount whether in France or in Ireland. In the case of deployment of fibre on the electricity network, then The Contractor must run a number of in-house courses for its personnel and 3rd party contractors. The courses are run and managed by The Contractor and are certified by ERDF.

On average, during the deployment phase, 70% of the work force involved in an FTTH project managed by The Contractor is made up of local companies; the remaining 30% is made up of experienced resources? Contractors who share their expertise and provide ‘on the job training’ during their daily activities to the other teams.

H. FTTP/ FTTDP Roll Out Assumptions

3. PURPOSE

To obtain evidence that assists in making assumptions on the potential speed of rollout / deployment of Fibre to the Premises (FTTP) and G. Fast using Fibre to the (powered) Distribution Point (FTTDP).

This is presented as additional supporting information to the NIC Cost Analysis Study.
This current version (v1.0) will be updated with other information as it becomes available.

1. INTERNATIONAL REFERENCE INFORMATION

Objective: Gather online research of available studies from overseas and UK on how long other roll-outs have taken or are forecast to take and in what geotypes/ terrains.

Although G.fast is off to a slow start, deployment is very likely to ramp up in 2019. Operators are holding off on massive deployments throughout their networks until they have more hands-on time with amendment 3 chipsets and systems, which are scheduled to be available in early 2018.

1.1. Swisscom (SWITZERLAND)

In the course of the more than four-year project phase, Swisscom and its technology partner, Huawei, have worked together to develop a specific G.Fast for the Swiss market.
Swisscom had already successfully provided the first pilot customers worldwide with the final standard of G.Fast and thereby gathered key insights for its further development in spring 2015.
G.Fast has allowed Swisscom to reach transmission speeds of up to 500 Mbit/s. This is made possible through the use of a higher frequency spectrum on copper cables.
Swisscom has invested around CHF 1.8 billion in its IT and infrastructure throughout 2016. In total, Swisscom has connected more than 3.3. million homes and offices with ultra-fast broadband by the end of June 2016 – of which more than 2.2 million were with the latest fibre-optic technologies.
In the medium to long term, Swisscom intends to modernise the fixed broadband network in all Swiss municipalities. By doing so, 85% of all Swiss households and businesses will benefit from a bandwidth of at least 100 Mbit/s by the end of 2020. In terms of broadband coverage, Switzerland takes the top spot across Europe and worldwide, and is No. 1 in Europe for high bandwidth coverage.
This translates to 8,300 premises a week or an average 1,660 premise per day, based on the following assumptions:

a. Over and beyond the initial 3.3 million connected premises an additional 1.2 million will receive G.Fast.
b. A circa 36-month deployment period is implemented to the end of 2020.

1.2. Openreach (UK)

Openreach has confirmed that its trials of G.Fast broadband technology are to be expanded to 26 additional locations. Thousands of people living in parts of Manchester, Liverpool and Rochdale will be among the first in the country to benefit from a new ultrafast broadband network being built by Openreach.

The Superfast Cymru project will also give access to high speed broadband to the majority of homes and businesses in Wales. Openreach are installing not only its latest G.Fast technology but also its ultrafast broadband network (i.e. FTTP where line lengths exceed G.Fast specifications) to more than 12,500 households and businesses in Swansea.

As of August 2017, the current pilot locations are detailed below:

- Bolton, Greater Manchester
- Cherry Hinton, Cambridgeshire
- Cheltenham, Gloucestershire
- Derby, Derbyshire
- Donaldson, Edinburgh
- Gillingham, Kent
- Huntingdon, Cambridgeshire
- Langside, Glasgow
- Luton, Bedfordshire
- Newbury, Berkshire
- Newmarket, Suffolk
- Rusholme, Manchester
- St. Austell, Cornwall
- South Clapham, Balham and Upton Park, London
- Swansea, Wales
- Swindon, Wiltshire
- Sheffield

Openreach plans to make ultrafast broadband available to 12 million homes and businesses by 2020, and anticipates G.Fast will reach 10 million of these.

This translates to 83,300 premises a week or an average 16,660 premises per day, based on the following assumptions:

a. 10 million premises receive G.Fast and 2 million receive FTTP by 2020
b. The stated target relates to completion by mid-2020, giving a 36- month deployment period

Using the quantified model (average) data at tables 5 and 6 (on pages 32 and 33) this also implies over 2,500 daily FTTP installations to consumer premises deployed nationally across the 36-month period, assuming the core network infrastructure is in existence.

1.3. AT&T (USA)

AT&T has begun rolling out G. Fast-based services in 22 metro markets across the United States, signalling the service provider's desire to extend higher speed broadband services in premises where it can't make a business case for all fibre. Following a G. Fast trial in Minneapolis, AT&T has named eight initial cities that have properties equipped with the hybrid fibre/copper and coaxial technologies. A number of these cities, including Boston and New York City, are outside of AT&T's traditional 21 state Internet serving area.

1.4. Century Link (USA)

Century Link is continuing to move forward with its own G. Fast rollout. In September 2016, Century Link installed G. Fast in Platteville, Wisconsin, to deliver up to 500 Mbps broadband in 44 multi-dwelling-units (MDUs). It is also conducting similar deployments in Minnesota. However, the telecommunications provider sees the opportunity to use the technology to enhance the reach of its Ethernet service.

1.5. Deutsche Telecom (GERMANY)

Deutsche Telecom have begun lab testing the latest standard iteration of G. Fast technology over copper for multi-dwelling units (MDUs) in Germany. The testing uses a fibre-to-the-business (FTTB) model, using fibre to the MDU and then making use of G. Fast over existing wiring within the building itself. The G. Fast standard doubles the usable spectrum, allowing service providers to deliver gigabit speeds over a single copper pair.

2. QUANTIFIABLE DEPLOYMENT MODEL

Objective: To identify typical build durations based on quantifiable data from contractors and previous build projects, through a staged model using source data from previous analysis[3] updated with reference data from Tactis design and cost models. A fully worked excel model has been produced, from which the following calculation steps have been derived.

2.1. Step 1:

Gather information on typical metre dig distances per day of different techniques from quotes, projects, contacts and calls with contractors.

Terrain Type	Dig Technique	Typical Achievable Distance (metres) per day (1 gang)
Verge (A)	Mini Digger, Narrow Trench	200
Verge (B)	Mole Ploughing – Direct bury duct	1000
Footway	Mini Digger, Narrow Trench	50
Carriageway (A)	Std Digger, Traditional Trench	25
Carriageway (B)	Mini Digger, Narrow Trench	200
City Centre	Mini Digger, Diamond Core nb: reduced from Carriageway & footway to reflect tighter restrictions	15

Table 1 – Typical Dig Techniques and Achievable Distances

Specific data in section 2.1 table 1 was gathered from a number of industry specialists and experts who have been involved in next generation broadband projects over the last 10 years.

By way of examples, the bullet points below detail some of the projects where data was taken from:

- Gigaclear – (Oxford, Gloucester, Somerset & Devon)
- Truespeed – (Bath & Chew Valley)
- Virgin / Ericsson / Huawei
- South Yorkshire Digital Region

Note 1: Dig technique assumes construction activities such as set up, excavation, plant, reinstatement and inspection.

2.2. Step 2:

[3] Includes source data used for Analysys Mason 2008 report for BSG

Confirm typical premises distance for each of the 6 ONS Geotypes used in the analysis. Include core network distances.

Geotype #	Geotype Description	Network Length (kilometres)	DP to Premises Typical Distance (metres)
1	Mainly Rural	162.8	149.25
2	Largely Rural	133.5	33.5
3	Urban with Significant Rural	89.5	33.5
4	Urban with City and Town	60.1	23.5
5	Urban with Minor Conurbation	26.3	16
6	Urban with Major Conurbation	35.2	11.5

Table 2 – Typical Core Network & Distances from DP to Premises by Geotype

Note 1: Network Length represents the total length of dig required for a core network- between PoP/ OCN and its serving cabinets/ OSCs

Note 2: DP to Premises Typical Distance represents the typical distance per geotype for premises connections from the final distribution point.

2.3. Step 3:

Calculate the average dig time per serving area network/ DP as appropriate

Geotype #	Geotype Description	Network Length (kilometres)	Average Dig time per network area (months)	Average install time onto DP (days)
1	Mainly Rural	162.8	3	2
2	Largely Rural	133.5	3	2
3	Urban with Significant Rural	89.5	6	2
4	Urban with City and Town	60.1	8	2
5	Urban with Minor Conurbation	26.3	11	2
6	Urban with Major Conurbation	35.2	13	2

Table 3 – Average dig time from Core Network to DP serving area

Note 1: Table 3 calculations made considering the detail at table 1 with regards to geotype versus dig technique.
Note 2: Number of Gangs deployed (see below) based on best practice and historic engagement with local highways authorities

- 8 – 10 Gangs can operate within a reasonably large area, comprising
  - 4 - 6 x 3-man Gangs can operate opening pavements, roads, crossings, drives and mole ploughs.
  - 3 - 4 Cable teams pulling, jointing and splicing fibre networks following behind the construction gangs

2.4. Step 4:

Multiply by premises numbers/ network numbers to estimate G. Fast rollout times

Geotype #	(Mean) Number of Premises per Fibre Serving Area	(Mean) Number of Active Cabinets	(Mean) Number of serving DPs	Average install time onto DP (days)	Estimated rollout time (months)(scenario 2)
1	7057	20	1200	2	19
2	4998	14	840	2	15
3	3587	9	540	2	30
4	6834	19	1140	2	23
5	24940	62	3720	2	45
6	35000	70	4200	2	55

Table 4 – Roll-out time to extend network into / onto DP

Assumption 1: The number of construction teams deployed takes into consideration the geotype and density of local area
Assumption 2: Core Network Dig in Table 3 is not included within these numbers
Assumption 3: Ratio of serving DP's per Active Cabinet is 60:1 as detailed in Analysys Mason report to Ofcom dated 15th January 2010
Assumption 4: Includes the requirement to spur off the Core Network, install fibre and active consumer unit onto the associated DP
Assumption 5: Install time does not include enabling the consumer connection to the ISP

2.5. Step 5:

Change reference to provision of Fibre in existing ducts

Geotype #	Existing Duct	Estimated Achievable Fibre Installation Distances Daily (metres)
1	Y	2000
2	Y	2000
3	Y	1500
4	Y	1000
5	Y	1000
6	Y	500

Table 5 – Conventional Fibre Roll-out Achievable Distances

Assumption 1: only 60% of 'Exchange side' ducts are usable, through congestion or collapse (working assessment based on early feedback from PIA/ DPA2 trials with Openreach)
Assumption 2: remaining 40% require new duct, using the same calculation basis as above
Assumption 3: Distances achieved above are for one fibre team in one area who also carry out spicing within the manhole joints
Assumption 4: Maximum section distances of conventional fibre pulling are 500 metres

2.6. Step 6:

Additional deployment time for DP to Premises connections based on FTTP

Geotype #	Existing Duct	Deployment Time to Premises	New Duct	Deployment Time to Premises
1	Y	4 hours	Y	1 day
2	Y	4 hours	Y	1 day
3	Y	4 hours	Y	1 day
4	Y	4 hours	Y	1 day
5	Y	4 hours	Y	1 day
6	Y	4 hours	Y	1 day

Table 6 – Premises Deployment Estimates

Assumption 1: c.80% of premises have 'usable duct or pole' from the DP (working assessment based on early feedback from PIA/ DPA2 trials with Openreach); the rest require re-instatement or are served by direct cable outside of duct

Assumption 2: remaining 20% of premises require an average construction time of 4 hours and additional integration time to test the fibre back to the serving node.

3. CONCLUSIONS

Using the modelled data above, the following typical roll out times could be achieved based on the following assumptions:

- Provision of infrastructure to pass 31 million UK premises
- Resources allocated for deployment would be in the region of 900 construction and fibre installation teams across the UK

3.1. Indicative Typical Roll out duration for FTTP using all-new infrastructure (scenario 1)

	(Months)
Programme Development and Pilot Period	12
Deployment effort for serving areas in G1	16
Deployment effort for serving areas in G2	12
Deployment effort for serving areas in G3	26
Deployment effort for serving areas in G4	19
Deployment effort for serving areas in G5	42
Deployment effort for serving areas in G6	53
ANTICIPATED DEPLOYMENT TIME G1 – G6	**180** 15 years

Note 1: Network and spur off network activities to be run in parallel; the critical path being the spur off the network to the DP activity.

3.2. Indicative Typical Roll out duration for FTTP using existing infrastructure (scenario 2)

	(Months)
Programme Development and Pilot Period	9
Deployment effort for serving areas in G1	16
Deployment effort for serving areas in G2	13
Deployment effort for serving areas in G3	11
Deployment effort for serving areas in G4	14
Deployment effort for serving areas in G5	32
Deployment effort for serving areas in G6	46
ANTICIPATED DEPLOYMENT TIME G1 – G6	**141** 12 years

Note 2: Assumes the implementation of a similar cable gang model as deployed in 4.

3.3. Indicative Typical Roll Out duration for G.fast on FttDP (scenario 5)

	(Months)
Programme Development and Pilot Period	9
Deployment effort for serving areas in G1	11
Deployment effort for serving areas in G2	7
Deployment effort for serving areas in G3	4
Deployment effort for serving areas in G4	9
Deployment effort for serving areas in G5	23
Deployment effort for serving areas in G6	26
ANTICIPATED DEPLOYMENT TIME G1 – G6	89
	7.5 years

I. Comparison of Cost Differences with the BSG 2008 Report

1. PURPOSE

The purpose of this Appendix is to provide a brief explanation of the cost differences of a 100% FTTP deployment as detailed in the 2008 BSG Report and the costs detailed within the NIC report 2017.

The overall cost submission within the BSG report is more than 9 years old. Since that time design, equipment, deployment methodologies and broadband demand have changed. We are not privy to the full breakdown of costs from the BSG report and therefore offer this high-level view of the changes within the industry over the intervening period.

2. Direct comparison of headline findings

- FTTP 100% deployment and no reuse:
  - BSG report nominates a headline Cost of deployment at £28.8 billion
  - The NIC report nominates a headline Cost of £28.1 billion
  - Variance- £700 million (2.5% reduction)

- Total premises count:
  - BSG is based upon 27,256,460 domestic and business premises
  - NIC is based upon 31,120,319 domestic and business premises
  - Variance- 3.86 million (14.2% increase)

- Cost per premise passed
  - BSG averages £1,057
  - NIC averages £903
  - Variance- £154 per premise (average) (15% reduction)

3. Principle changes contributing to the variance

1. Increase in Demand. It should be noted that the largest change is the demand for broadband services and the increase in bandwidth requirements. Based on this demand, investment within the sector has been significant, with alternate design and build techniques being developed and an increase in operators applying different commercial models to the traditional 'vertically integrated' operator approach.

   The NIC analysis has drawn capex costs that are currently being billed/paid today on live projects in the UK and/ in Europe. We have direct experience of FTTH Design, Build and Operation of Wholesale Access networks. These costs have come from a variety of sources including existing FTTP operators, civil contractors and telecom consultancy houses, all of which have been used to validate the unit costs applied. We have then benchmarked these costings against existing and current deployment costs within the UK market.

2. Greater market experience of FTTP deployment. In 2008 very little FTTP had been delivered by any UK operator except for Fibre to the Cabinet FTTC (BT) with some FTTP/O, Fibre to the Premise/Office delivered by BT and alternative operators and finally Cable TV (DocSiS) Virgin Media.

3. Improvements in construction techniques. In 2008 the majority of fibre deployment was carried out with standard digging techniques with a trench width of circa 450mm wide with standard over - re-instatement required by local authorities. Desk top studies were used, but the planning tools were limited, therefore a higher % of labour was focused on survey and remedial "on-site" design and planning during construction.

   There are significant benefits from using improved techniques that, whilst available in 2008, were not yet developed and refined sufficiently for wide-scale adoption. For example, a standard 450mm width trench delivered using a digger and associated road closures etc carries a cost of circa £70 p/metre and typically achieves between 50-100 metres per day; a narrow trenching machine delivering a trench 100mm wide carries costs of £30 p/metre and consistently delivers 200- 250 metres per day per team.

4. Better and more accurate design techniques. When comparing the overall design costs of FTTP in 2008 compared with the advancement of desktop tools, GIS software, Google Maps, Street view etc the reduction in the time taken to deliver both a High-Level Design HLD and Low-Level Design LLD capable of build is substantially less in both the cost of manpower, design and survey works. The latest technology allows for a street survey to confirm a detailed Low - Level Design. The civils deployment of that design is likely to have a 99% success rate as the survey and desktop design is of a much higher quality than 10 years ago.

5. Greater premises densification. The increase in premises between 2008 and 2017 totalling 3.8 Million is likely to be predominantly based in urban areas which decreases the average metres per home passed, therefore driving efficiencies into the overall headline numbers between the two reports.

6. Changes in workforce skills. Finally, the skill-levels of the workforce required to deploy a FTTP network based upon civil construction and fibre splicing/ connection methods has reduced considerably with the advancement of materials, fibre, slack holders and network splicing technology. The skilled resource levels only increase when you start to deliver FTTP over existing assets like power lines, however the trade-off is the increased output of metres per day per team.

7. Opex reductions. In addition to the variations affecting capex described above, there are also changes that affect opex. Most relevant are
   a. Greater understanding (and hence reduction) of fibre support and maintenance costs
   b. Improvements in equipment reliability and replacement costs, due to the general trend in the prevailing technologies.

4. Concluding comment regarding asset sharing

This review has not attempted to justify the comparison between the BSG report and the NIC report when comparing cost savings with the use of asset sharing. Today, across Europe, specifically in France and Ireland the deployment of FTTP using aerial and underground ducted networks is substantial. As mentioned in our report, parts of rural France have less than a 10% new civils build content in large scale FTTH deployments. However, if you look at Virgin Media's 'Project Lightning" build it has no sharing of any existing assets and this is probably going to repeat itself with the recently announced City Fibre deployment for an initial 1 Million homes.

Appendix F: Operator Survey Results and Analysis

National Infrastructure Commission Operator Survey:

Anonymised and Compiled Results

Date Created:	Wednesday, May 31, 2017
Date of Result Analysis:	Friday,September 15, 2017

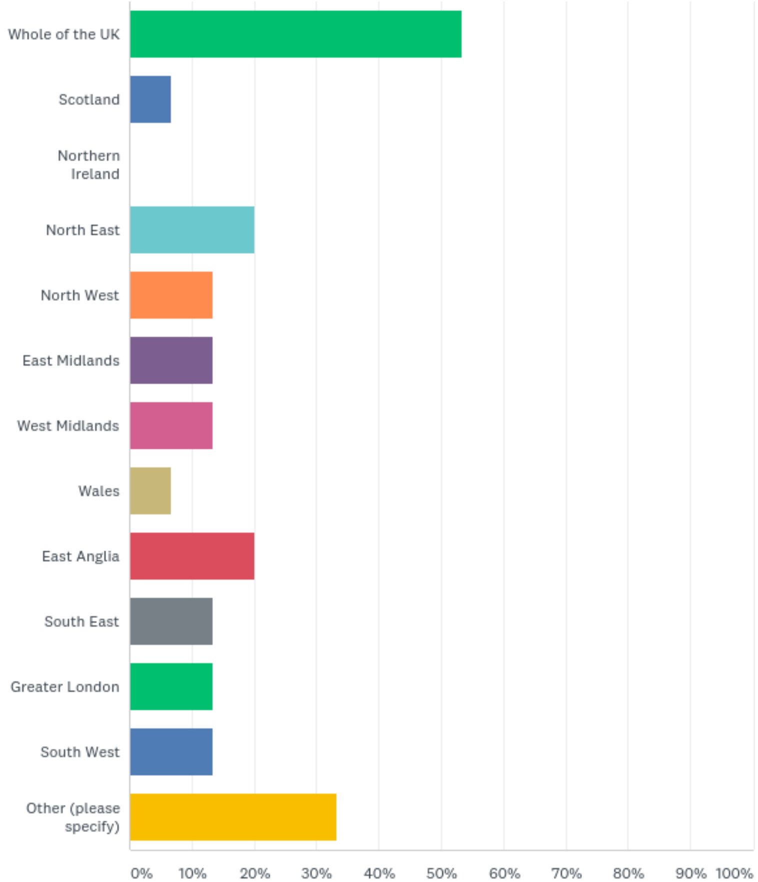
15 Total Responses (44% of all invitations)

NOTE: Results are only shown for Questions with a valid response against them. The Questions retain their original number form the Survey for reference.

Part A: Background information on Respondents and nature of network involvement

Q2: Which areas of the UK do your services cover?

Answered: 15   Skipped: 0

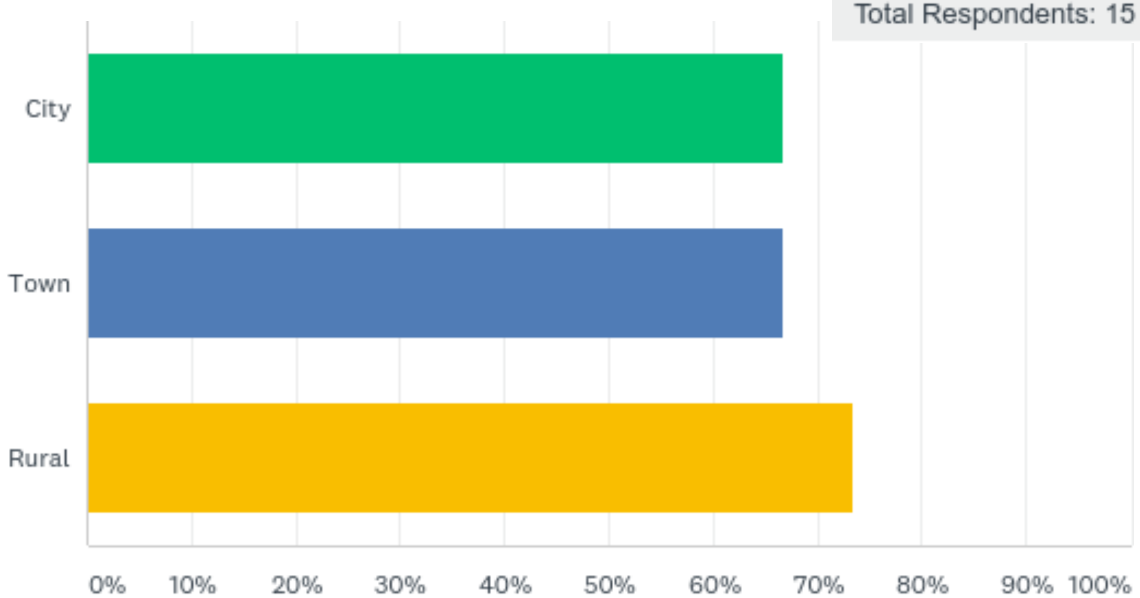


ANSWER CHOICES	RESPONSES	
Whole of the UK	53.33%	8
Scotland	6.67%	1
Northern Ireland	0.00%	0
North East	20.00%	3
North West	13.33%	2
East Midlands	13.33%	2
West Midlands	13.33%	2
Wales	6.67%	1
East Anglia	20.00%	3
South East	13.33%	2
Greater London	13.33%	2
South West	13.33%	2
Other (please specify)	33.33%	5
Total Respondents: 15		

Q3: Please indicate which areas you mainly deploy networks in. (Tick all that apply)

Answered: 15   Skipped: 0

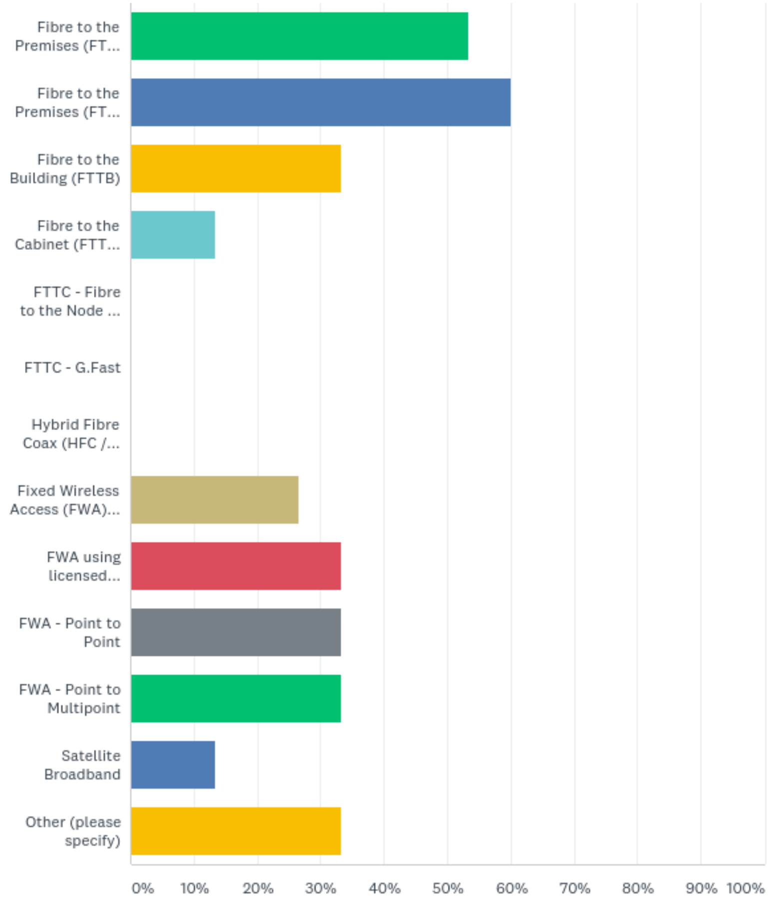
ANSWER CHOICES	RESPONSES	
City	66.67%	10
Town	66.67%	10
Rural	73.33%	11
Total Respondents: 15		



Q4: What type of networks do you build? (Tick all that apply)

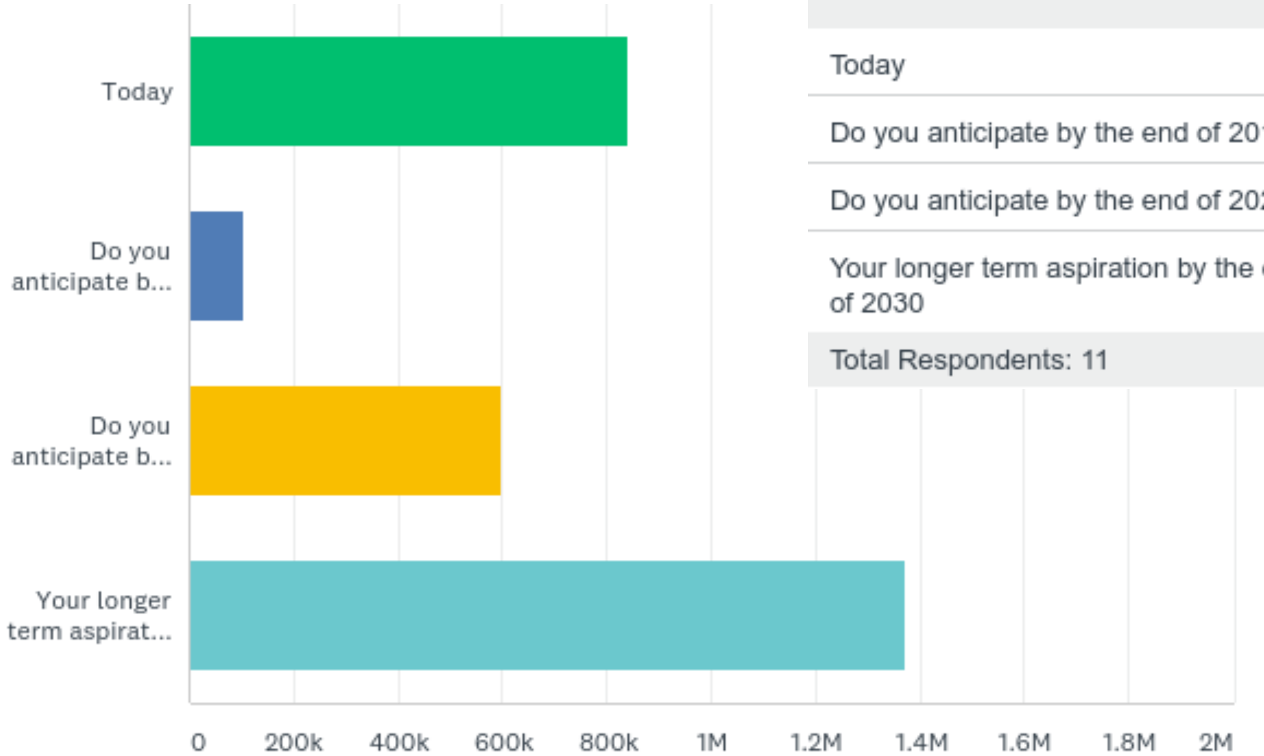
Answered: 15 Skipped: 0

ANSWER CHOICES	RESPONSES	
Fibre to the Premises (FTTP, FTTH) Point to Point	53.33%	8
Fibre to the Premises (FTTP, FTTH) GPON	60.00%	9
Fibre to the Building (FTTB)	33.33%	5
Fibre to the Cabinet (FTTC) - LLU	13.33%	2
FTTC - Fibre to the Node / SLU	0.00%	0
FTTC - G.Fast	0.00%	0
Hybrid Fibre Coax (HFC / DOCSIS 3.x)	0.00%	0
Fixed Wireless Access (FWA) using unlicensed or lightly licenced spectrum	26.67%	4
FWA using licensed spectrum	33.33%	5
FWA - Point to Point	33.33%	5
FWA - Point to Multipoint	33.33%	5
Satellite Broadband	13.33%	2
Other (please specify)	33.33%	5
Total Respondents: 15		



Q5: Approximately how many premises do your networks pass?

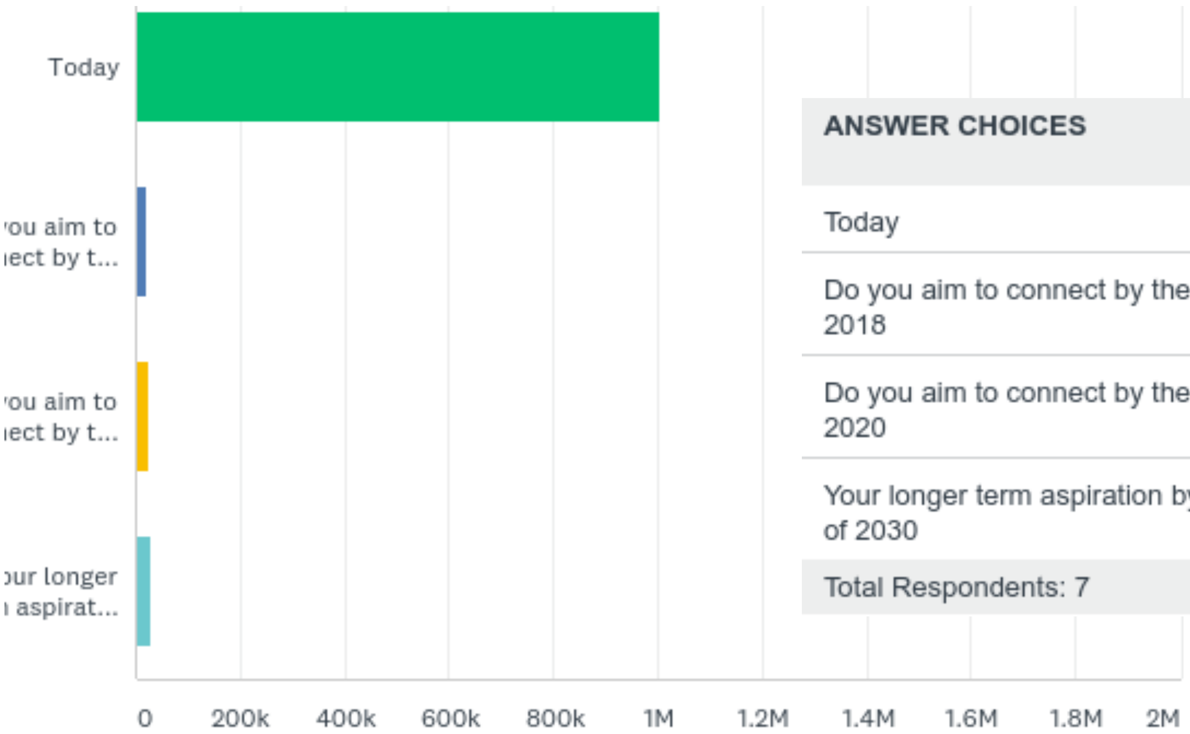
Answered: 11   Skipped: 4



ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
Today	840,873	9,249,600	11
Do you anticipate by the end of 2018	106,111	955,000	9
Do you anticipate by the end of 2020	598,800	5,988,000	10
Your longer term aspiration by the end of 2030	1,372,143	9,605,000	7
Total Respondents: 11			

Q6: Approximately how many end-users are connected to your networks?

Answered: 7 Skipped: 8

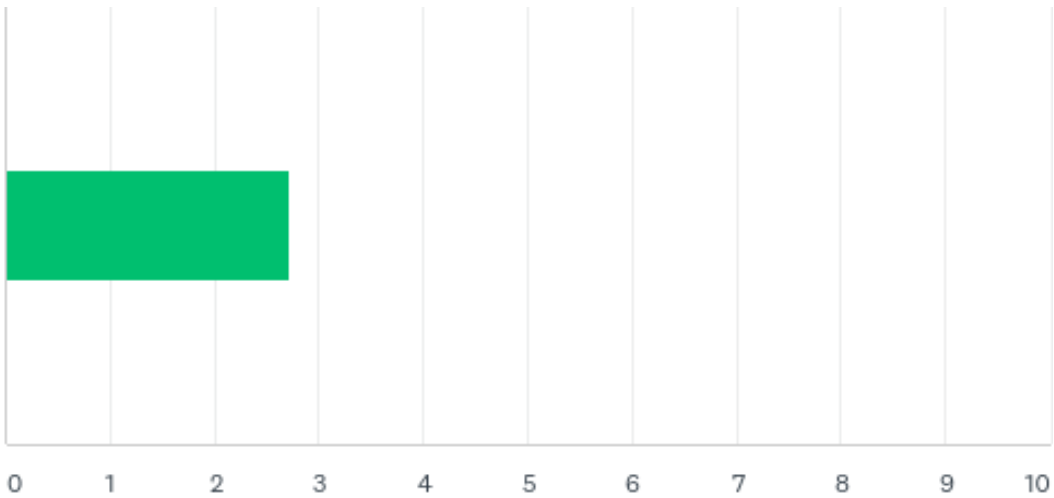


ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
Today	1,005,447	6,032,680	6
Do you aim to connect by the end of 2018	20,617	123,700	6
Do you aim to connect by the end of 2020	24,167	145,000	6
Your longer term aspiration by the end of 2030	30,000	120,000	4
Total Respondents: 7			

Q7: Which market segment(s) do you primarily serve?

Answered: 15   Skipped: 0

	RESIDENTIAL	BUSINESS	BOTH RESIDENTIAL AND BUSINESS	TOTAL	WEIGHTED AVERAGE
(no label)	6.67% 1	13.33% 2	80.00% 12	15	2.73

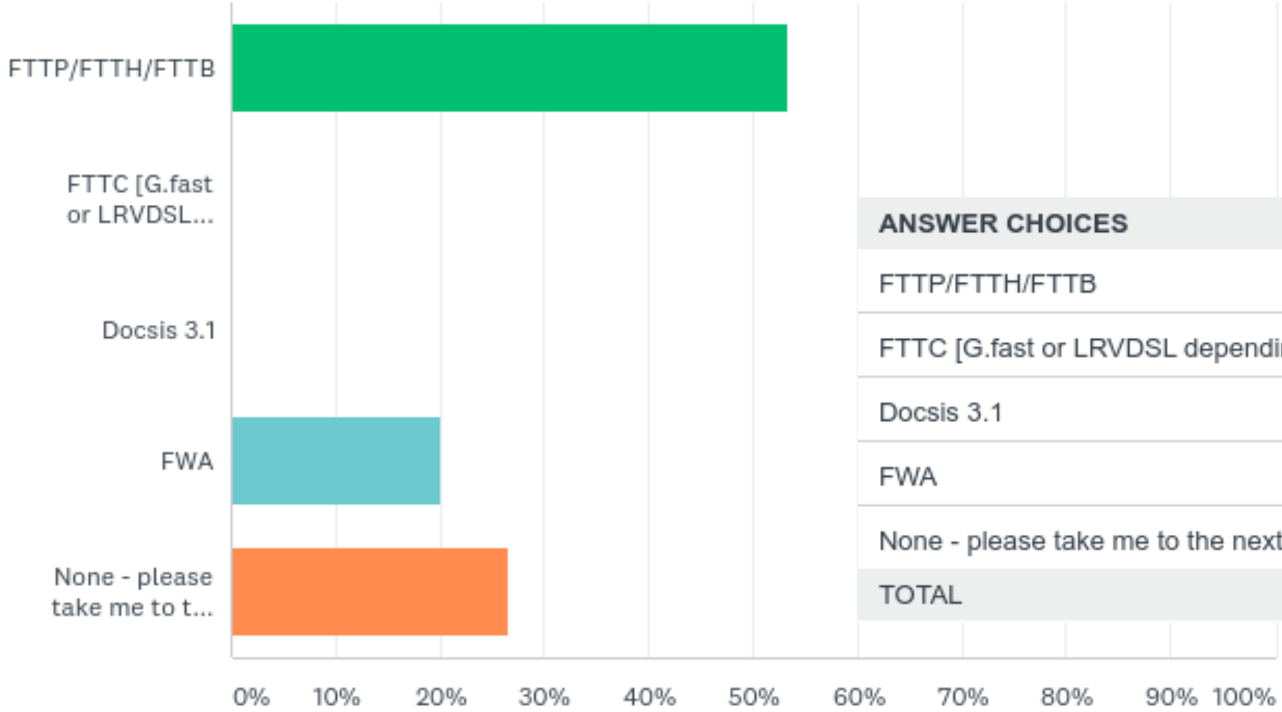


Part B: Scenario Reviews-

1. City

Q8: Which technology option do you wish to give feedback on for this scenario?

Answered: 15   Skipped: 0



ANSWER CHOICES	RESPONSES	
FTTP/FTTH/FTTB	53.33%	8
FTTC [G.fast or LRVDSL depending on geotype]	0.00%	0
Docsis 3.1	0.00%	0
FWA	20.00%	3
None - please take me to the next scenario	26.67%	4
TOTAL		15

Q9: FTTP Capex costs (a)

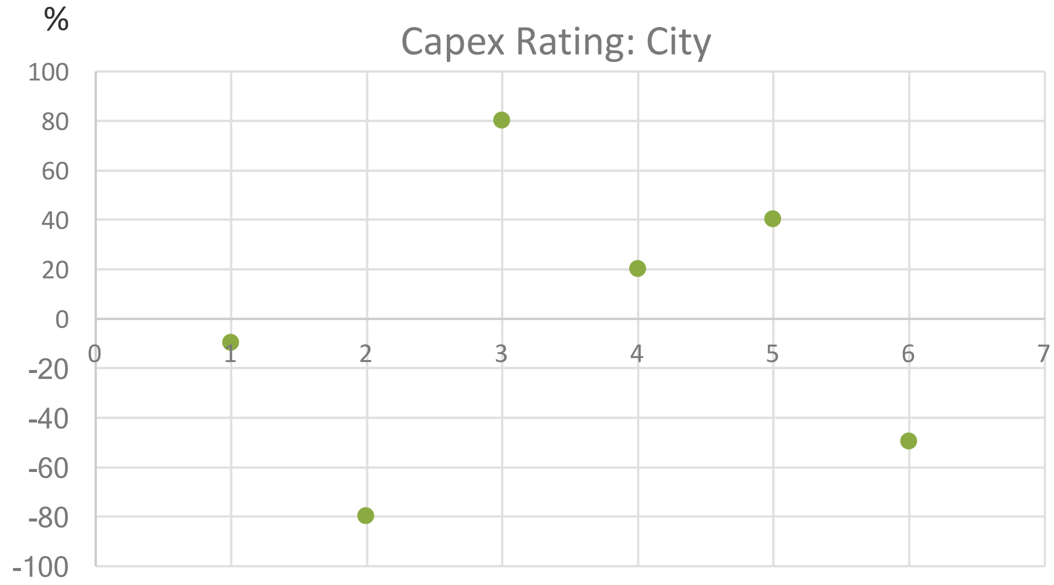
Question

The Capex costs estimated in Scenario 1 include costs in the access network alone, apportioned across civil engineering, passive and active components, but excluding backhaul and CPE. This is frequently referred to as "Cost of Homes Passed."

Thinking about your own experience with Capex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Answered: 6 Skipped: 9

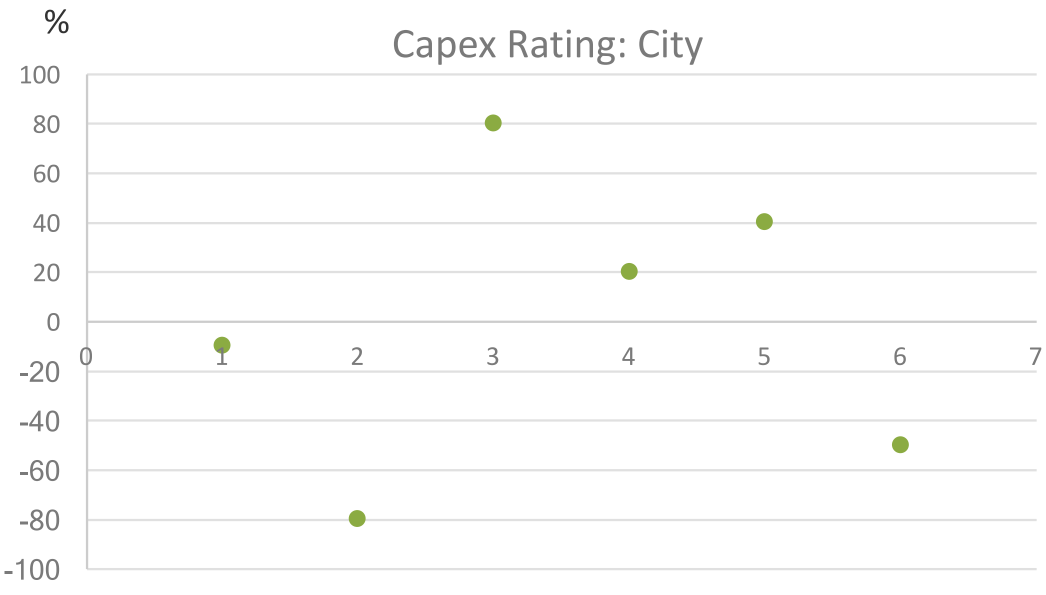
ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	0	0	6
Total Respondents: 6			



Q10: FTTP Capex costs- comments

Answered: 6   Skipped: 9

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	0	0	6
Total Respondents: 6			



Comments:

1. It's not clear Barking will be as low cost but our experience in Westminster dealing with listed buildings indicates much higher costs. This should not be a surprise of course. There will also be some modest economy of scale.

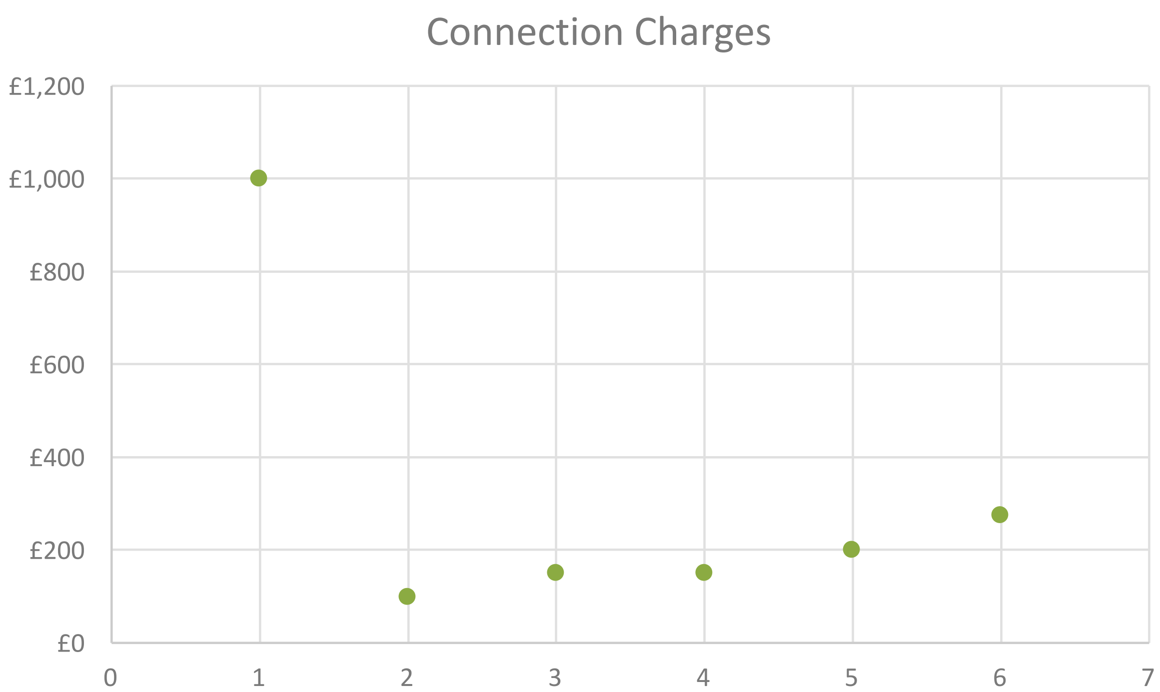
2. You need to model BT overlaying its network v Building a new one. For new build you provide a reasonable build cost. For overlay it is much too high - for instance you reduce the per metre cost from c£83pm to less than £13pm for clearing duct and pulling new cable. Overlaying cable on existing poles is £2 a metre - see notes supporting BT FoD costs.

3. The quoted costs could be achieved if micro-trenching is an acceptable deployment technology but our experience suggests that the degree of acceptance of micro-trenching techniques by local authorities around the UK varies widely.

4. The average Capex per metre is very low in our experience. It is typically £150 per meter. Connection per premises is typically £10,000 per premises. This assumes network is 25 metres away. This may be because my company only constructs point-to-point fibre connections for business users.

Q11: FTTP Connection Charges

Answered: 6   Skipped: 9



Q12&13: FTTP Opex costs

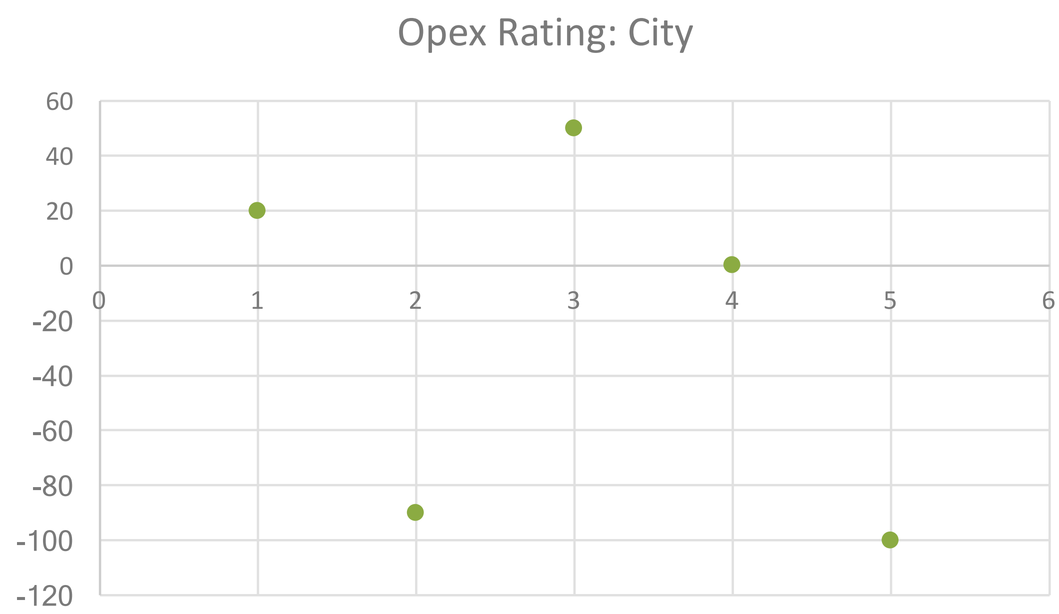
Question

The Opex costs estimated in Scenario 1 include the costs of running the network, e.g. support, monitoring and maintenance.

Thinking about your own experience with Opex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Answered: 5 Skipped: 10

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	-24	-120	5
Total Respondents: 5			



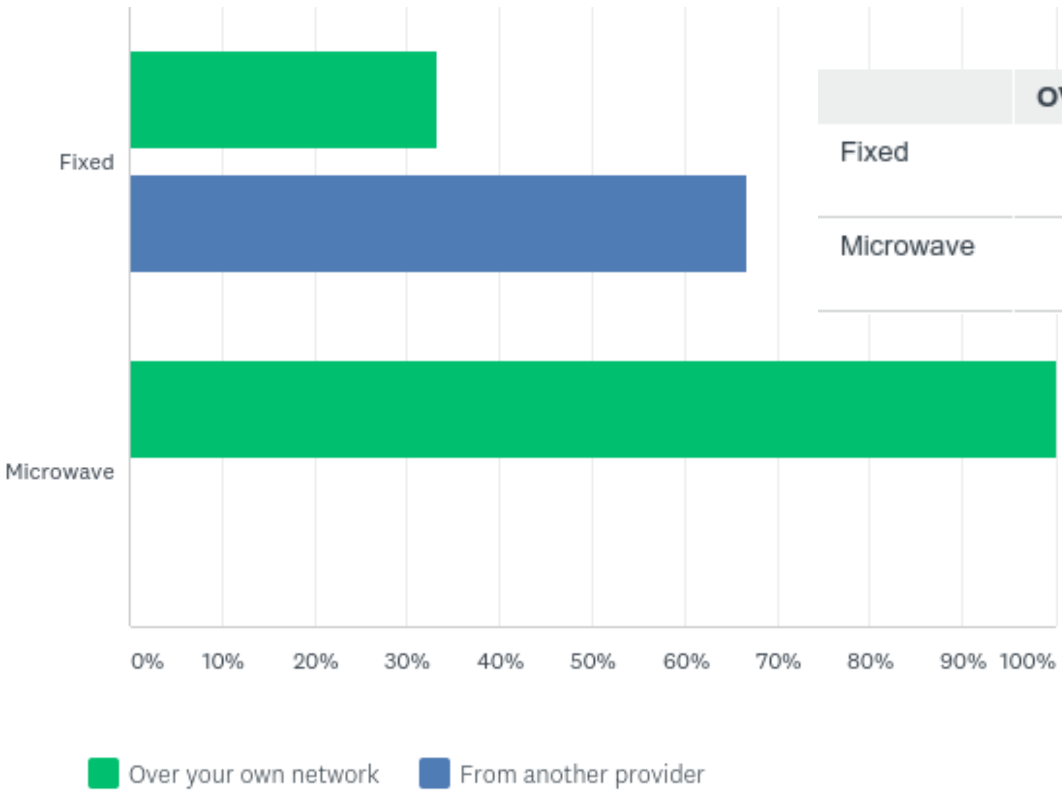
Comments:

1. There is no clear definition of what is included. If all opex back to the NNI is included then this is a significant underestimate.
2. I refer you to Audit Scotland who reference BT operational costs pa at £10 a customer.
3. Opex costs with business-grade SLA are much higher. Typically 10% of initial capital outlay, per annum.

Q14: FTTP Backhaul

Answered: 6 Skipped: 9

Question
Thinking about backhaul costs, in this scenario how would you typically obtain the backhaul for the local network.

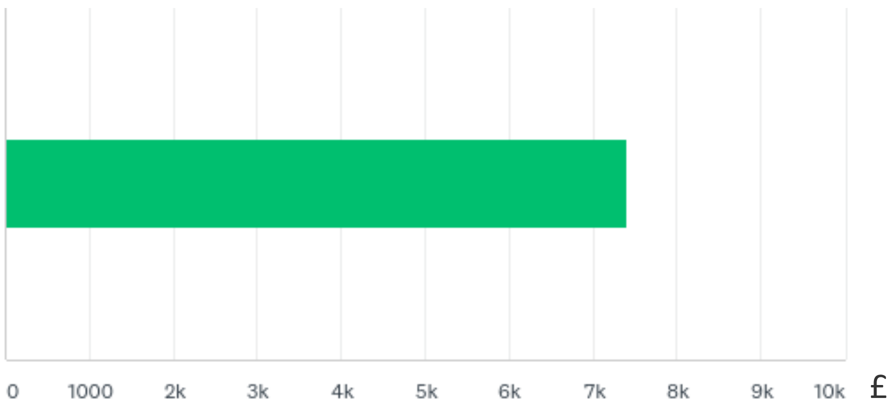


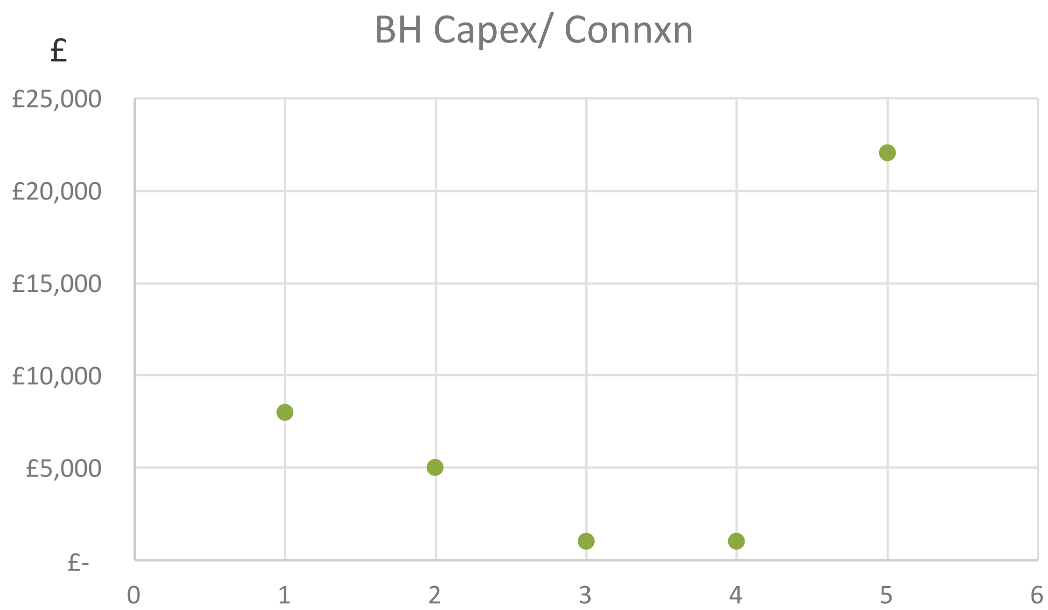
	OVER YOUR OWN NETWORK	FROM ANOTHER PROVIDER	TOTAL
Fixed	33.33% 2	66.67% 4	6
Microwave	100.00% 1	0.00% 0	1

Q15: FTTP Backhaul costs - Capex/Connection charges per GB/s

Answered: 5   Skipped: 10

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	7,400	37,000	5
Total Respondents: 5			

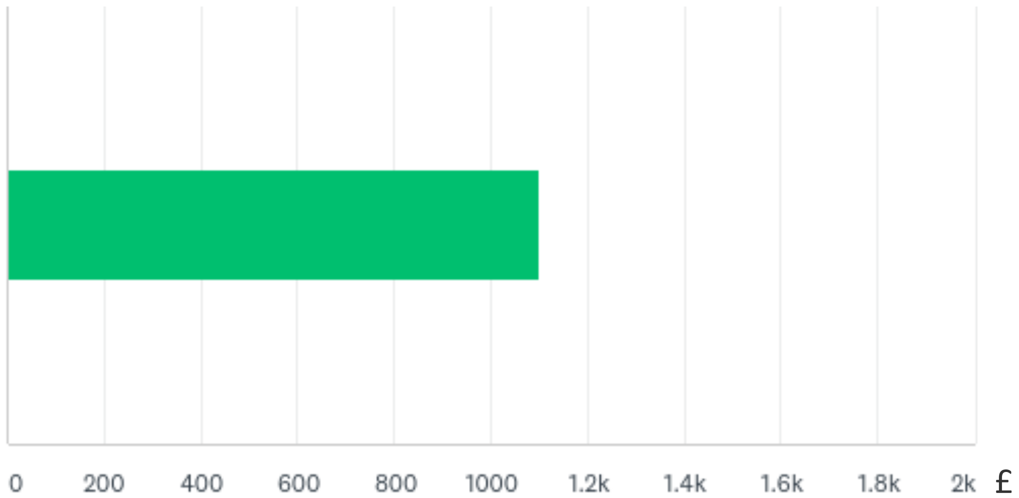


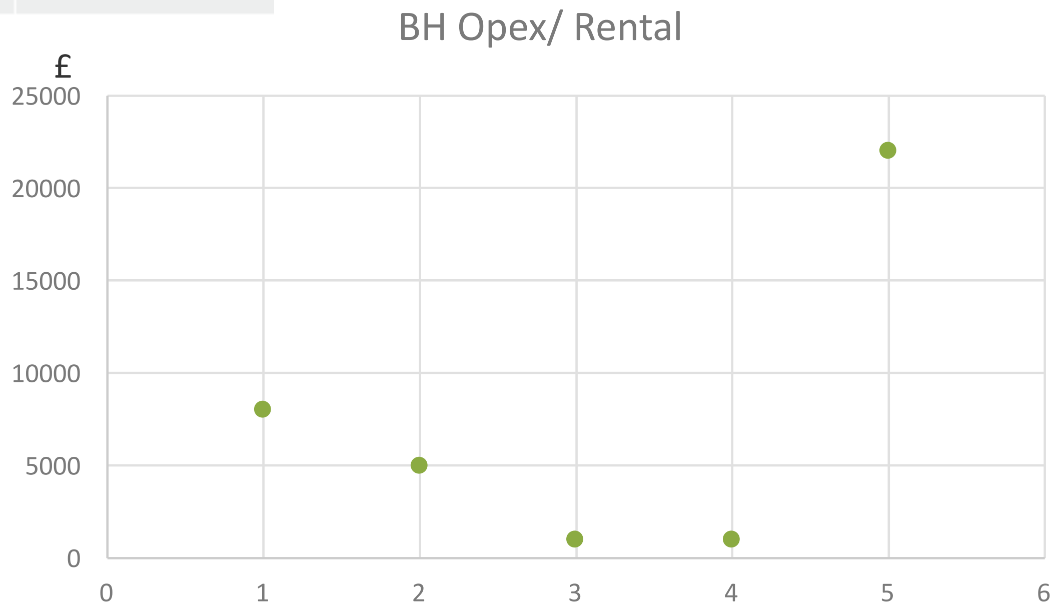


Q16: FTTP Backhaul costs - Opex/Rental charges

Answered: 5   Skipped: 10

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	1,100	5,500	5
Total Respondents: 5			





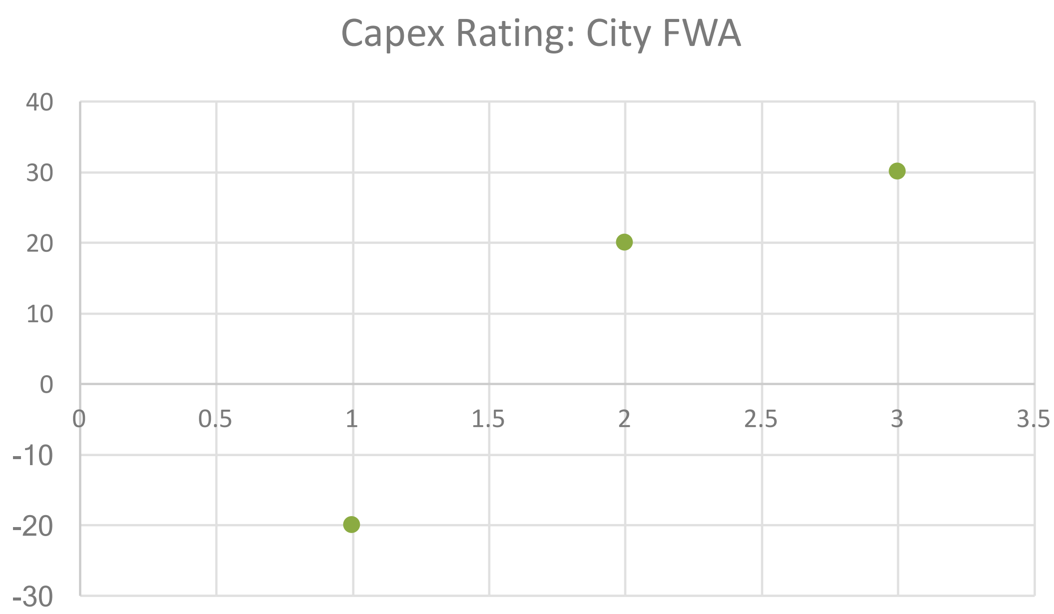
Q33: FWA Capex costs

Question
The Capex costs estimated in Scenario 1 include costs in the access network alone, apportioned across civil engineering, passive and active components, but excluding backhaul and CPE. This is frequently referred to as "Cost of Homes Passed."

Thinking about your own experience with Capex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Answered: 3   Skipped: 12

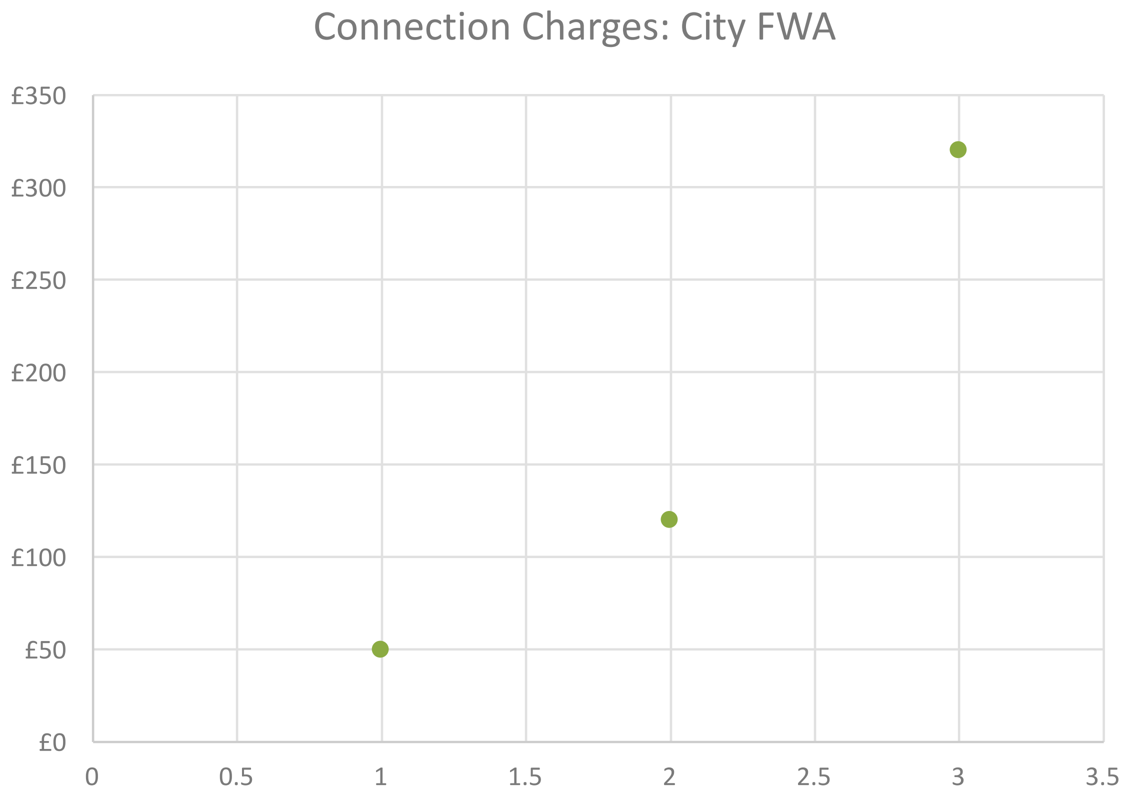
ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	10	30	3
Total Respondents: 3			



Comments:
1. Costs are around £60k capex per base station, £75k for hub sites including civils and equipment, I&C
2. Cambium access equipment provides relatively poor price performance compared with the best Multi User MIMO equipment in the market today.

Q11: FWA Connection Charges

Answered: 3 Skipped: 12



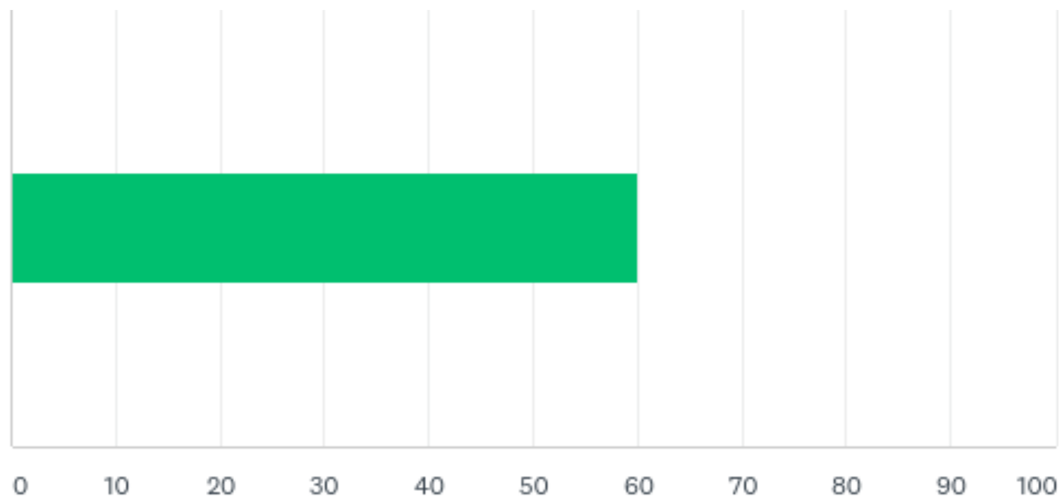
Q36: FWA Opex costs

Answered: 2   Skipped: 13

Question
The Opex costs estimated in Scenario 1 include the costs of running the network, e.g. support, monitoring and maintenance.

Thinking about your own experience with Opex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	60	120	2
Total Respondents: 2			



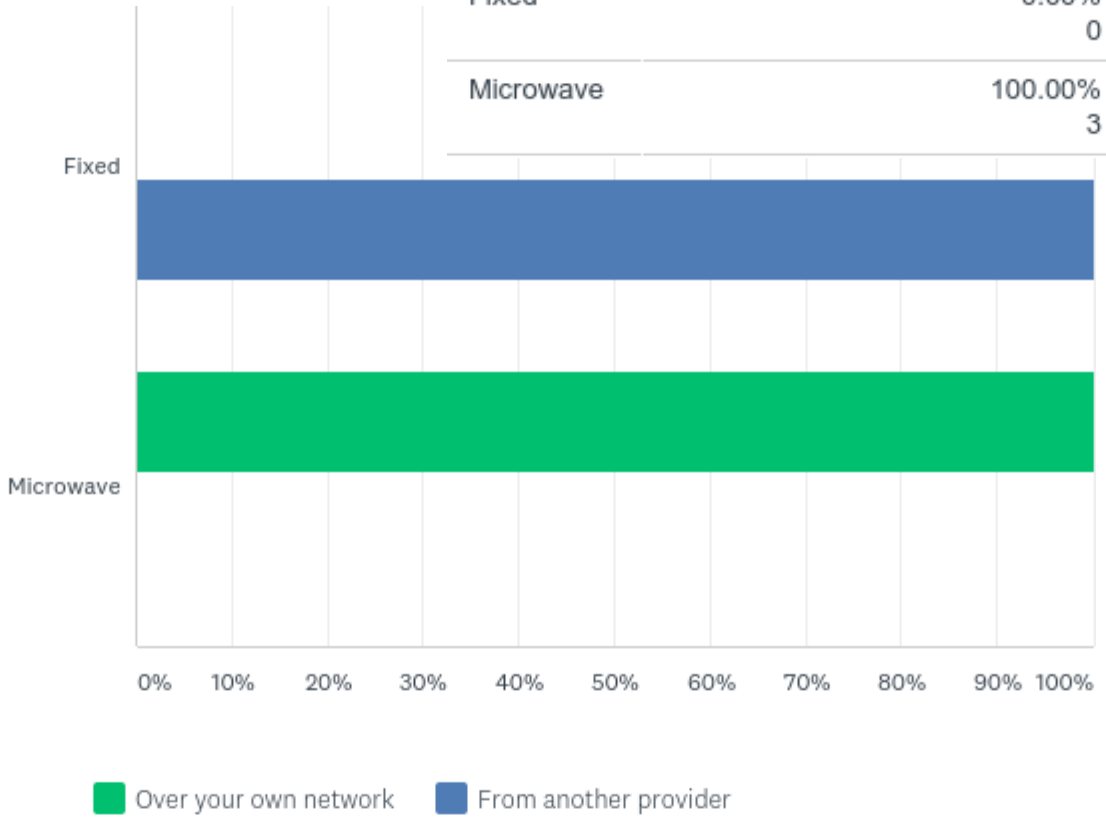
2 Responses: 20% over-estimate and 100% over estimate

Comments:
1. We expect around £20k pa for rent, rates, support, utilities etc

Q38: FWA backhaul

Answered: 3   Skipped: 12

	OVER YOUR OWN NETWORK	FROM ANOTHER PROVIDER	TOTAL
Fixed	0.00% 0	100.00% 3	3
Microwave	100.00% 3	0.00% 0	3

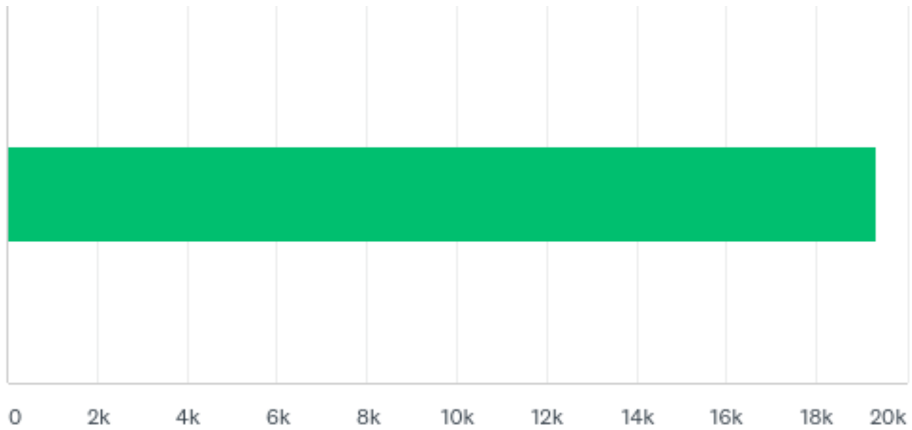


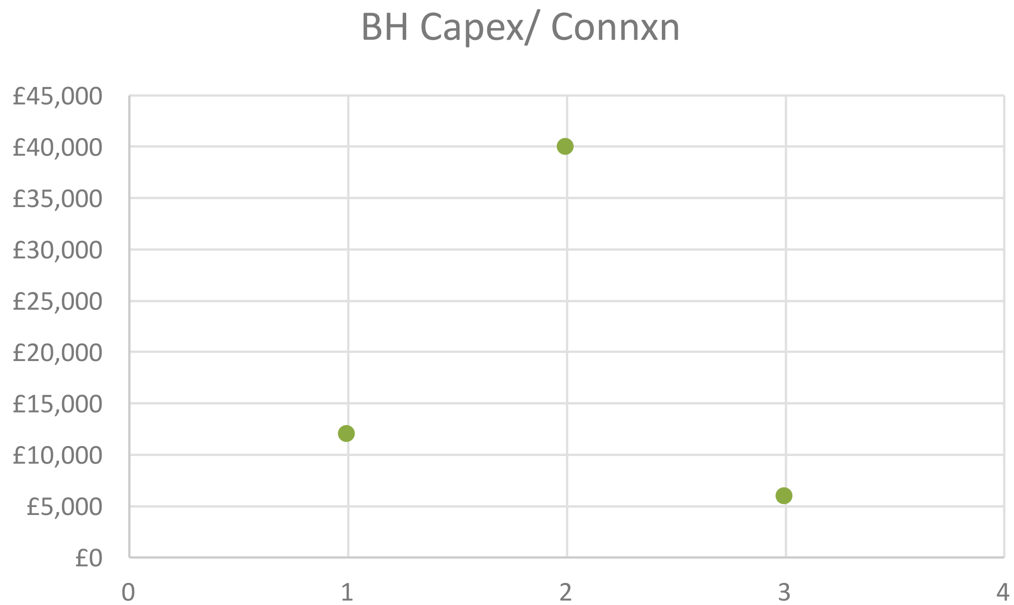
Thinking about backhaul costs, in this scenario how would you typically obtain the backhaul for the local network.

Q39: FWA Backhaul costs - Capex/Connection charges

Answered: 3 Skipped: 12

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	19,333	58,000	3
Total Respondents: 3			

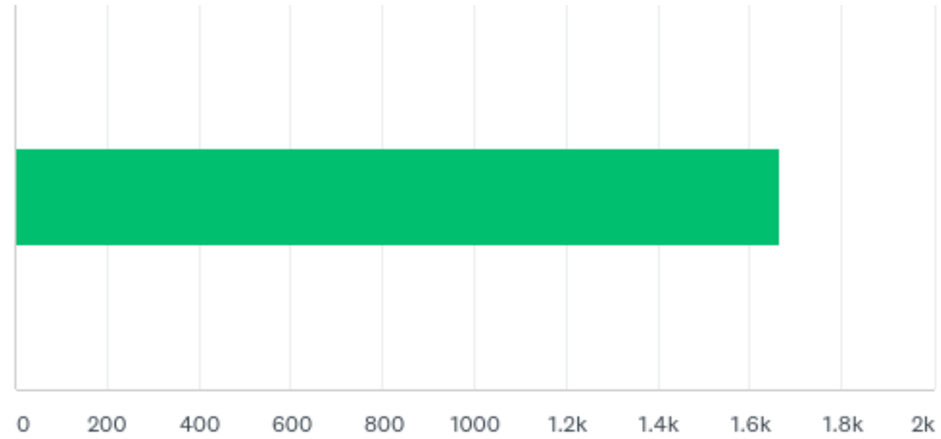


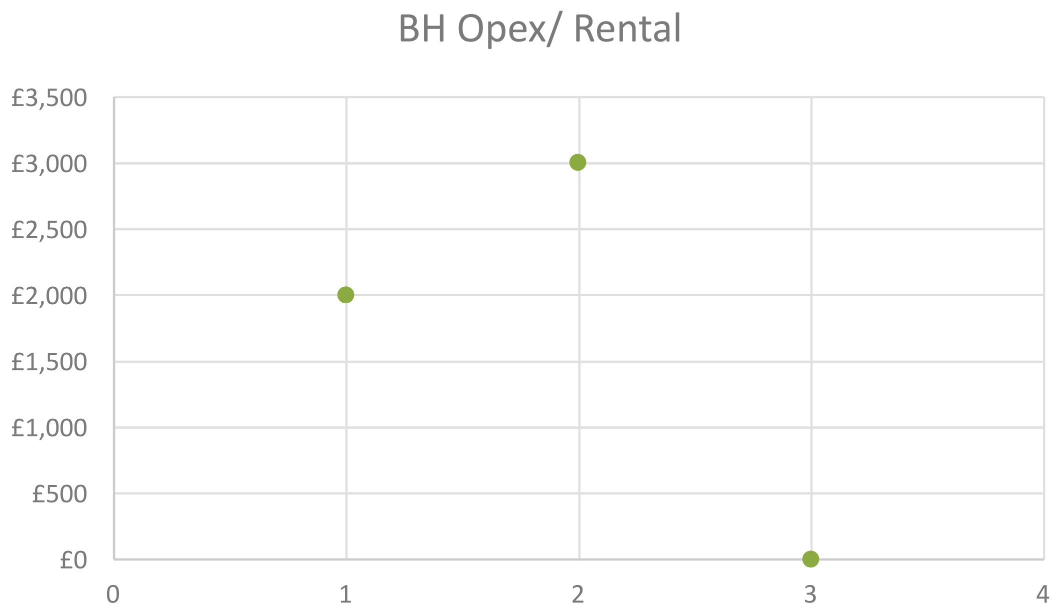


Q40: FWA Backhaul costs - Opex/Rental charges

Answered: 3 Skipped: 12

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	1,667	5,000	3
Total Respondents: 3			





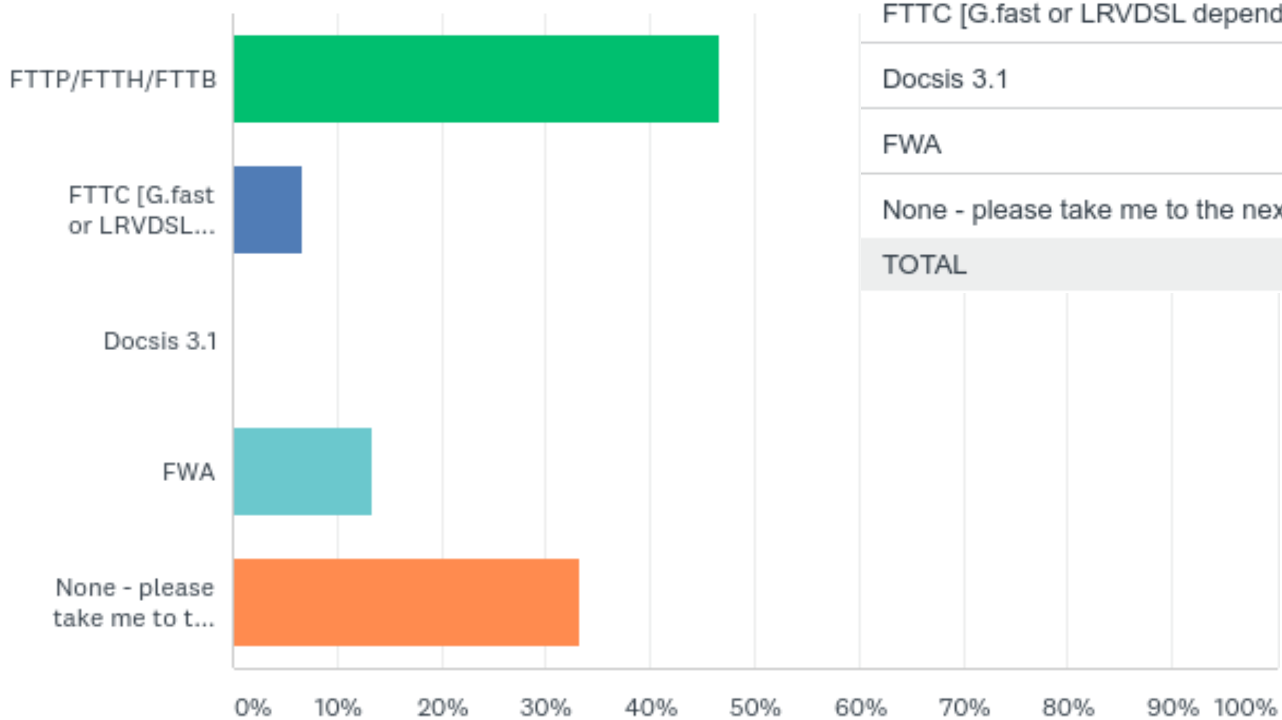
Part B: Scenario Reviews-

2. Town

Q41: Which technology option do you wish to give feedback on for this scenario?

Answered: 15   Skipped: 0

ANSWER CHOICES	RESPONSES	
FTTP/FTTH/FTTB	46.67%	7
FTTC [G.fast or LRVDSL depending on geotype]	6.67%	1
Docsis 3.1	0.00%	0
FWA	13.33%	2
None - please take me to the next scenario	33.33%	5
TOTAL		15



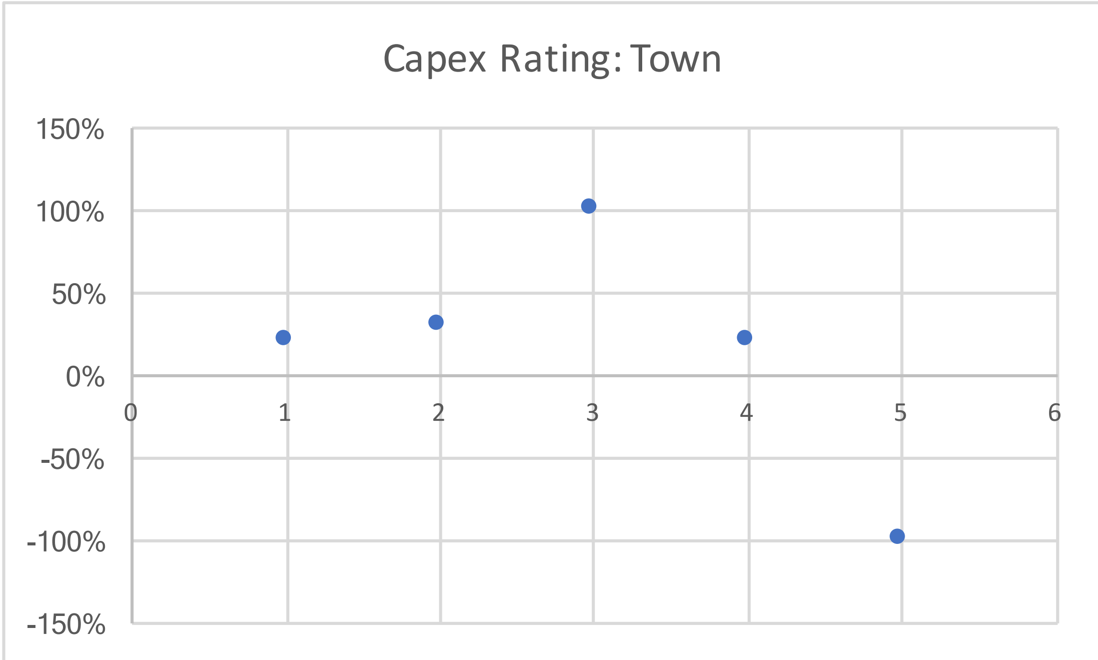
Q42: FTTP Capex costs

Question
The Capex costs estimated in Scenario 2 include costs in the access network alone, apportioned across civil engineering, passive and active components, but excluding backhaul and CPE. This is frequently referred to as "Cost of Homes Passed."

Thinking about your own experience with Capex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Answered: 5 Skipped: 10

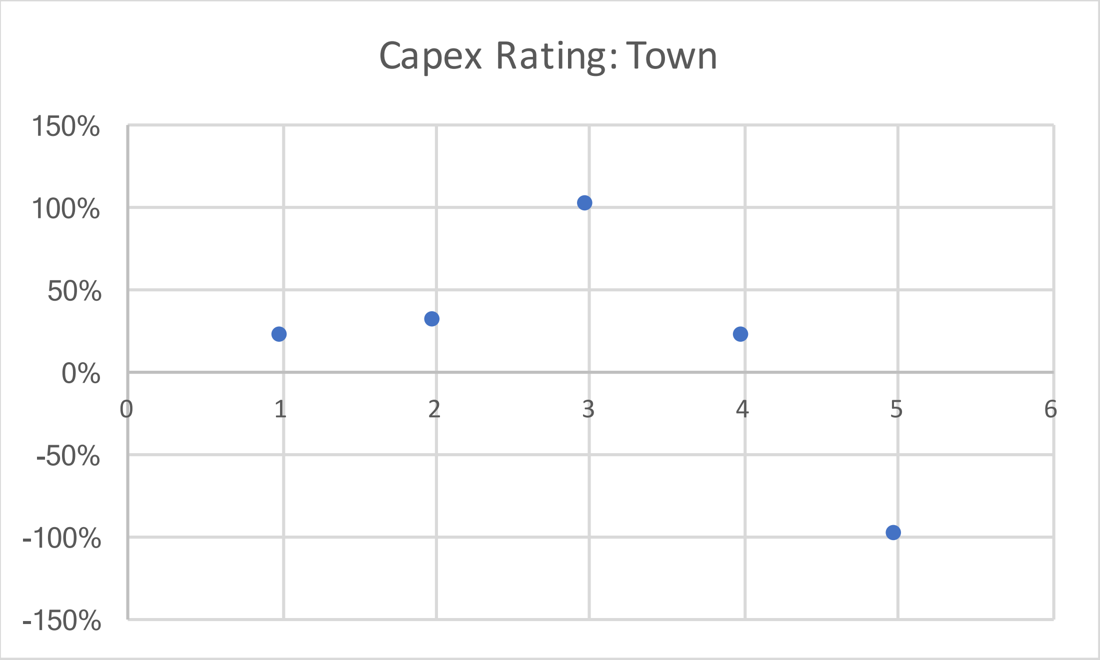
ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	14	70	5
Total Respondents: 5			



Q43: FTTP Capex costs- comments

Answered: 5   Skipped: 10

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	14	70	5
Total Respondents: 5			



Comments:

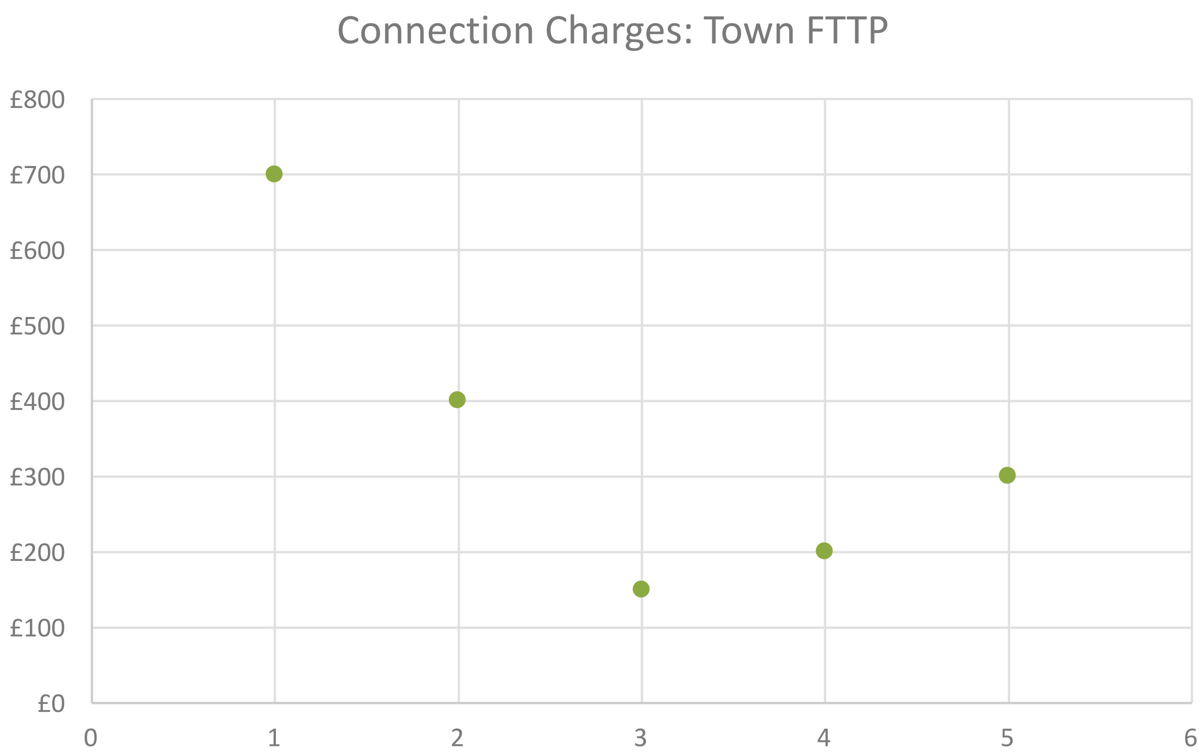
1. Use microduct to reduce width of trench/disruption (i.e. traffic measures) required, reducing civils and materials costs. - Use of aerial and existing duct is excessive and likely to be more costly, especially due to the rework needed on existing ducting, also long term sustainability of aerial is questionable.

2. These are about double the observed costs in the current unsubsidised FTTP deployments in small towns in the Republic of Ireland. It is likely to be the difference between overlay and new build costs. Given the FTTC deployments from which FTTP can be extended then the unit costs can drop further as the handover points and aggregation nodes are already in place.

3. We construct only point to point business fibre networks. The costs are very different

Q44: FTTP Connection Charges

Answered: 6   Skipped: 9



Q45&46: FTTP Opex costs

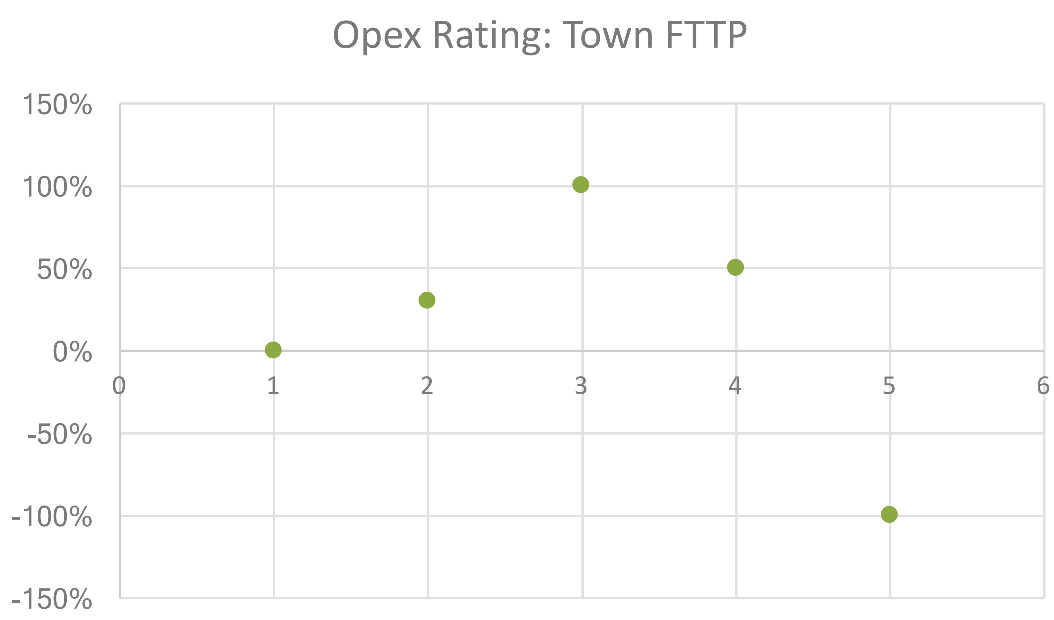
Question
The Opex costs estimated in Scenario 2 include the costs of running the network, e.g. support, monitoring and maintenance.

Thinking about your own experience with Opex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Comments:
(Refer to Scenario 1 FTTP)

Answered: 5   Skipped: 10

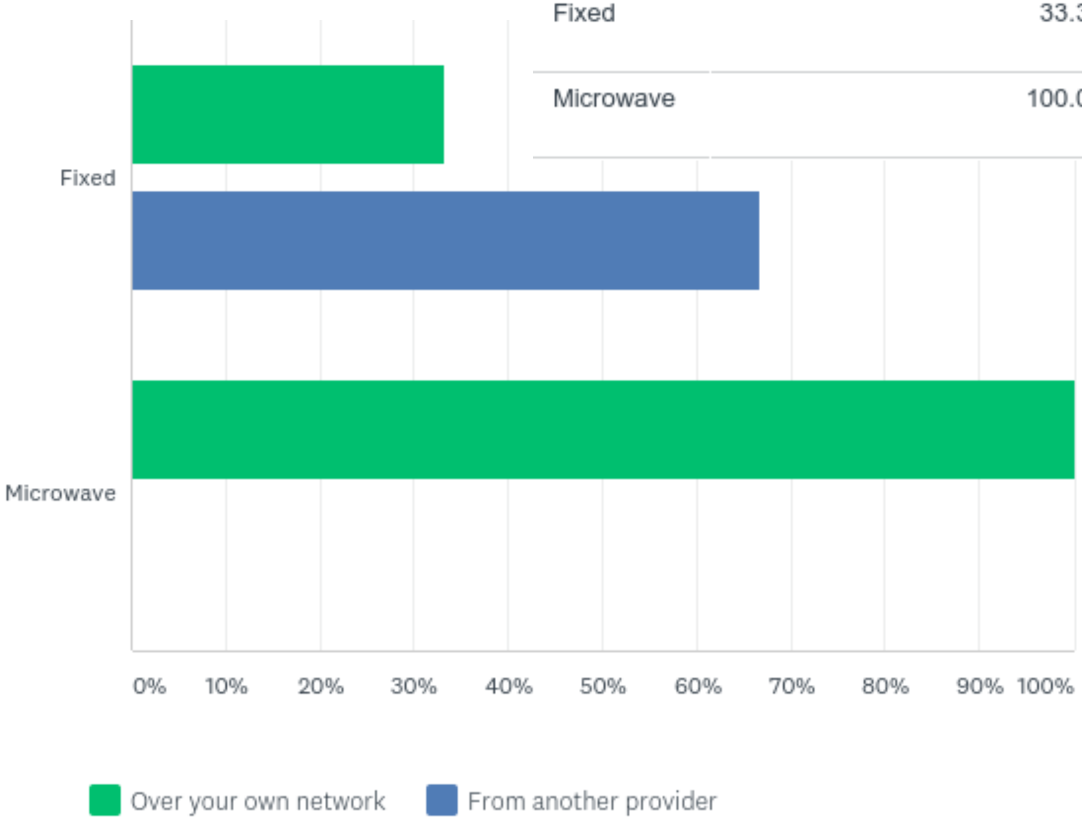
ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	16	80	5
Total Respondents: 5			



Q47: FTTP backhaul

Answered: 6   Skipped: 9

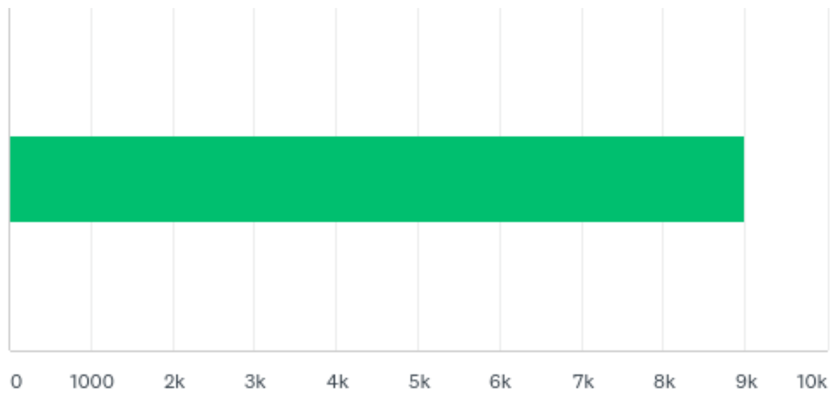
	OVER YOUR OWN NETWORK	FROM ANOTHER PROVIDER	TOTAL
Fixed	33.33% 2	66.67% 4	6
Microwave	100.00% 1	0.00% 0	1

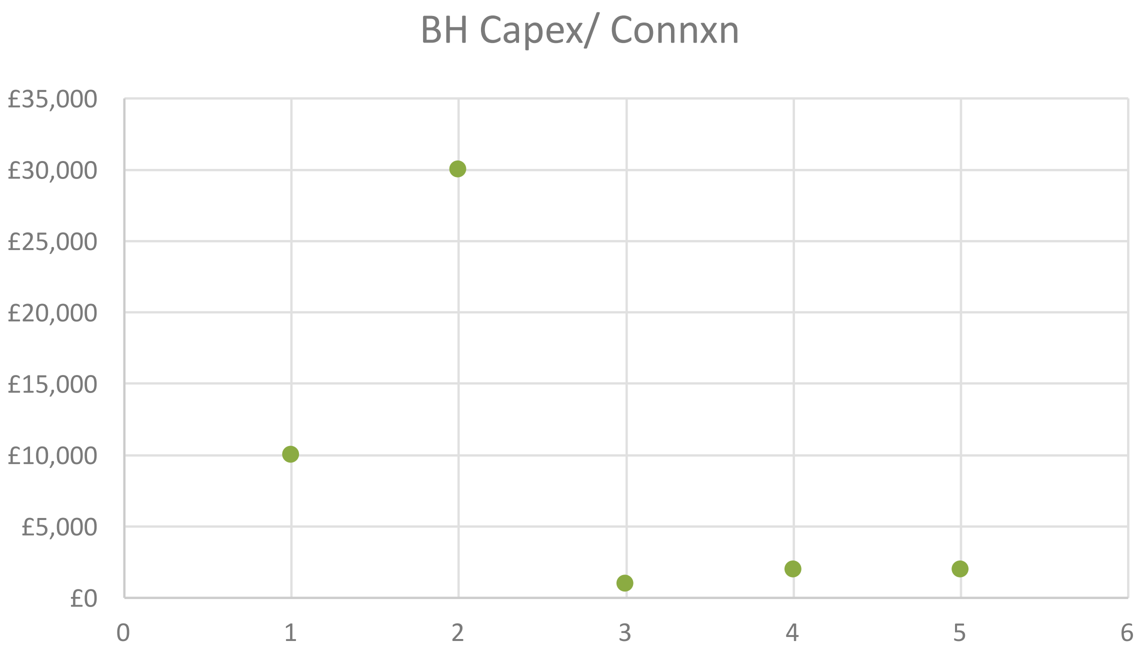


Q48: FTTP Backhaul costs - Capex/Connection charges

Answered: 5   Skipped: 10

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	9,000	45,000	5
Total Respondents: 5			

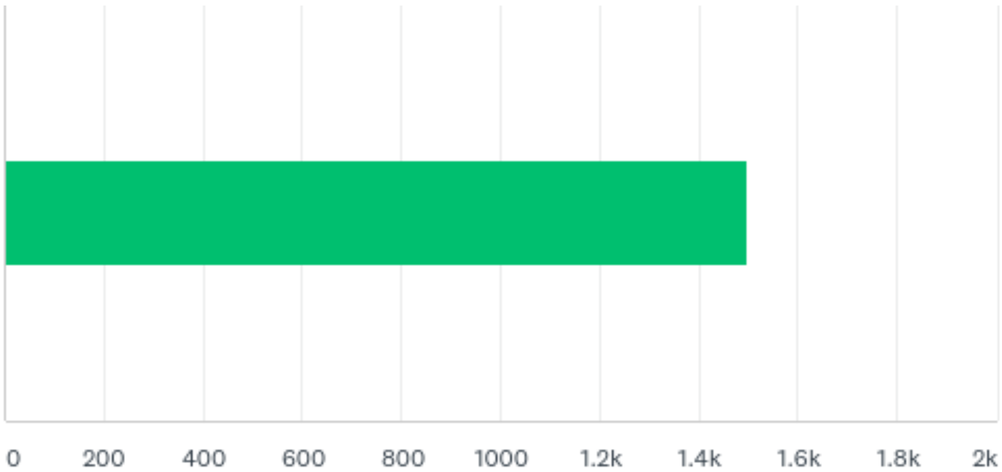


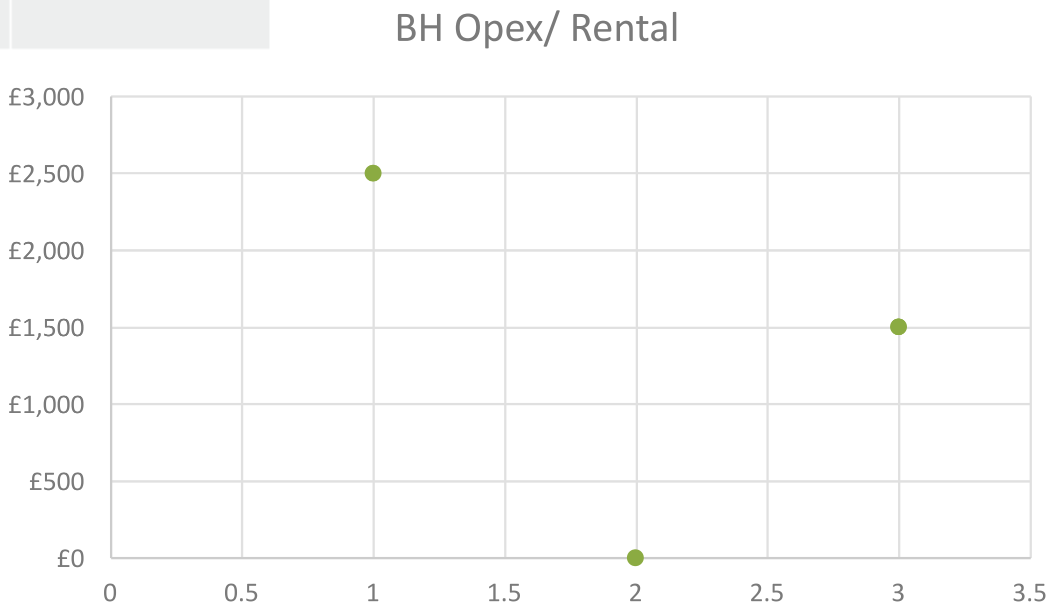


Q49: FTTP Backhaul costs - Opex/Rental charges

Answered: 5   Skipped: 10

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	1,500	7,500	5
Total Respondents: 5			





Q66&67: FWA Capex costs and comments

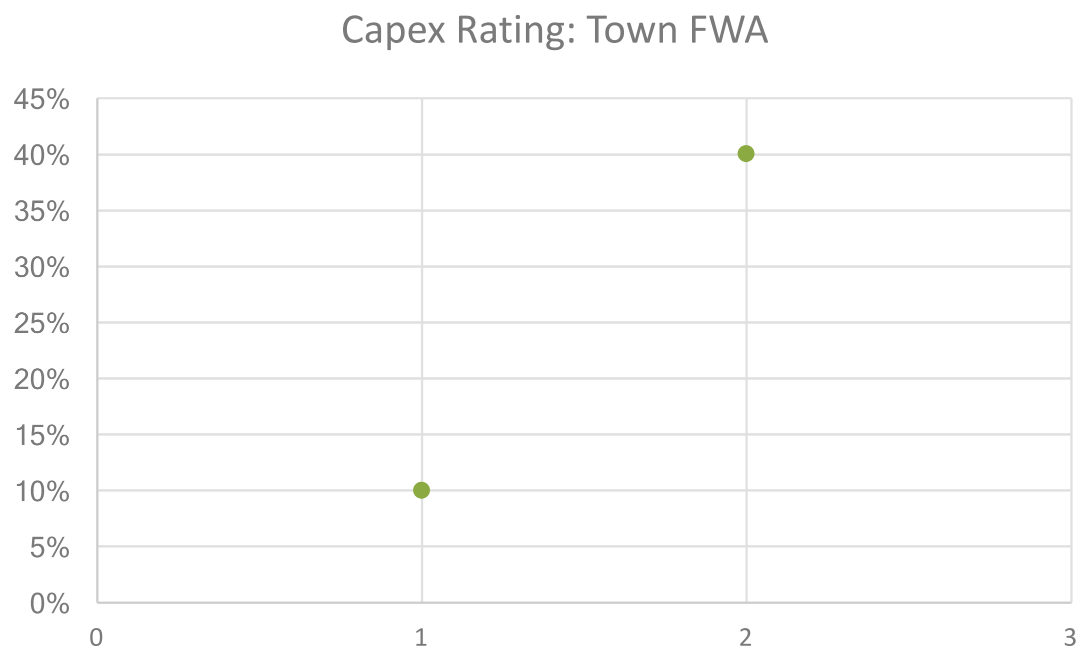
Question

The Capex costs estimated in Scenario 2 include costs in the access network alone, apportioned across civil engineering, passive and active components, but excluding backhaul and CPE. This is frequently referred to as "Cost of Homes Passed."

Thinking about your own experience with Capex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Answered: 2 Skipped: 13

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	25	50	2
Total Respondents: 2			

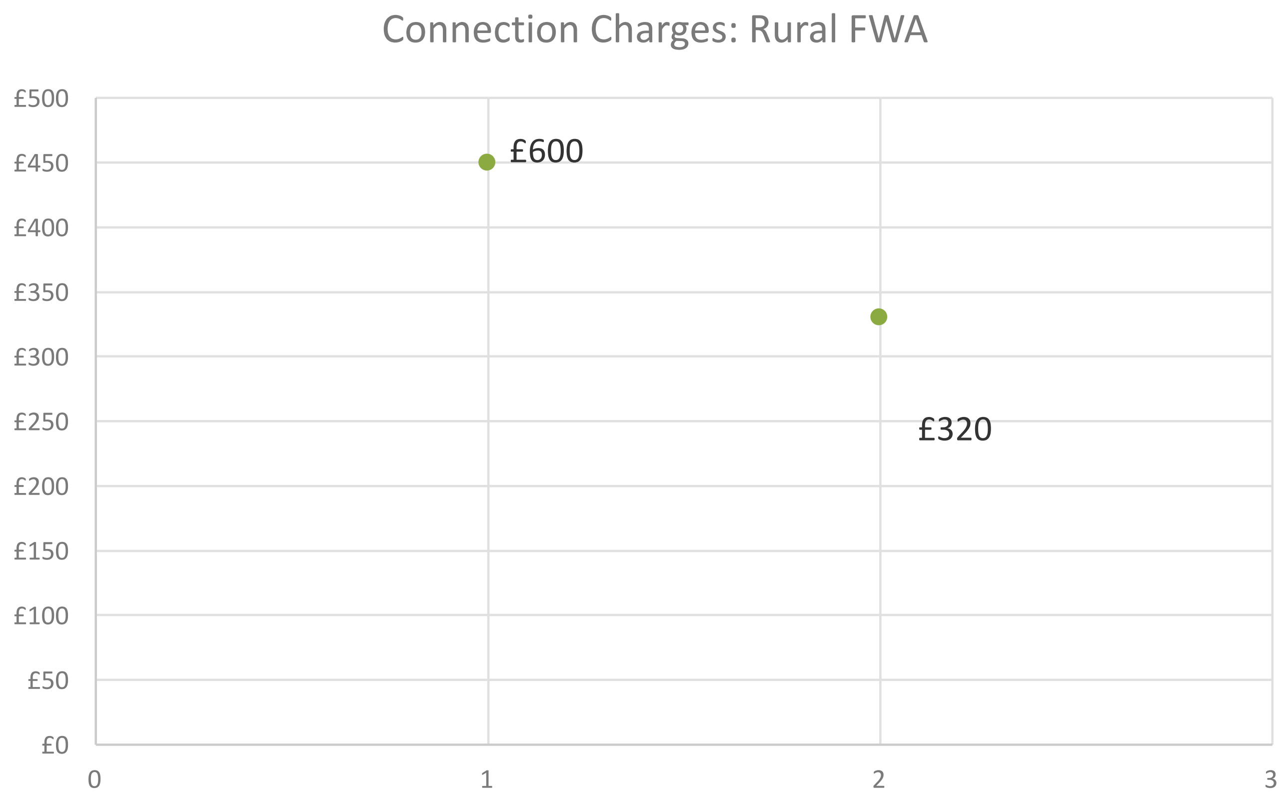


Comments:

1. Costs are around £60k capex per base station, £75k for hub sites including civils and equipment, I&C
2. Cambium access equipment provides relatively poor price performance compared with the best Multi User MIMO equipment in the market today.

Q68: FWA Connection Charges

Answered: 2   Skipped: 13



Q69: FWA Opex costs

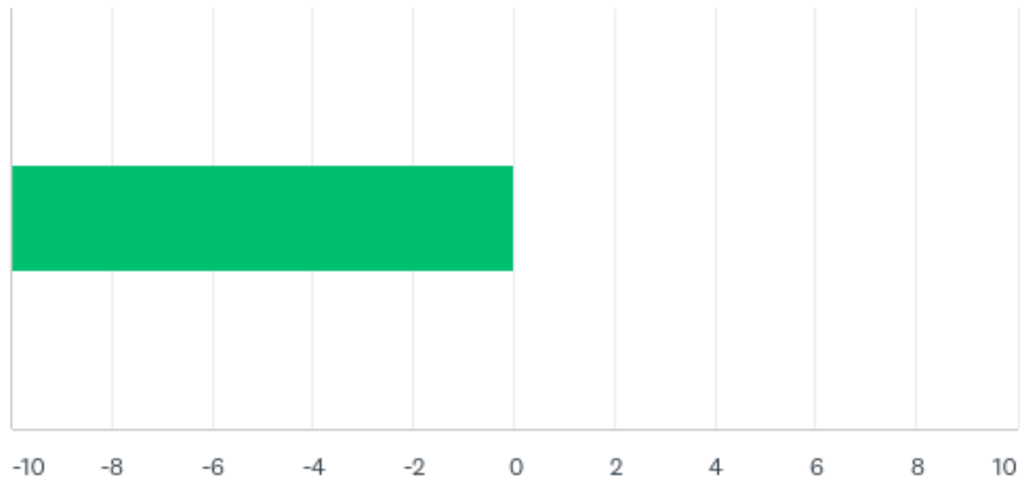
Question
The Opex costs estimated in Scenario 1 include the costs of running the network, e.g. support, monitoring and maintenance.

Thinking about your own experience with Opex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Comments:
None

Answered: 1   Skipped: 14

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	-10	-10	1
Total Respondents: 1			

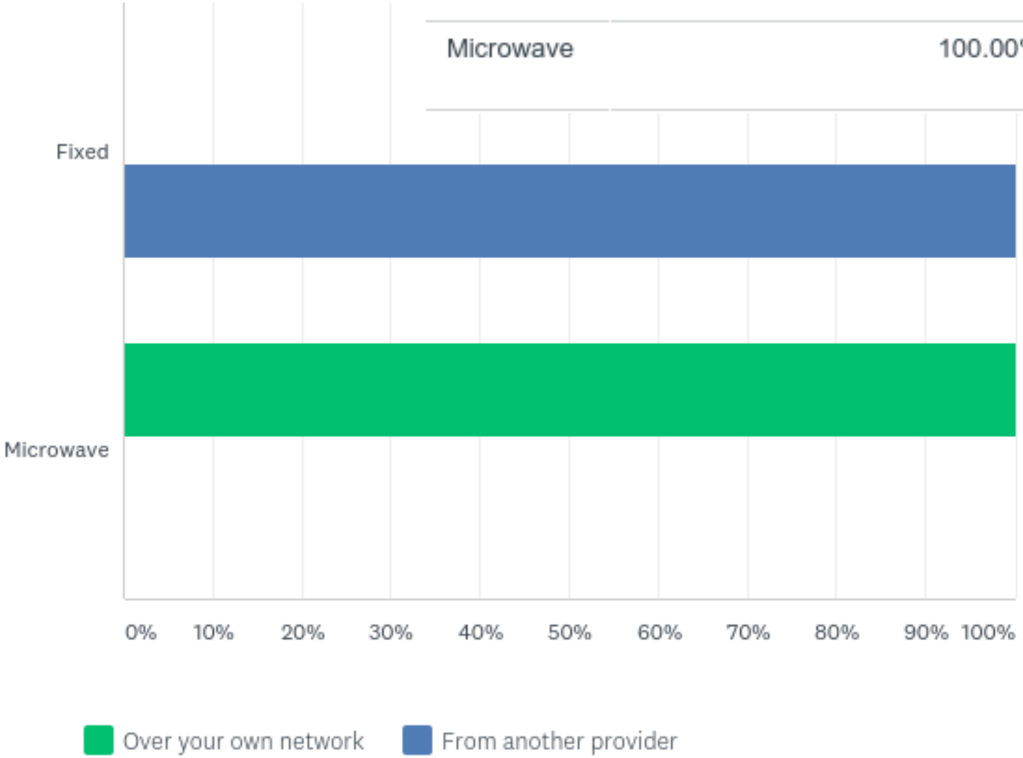


1 Response: 10% under-estimate

Q71: FWA Backhaul

Answered: 2   Skipped: 13

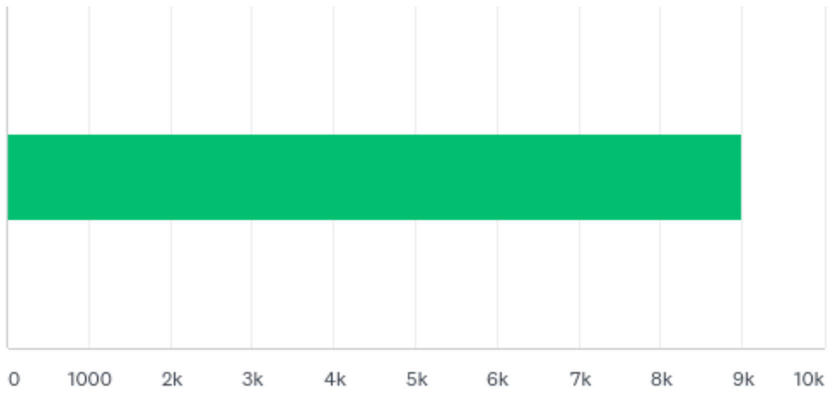
	OVER YOUR OWN NETWORK	FROM ANOTHER PROVIDER	TOTAL
Fixed	0.00% 0	100.00% 1	1
Microwave	100.00% 1	0.00% 0	1

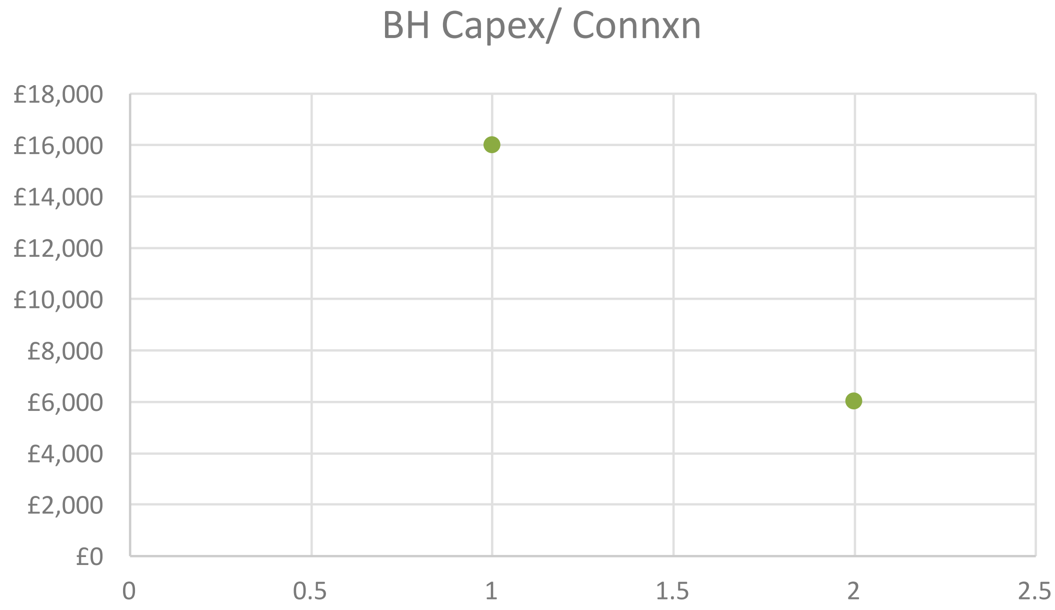


Q72: FWA Backhaul costs - Capex/Connection charges

Answered: 2   Skipped: 13

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	9,000	18,000	2
Total Respondents: 2			

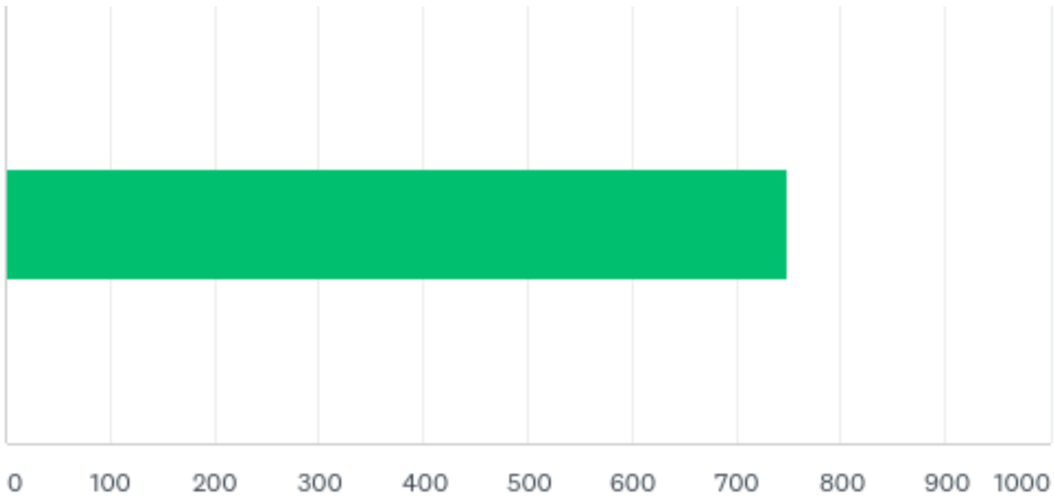




Q73: FWA Backhaul costs - Opex/Rental charges

Answered: 2   Skipped: 13

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	750	1,500	2
Total Respondents: 2			



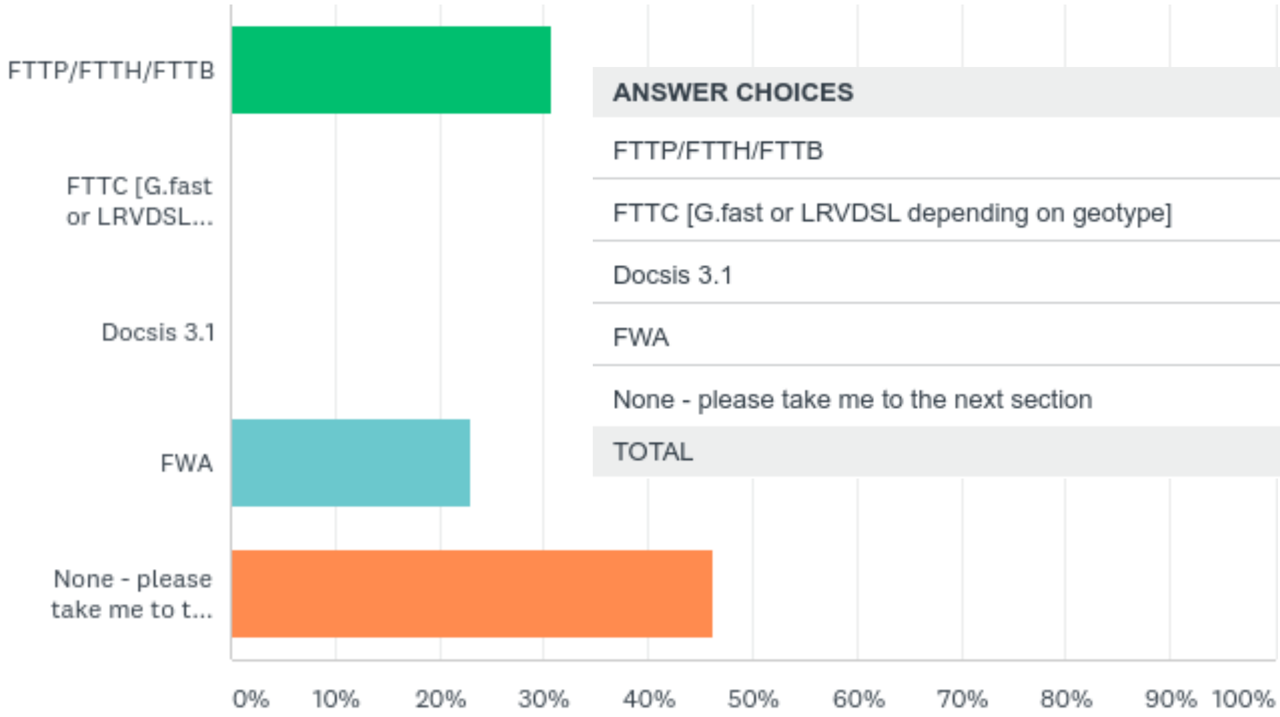
2 Responses: £1,500 and £0

Part B: Scenario Reviews-

3. Rural

Q74: Which technology option do you wish to give feedback on for this scenario?

Answered: 13 Skipped: 2



ANSWER CHOICES	RESPONSES	
FTTP/FTTH/FTTB	30.77%	4
FTTC [G.fast or LRVDSL depending on geotype]	0.00%	0
Docsis 3.1	0.00%	0
FWA	23.08%	3
None - please take me to the next section	46.15%	6
TOTAL		13

Q75&76: FTTP Capex costs and comments

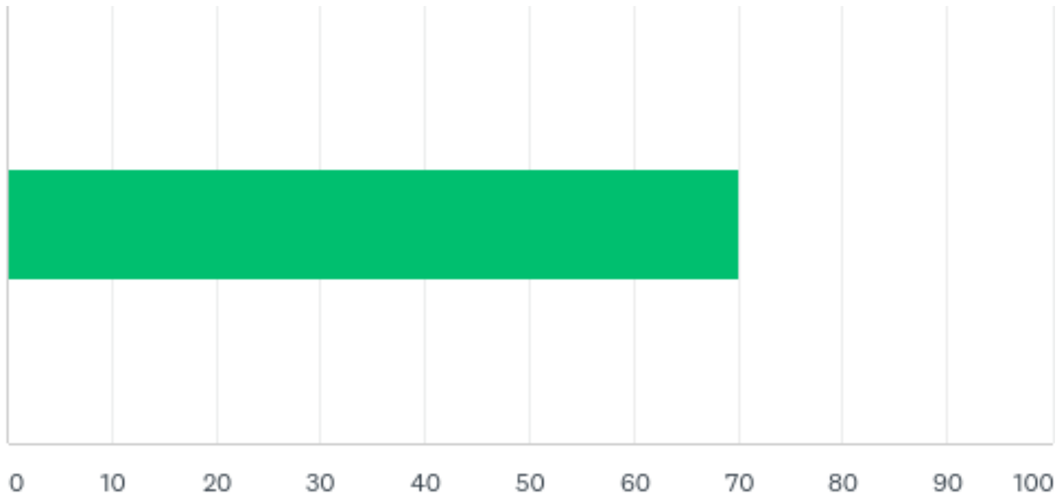
Question

The Capex costs estimated in Scenario 3 include costs in the access network alone, apportioned across civil engineering, passive and active components, but excluding backhaul and CPE. This is frequently referred to as "Cost of Homes Passed."

Thinking about your own experience with Capex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Answered: 2   Skipped: 13

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	70	140	2
Total Respondents: 2			



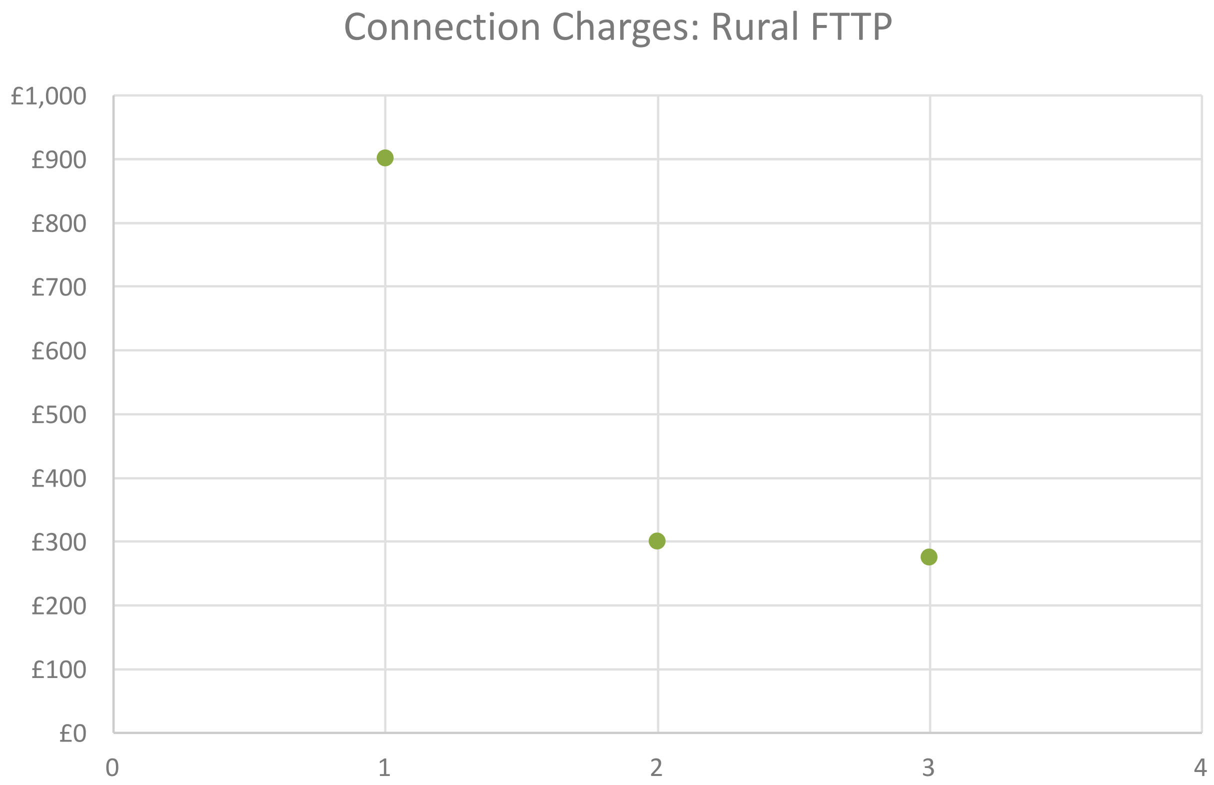
2 Responses: 40% over-estimate, 100% over-estimate

Comments:

1. Same reasons given in Q11 for towns, but the effects will be more pronounced over longer distances.
2. Extending an FTTC networks and overlaying FTTP where needed versus a full deployment cost. This is driving a much higher cost.

Q77: FTTP Connection Charges

Answered: 3   Skipped: 12



Q78&79: FTTP Opex costs and comments

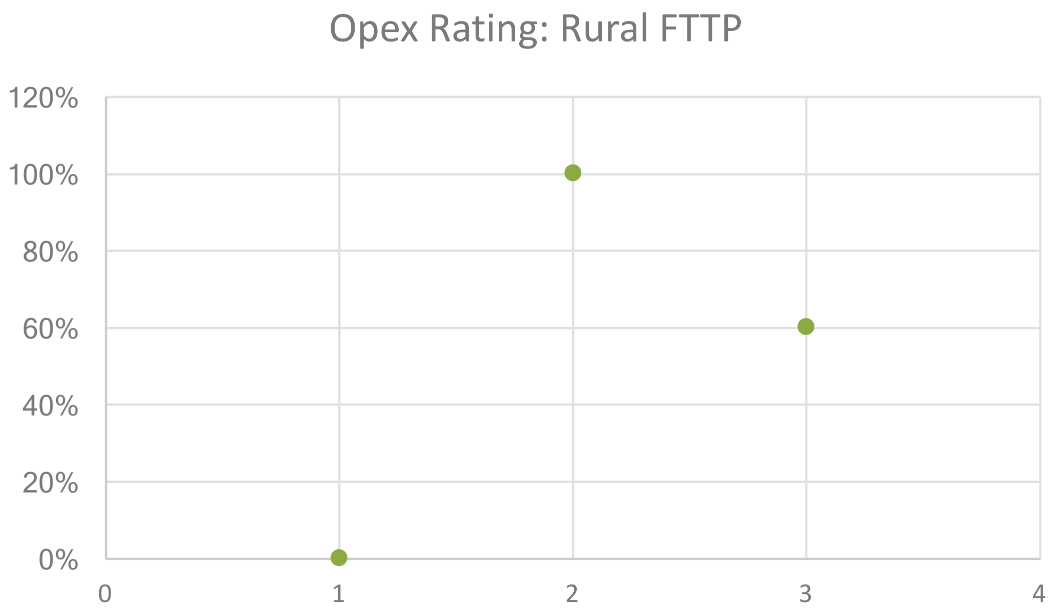
Question
The Opex costs estimated in Scenario 3 include the costs of running the network, e.g. support, monitoring and maintenance.

Thinking about your own experience with Opex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Comments:
1. Perhaps if you build a stand alone network in isolation then these might be ok, but this is unlikely so the scenario is unlikely.

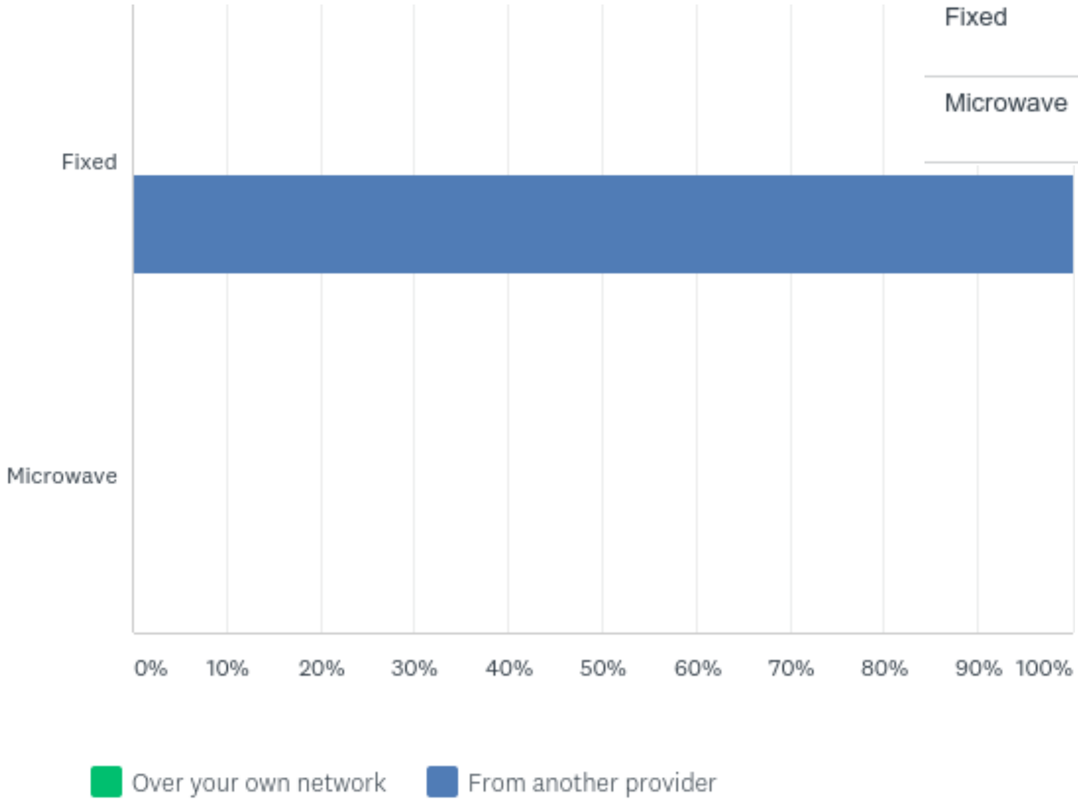
Answered: 3   Skipped: 12

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	53	160	3
Total Respondents: 3			



Q80: FTTP backhaul

Answered: 3   Skipped: 12

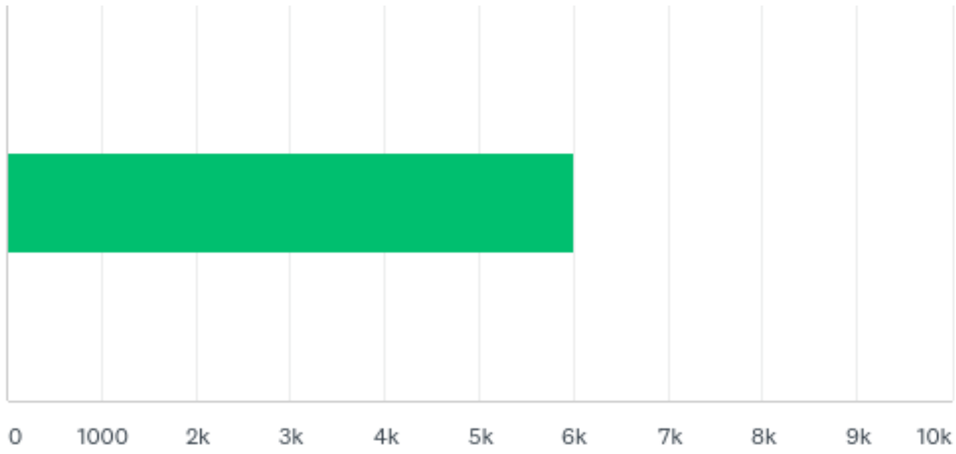


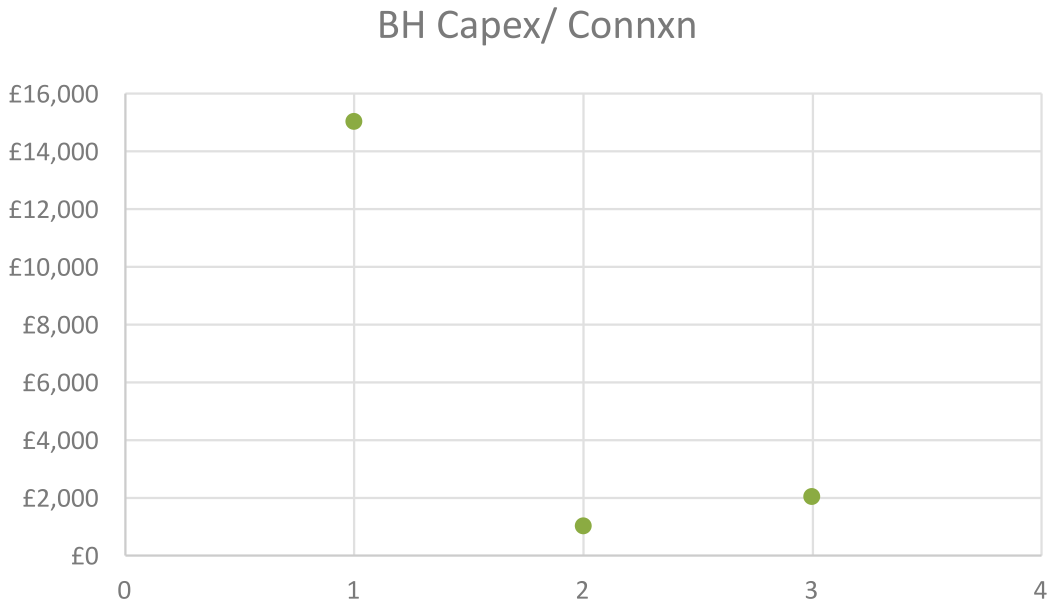
	OVER YOUR OWN NETWORK	FROM ANOTHER PROVIDER	TOTAL
Fixed	0.00% 0	100.00% 3	3
Microwave	0.00% 0	0.00% 0	0

Q81: Backhaul costs - Capex/Connection charges

Answered: 3 Skipped: 12

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	6,000	18,000	3
Total Respondents: 3			

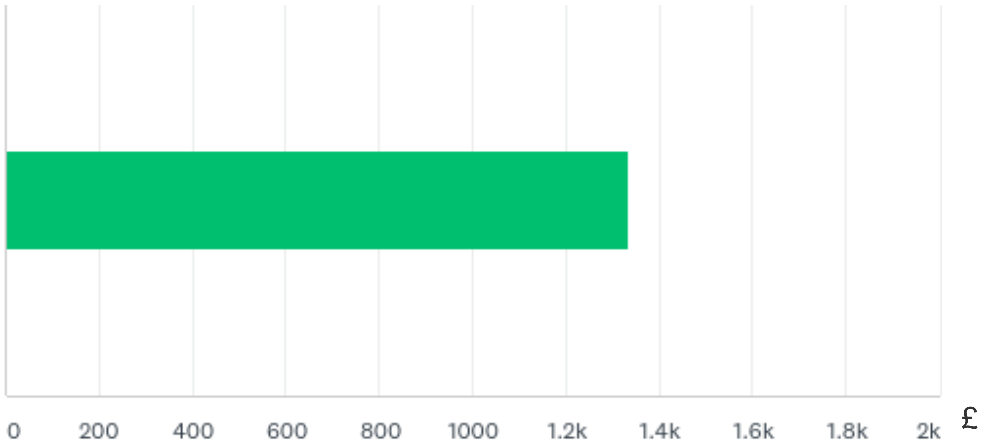


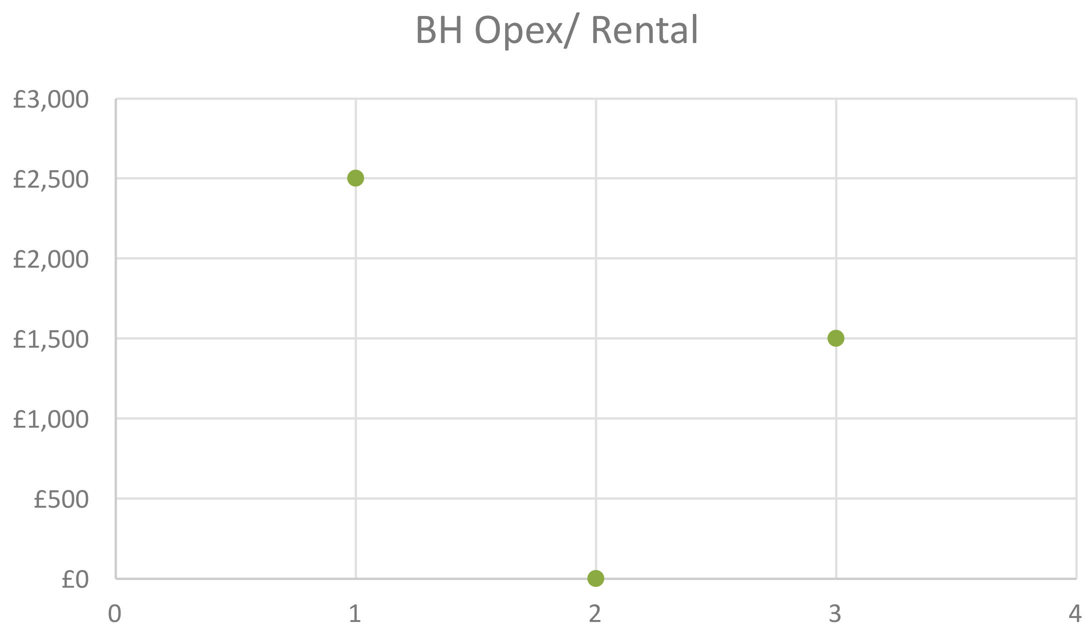


Q82: Backhaul costs - Opex/Rental charges

Answered: 3 Skipped: 12

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	1,333	4,000	3
Total Respondents: 3			





Q99&100: FWA Capex costs and comments

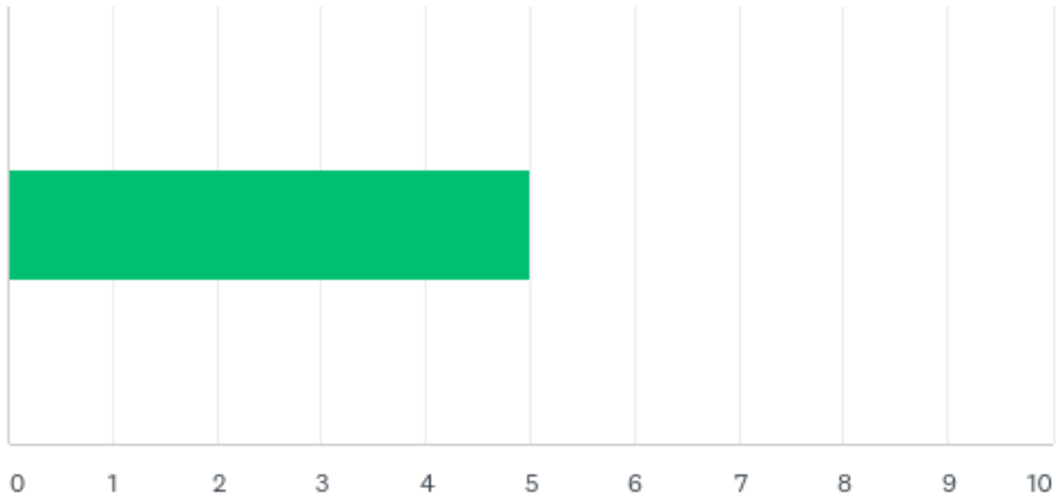
Question
The Capex costs estimated in Scenario 3 include costs in the access network alone, apportioned across civil engineering, passive and active components, but excluding backhaul and CPE. This is frequently referred to as "Cost of Homes Passed."

Thinking about your own experience with Capex in this type of scenario use the slider to indicate whether you think the estimated costs are about right (0), too high (to the right of the scale) or too low (to the left of the scale)

Comments:
None

Answered: 2 Skipped: 13

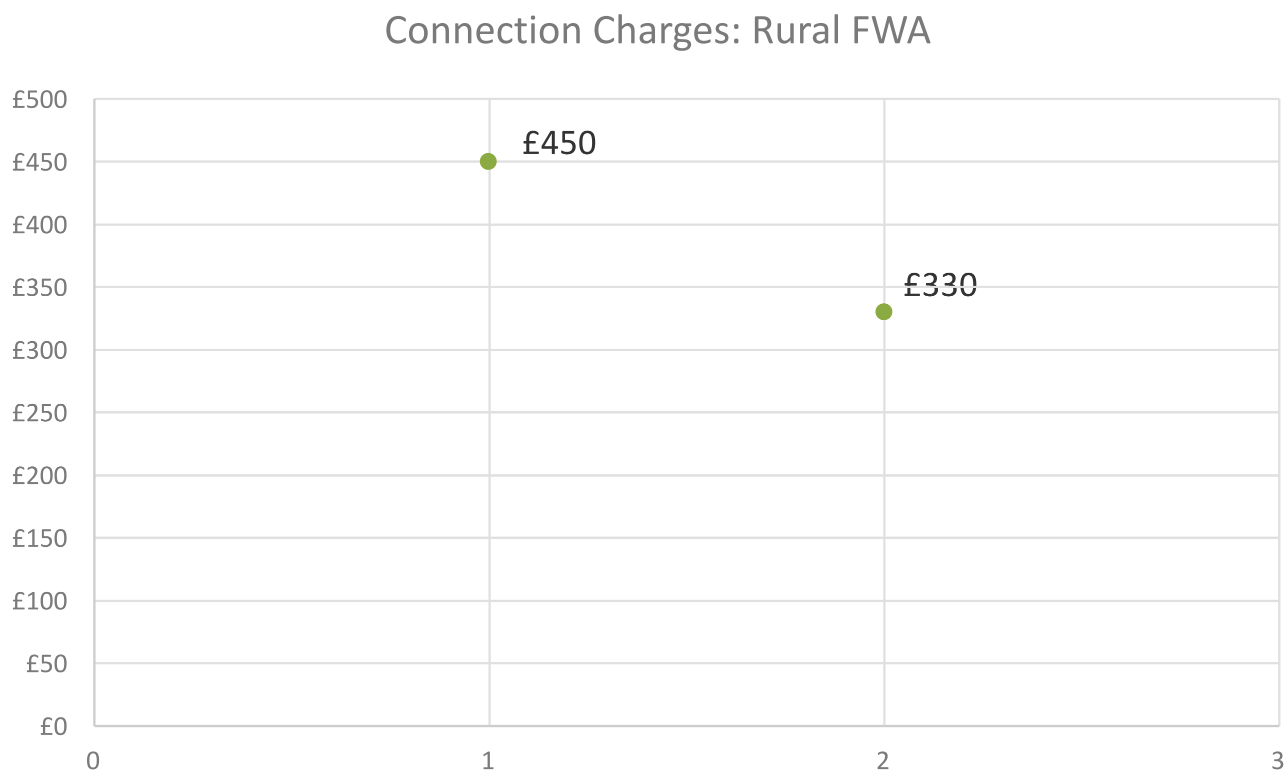
ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	5	10	2
Total Respondents: 2			



2 Responses: 10% under-estimate, 20% over-estimate

Q101: FWA Connection Charges

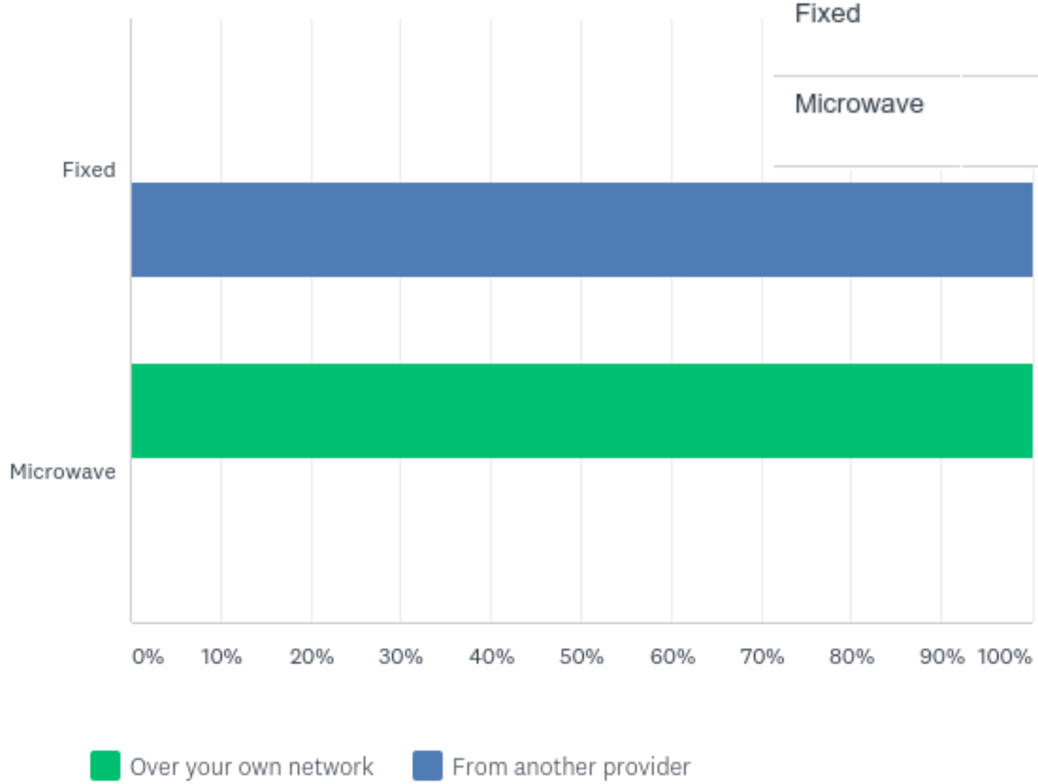
Answered: 2   Skipped: 13



Q104: FWA Backhaul

Answered: 2   Skipped: 13

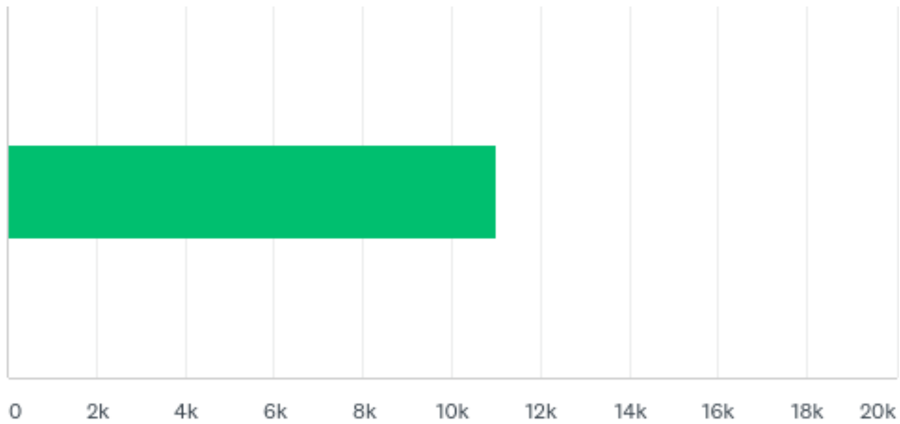
	OVER YOUR OWN NETWORK	FROM ANOTHER PROVIDER	TOTAL
Fixed	0.00% 0	100.00% 2	2
Microwave	100.00% 1	0.00% 0	1

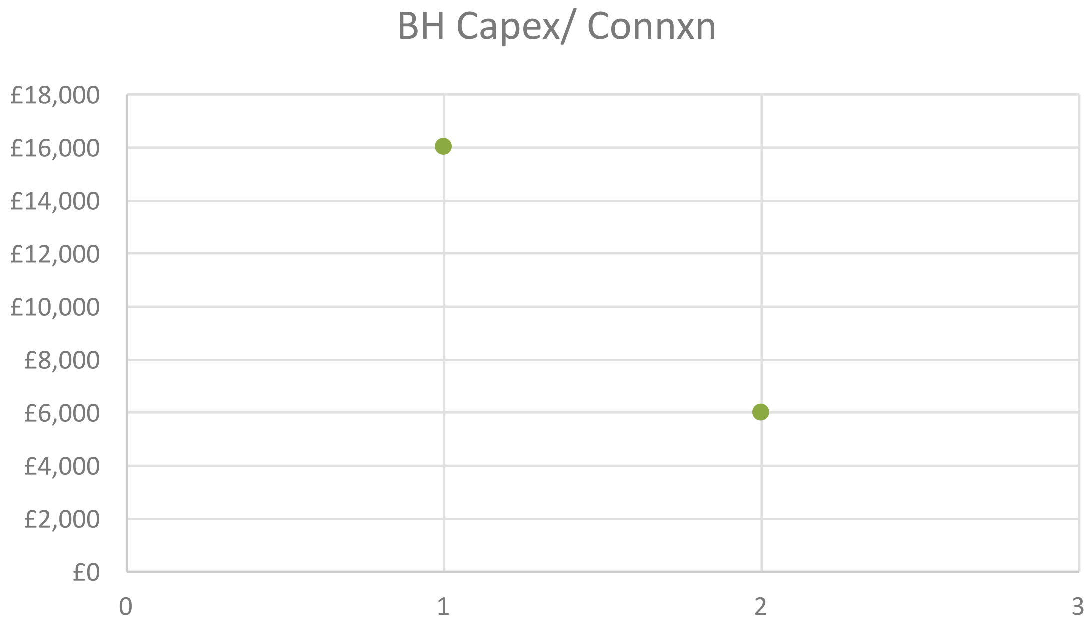


Q105: FWA Backhaul costs - Capex/Connection charges

Answered: 2   Skipped: 13

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	11,000	22,000	2
Total Respondents: 2			

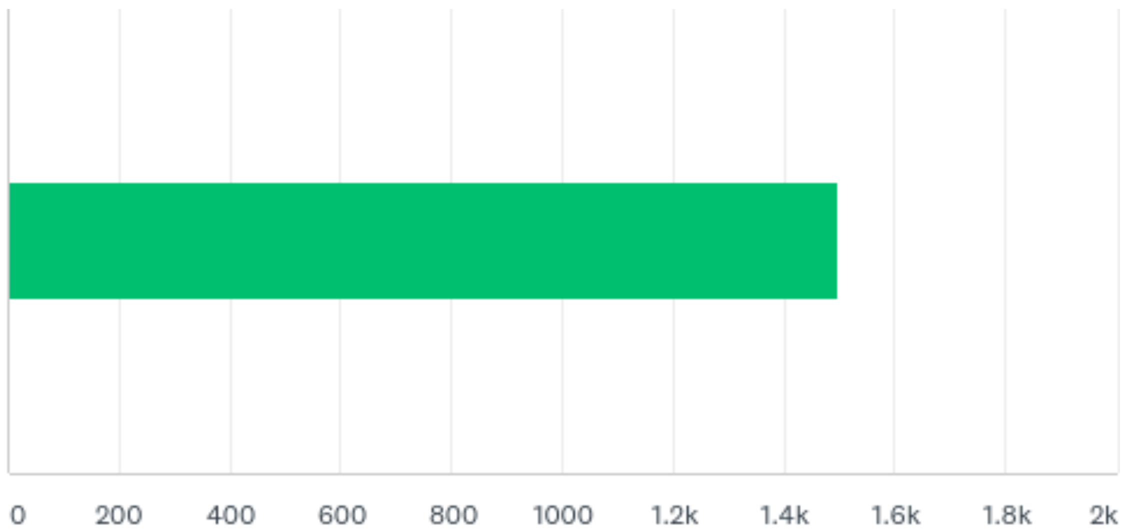




Q106: FWA Backhaul costs - Opex/Rental charges

Answered: 1   Skipped: 14

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	1,500	1,500	1
Total Respondents: 1			

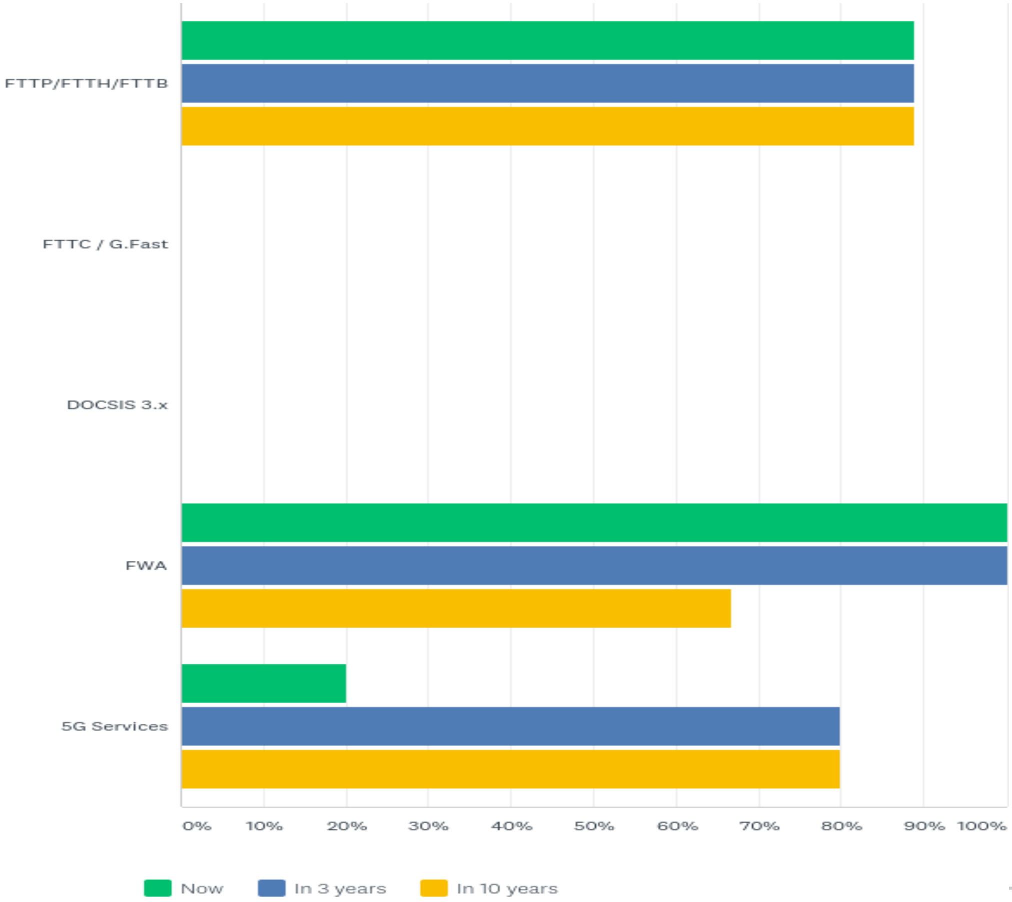


1 Response: £1,500

Part C: Future Innovations

Q107: Thinking about new city deployments. Which technologies do you mainly deploy now and anticipate deploying in future

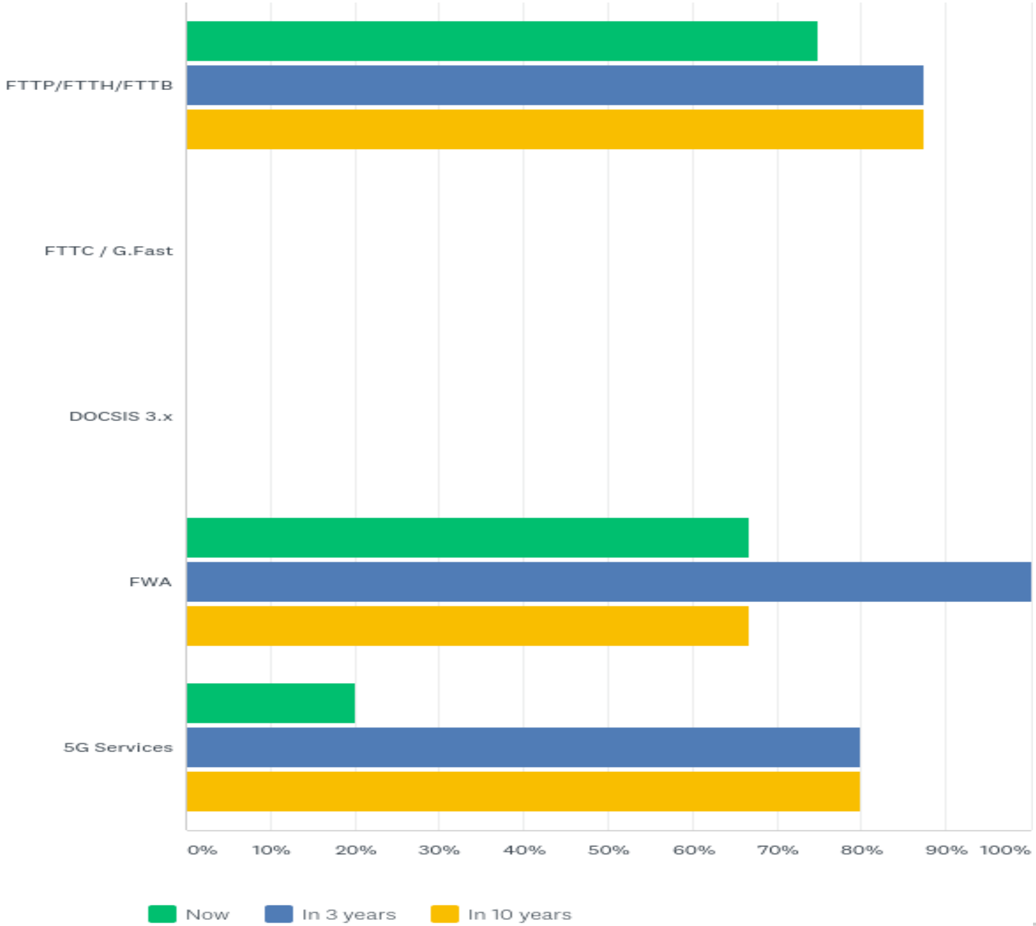
Answered: 10 Skipped: 5



	NOW	IN 3 YEARS	IN 10 YEARS	TOTAL RESPONDENTS
FTTP/FTTH/FTTB	88.89% 8	88.89% 8	88.89% 8	9
FTTC / G.Fast	0.00% 0	0.00% 0	0.00% 0	0
DOCSIS 3.x	0.00% 0	0.00% 0	0.00% 0	0
FWA	100.00% 3	100.00% 3	66.67% 2	3
5G Services	20.00% 1	80.00% 4	80.00% 4	5

Q108: Thinking about new town deployments. Which technologies do you mainly deploy now and anticipate deploying in future

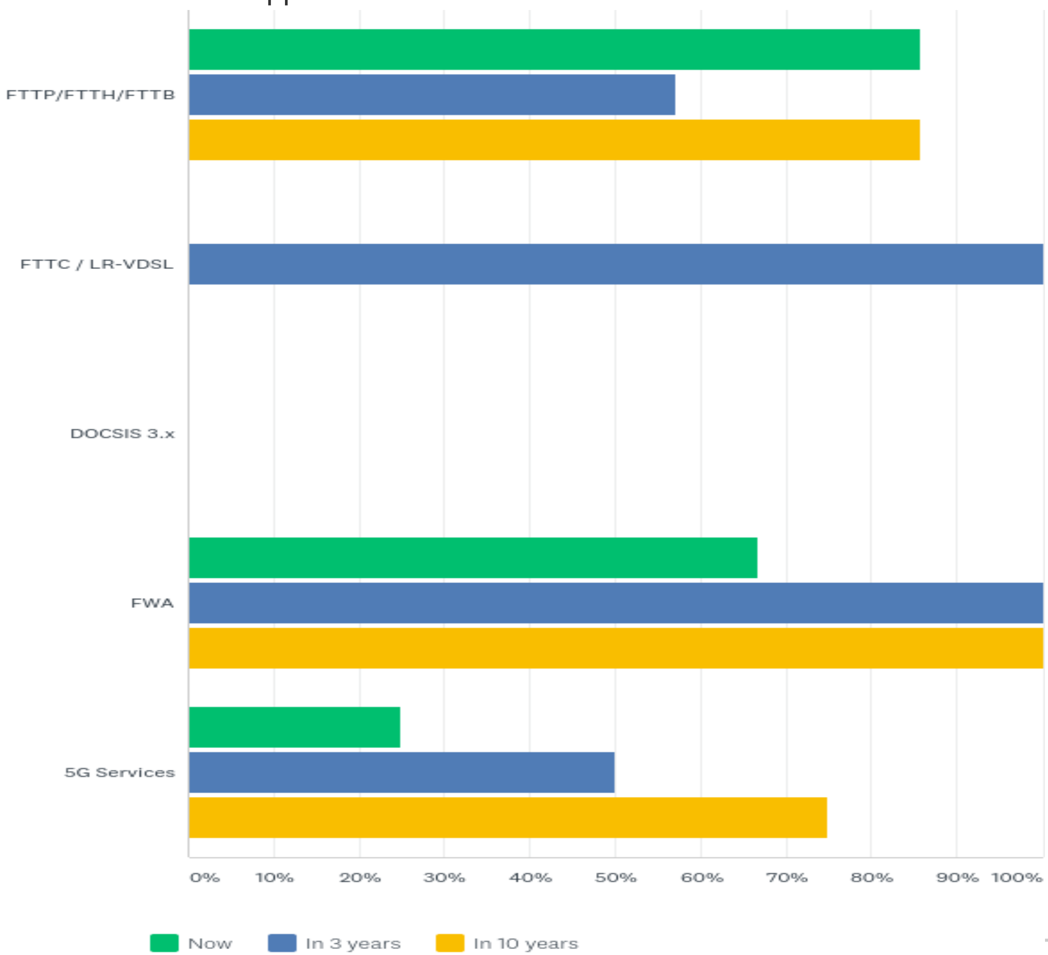
Answered: 9 Skipped: 6



	NOW	IN 3 YEARS	IN 10 YEARS	TOTAL RESPONDENTS
FTTP/FTTH/FTTB	75.00% 6	87.50% 7	87.50% 7	8
FTTC / G.Fast	0.00% 0	0.00% 0	0.00% 0	0
DOCSIS 3.x	0.00% 0	0.00% 0	0.00% 0	0
FWA	66.67% 2	100.00% 3	66.67% 2	3
5G Services	20.00% 1	80.00% 4	80.00% 4	5

Q109: Thinking about new rural deployments. Which technologies do you mainly deploy now and anticipate deploying in future

Answered: 9 Skipped: 6



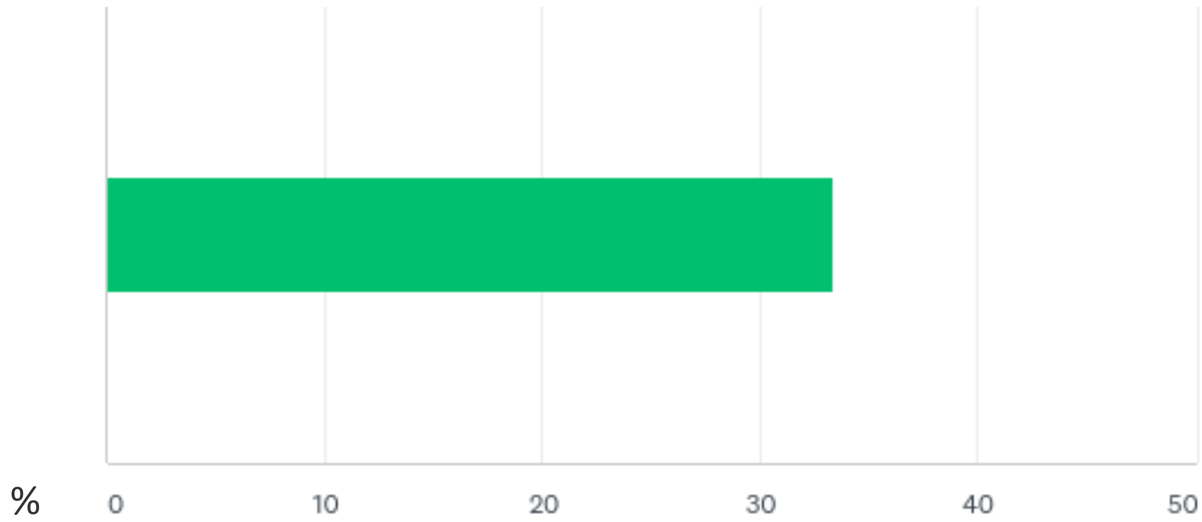
	NOW	IN 3 YEARS	IN 10 YEARS	TOTAL RESPONDENTS
FTTP/FTTH/FTTB	85.71% 6	57.14% 4	85.71% 6	7
FTTC / LR-VDSL	0.00% 0	100.00% 1	0.00% 0	1
DOCSIS 3.x	0.00% 0	0.00% 0	0.00% 0	0
FWA	66.67% 2	100.00% 3	100.00% 3	3
5G Services	25.00% 1	50.00% 2	75.00% 3	4

Q110: Infrastructure Re-use: Openreach ducts and poles in cities

Question
Re-use of Openreach ducts and poles could significantly reduce deployment costs. Based on current assumptions how much do you think PIA could reduce costs in percentage terms in cities?

Answered: 9 Skipped: 6

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	33	300	9
Total Respondents: 9			

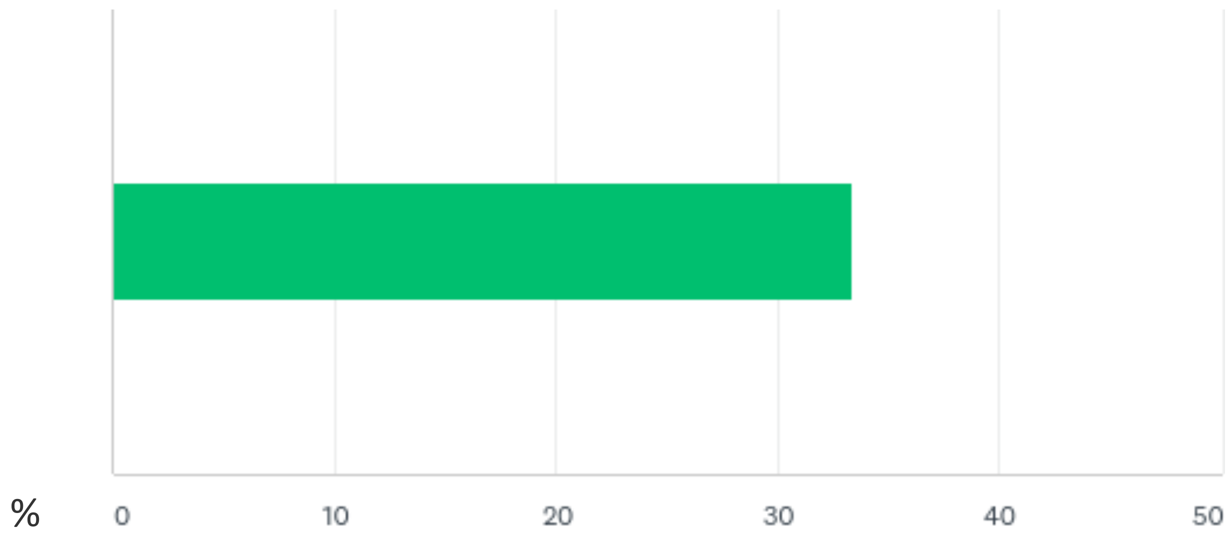


Q111: Infrastructure Re-use: Openreach ducts and poles in towns

Question
Re-use of Openreach ducts and poles could significantly reduce deployment costs. Based on current assumptions how much do you think PIA could reduce costs in percentage terms in towns?

Answered: 9 Skipped: 6

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	33	300	9
Total Respondents: 9			

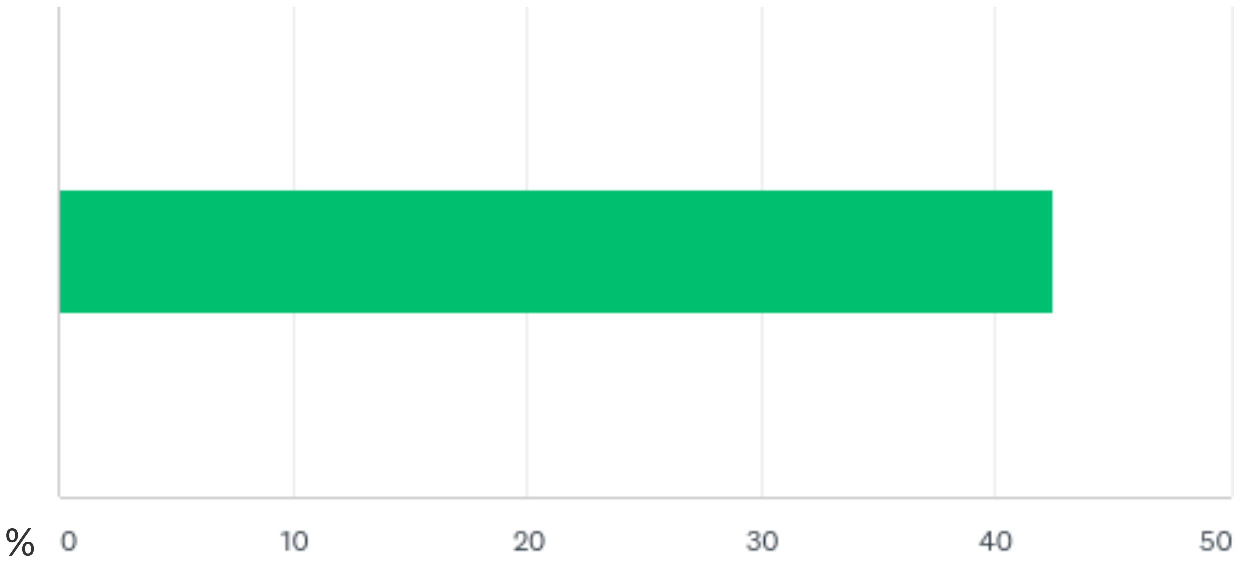


Q112: Infrastructure Re-use: Openreach ducts and poles in rural

Question
Re-use of Openreach ducts and poles could significantly reduce deployment costs. Based on current assumptions how much do you think PIA could reduce costs in percentage terms in rural areas?

Answered: 8 Skipped: 7

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	43	340	8
Total Respondents: 8			



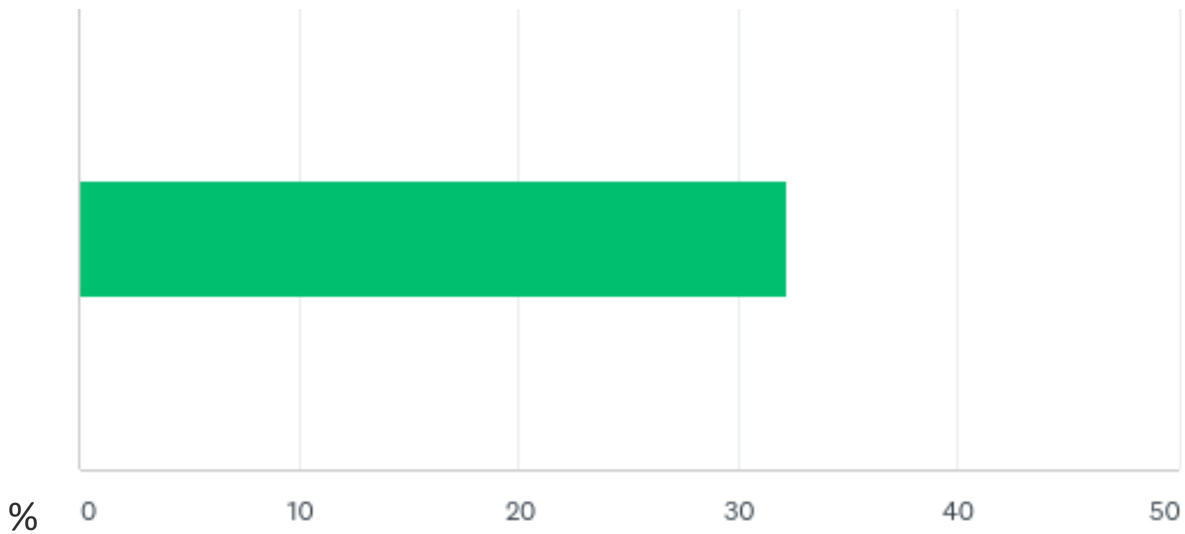
Q113: Infrastructure Re-use: other passive infrastructure in cities and towns

Question

Re-use of other passive infrastructure could significantly reduce deployment costs - e.g. local authority ducts, utility company infrastructure. In your opinion how much do you think access to alternative infrastructure can reduce costs in percentage terms in cities and towns?

Answered: 9 Skipped: 6

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	32	290	9
Total Respondents: 9			



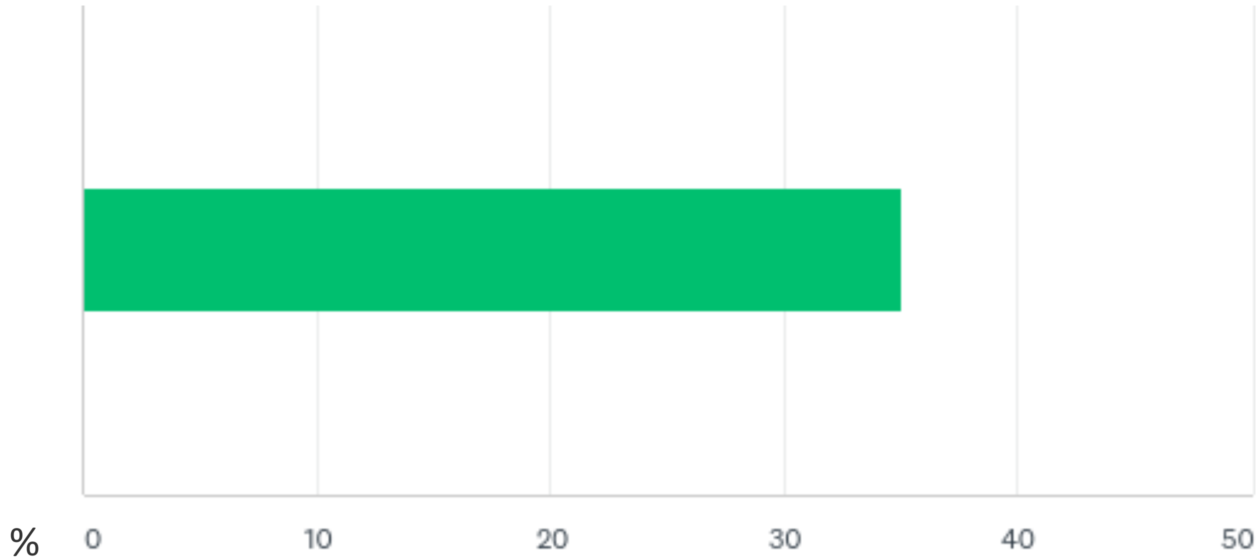
Q114: Infrastructure Re-use: other passive infrastructure in rural areas

Question

Re-use of other passive infrastructure could significantly reduce deployment costs - e.g. local authority ducts, utility company infrastructure. In your opinion how much do you think access to alternative infrastructure can reduce costs in percentage terms in rural areas?

Answered: 8   Skipped: 7

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	35	280	8
Total Respondents: 8			



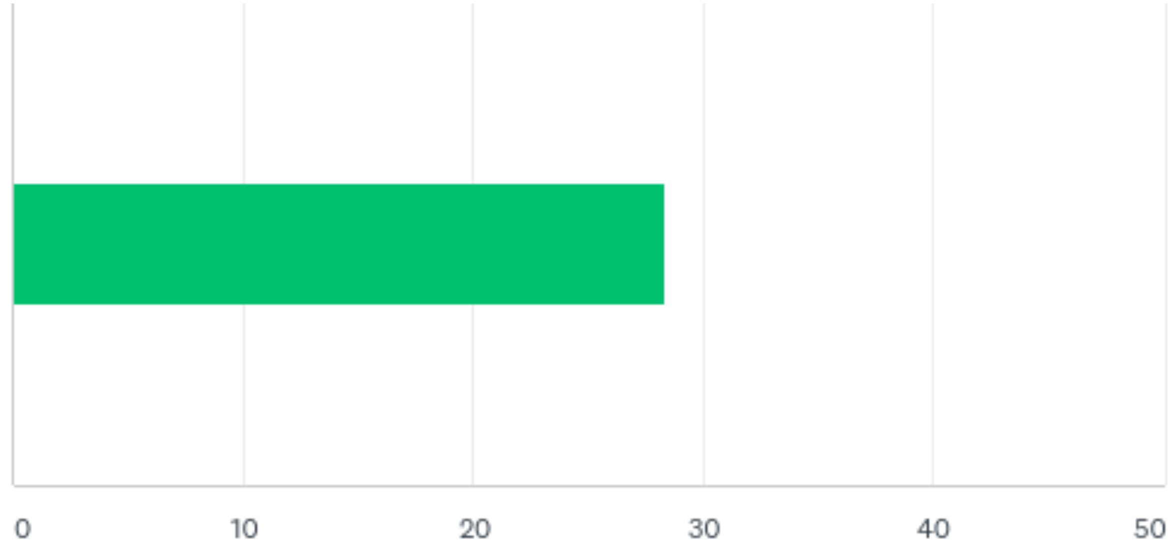
Q115: Construction techniques: Narrow trenching / slot cutting

Question

Narrow trenching / slot cutting can have a significant impact on deployment costs of new fixed networks. What impact on project costs do you think these techniques can have?

Answered: 6   Skipped: 9

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	28	170	6
Total Respondents: 6			



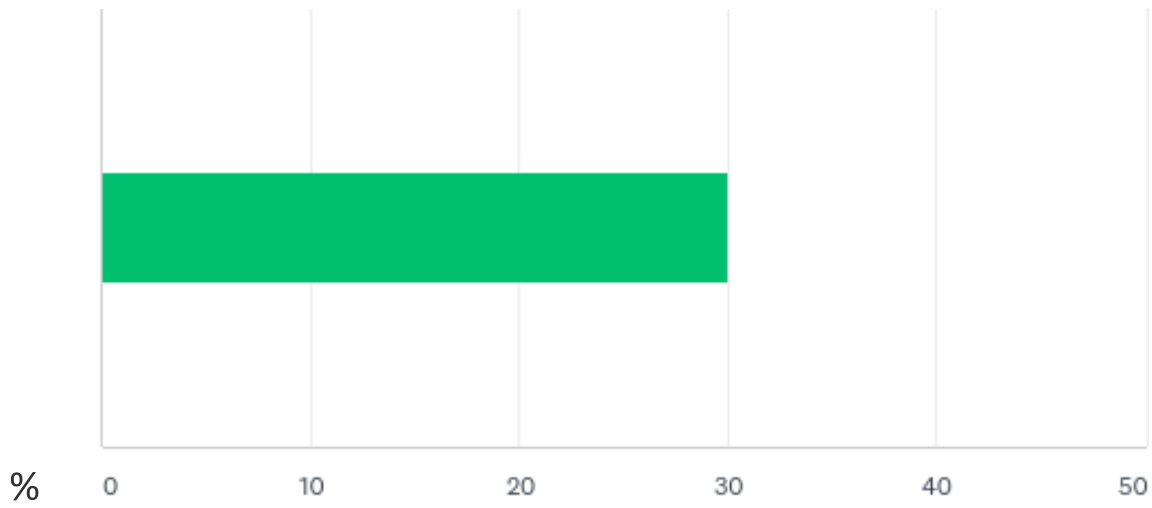
Q116: Licencing: mast sites

Question

Better arrangements for sharing mast sites could have a significant impact on deployment costs for wireless networks. What impact on costs do you think better sharing arrangements could have?

Answered: 4 Skipped: 11

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	30	120	4
Total Respondents: 4			



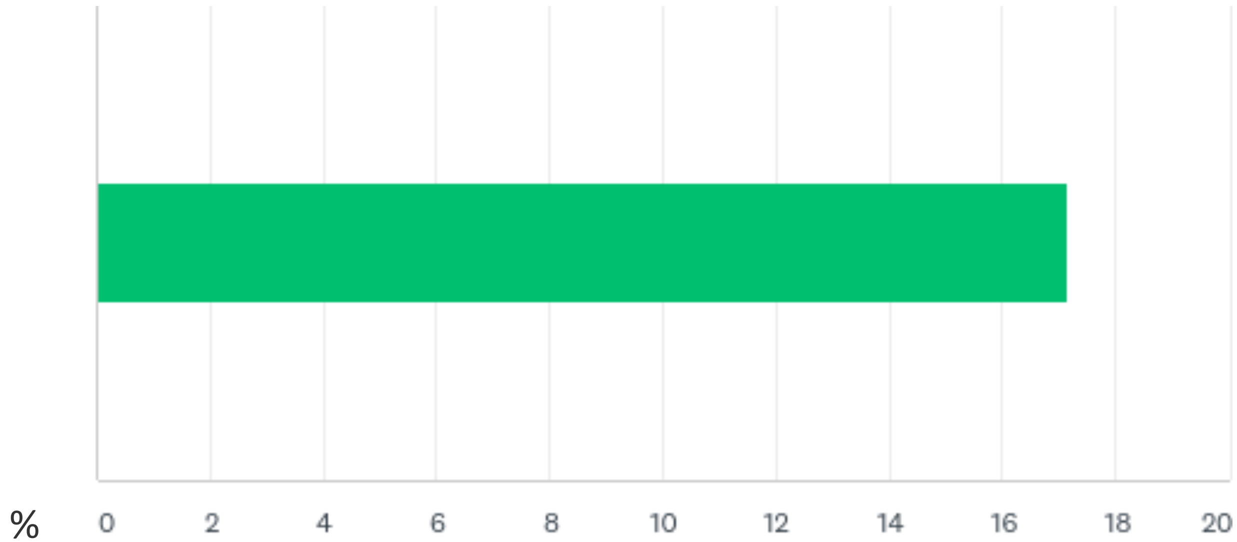
Q117: Licencing: Obtaining wayleaves, street works permissions and consents

Question

Obtaining wayleaves, street works permissions and other consents can form a significant proportion of project costs. In your experience what percentage are these costs of the overall project costs?

Answered: 7 Skipped: 8

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	17	120	7
Total Respondents: 7			



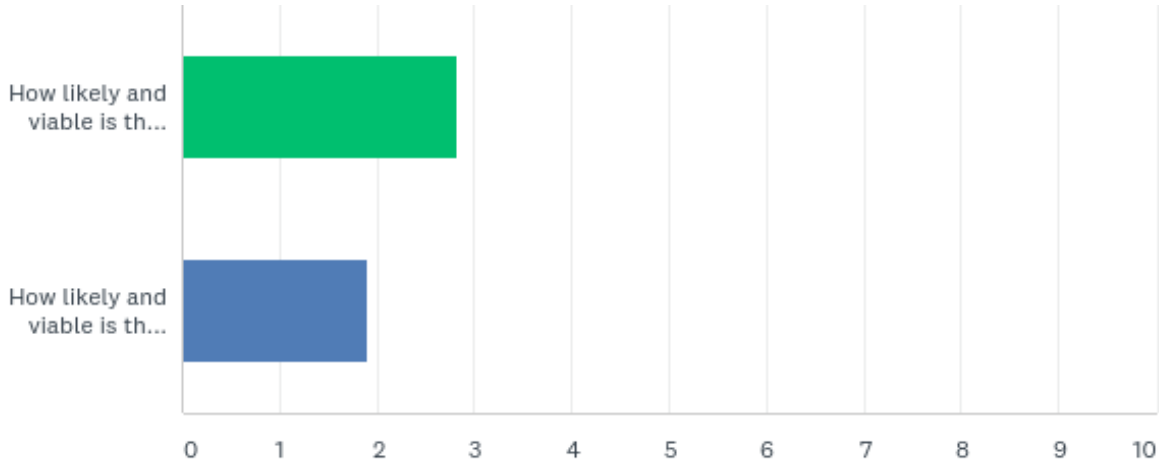
Q118: 5G Access: perceived viability and likelihood in 5 years

Question
5G has been mooted as a potential access technology. For instance one option is to deploy 5G to lamp-posts and use this as an alternative technology for the final drop to premises.

Looking at a 5-year time horizon, from your specific perspective:(1 = zero impact, 5 = high impact)

Answered: 11 Skipped: 4

	1	2	3	4	5	TOTAL	WEIGHTED AVERAGE
How likely and viable is this in urban areas	0.00% 0	36.36% 4	45.45% 5	18.18% 2	0.00% 0	11	2.82
How likely and viable is this in rural areas	50.00% 5	20.00% 2	20.00% 2	10.00% 1	0.00% 0	10	1.90

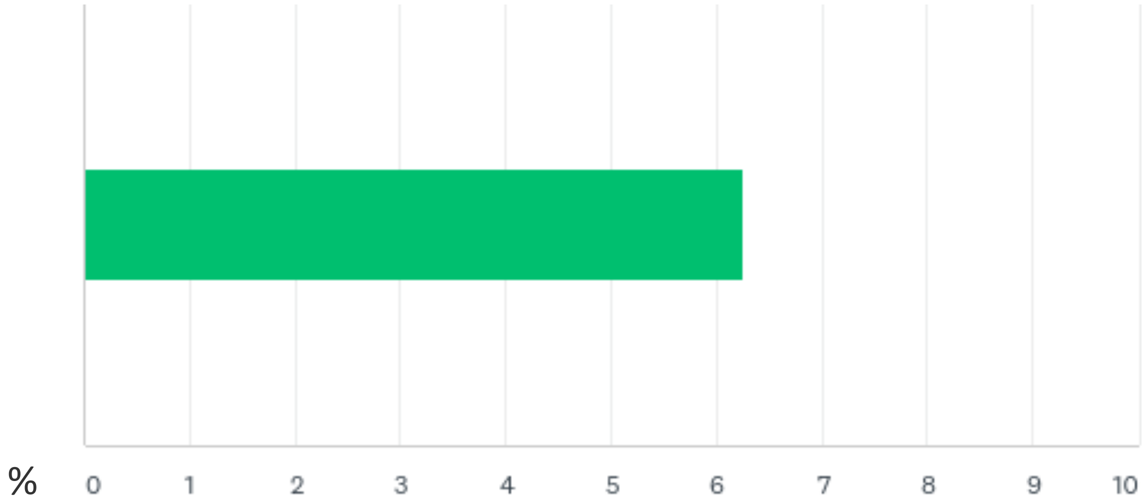


Q119: 5G Access: perceved Capex cost impact

Question
What is the likely cost impact this would have on Capex?

Answered: 8 Skipped: 7

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	6	50	8
Total Respondents: 8			

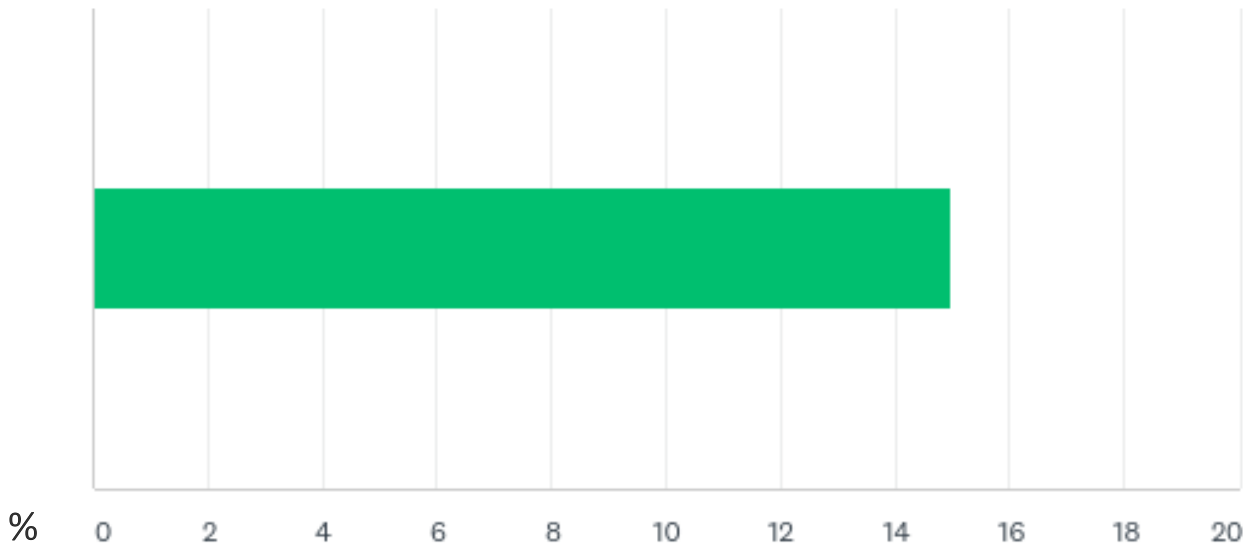


Q120: 5G Access: perceived Opex cost impact

Question
What is the likely cost impact this would have on Opex?

Answered: 6 Skipped: 9

ANSWER CHOICES	AVERAGE NUMBER	TOTAL NUMBER	RESPONSES
	15	90	6
Total Respondents: 6			

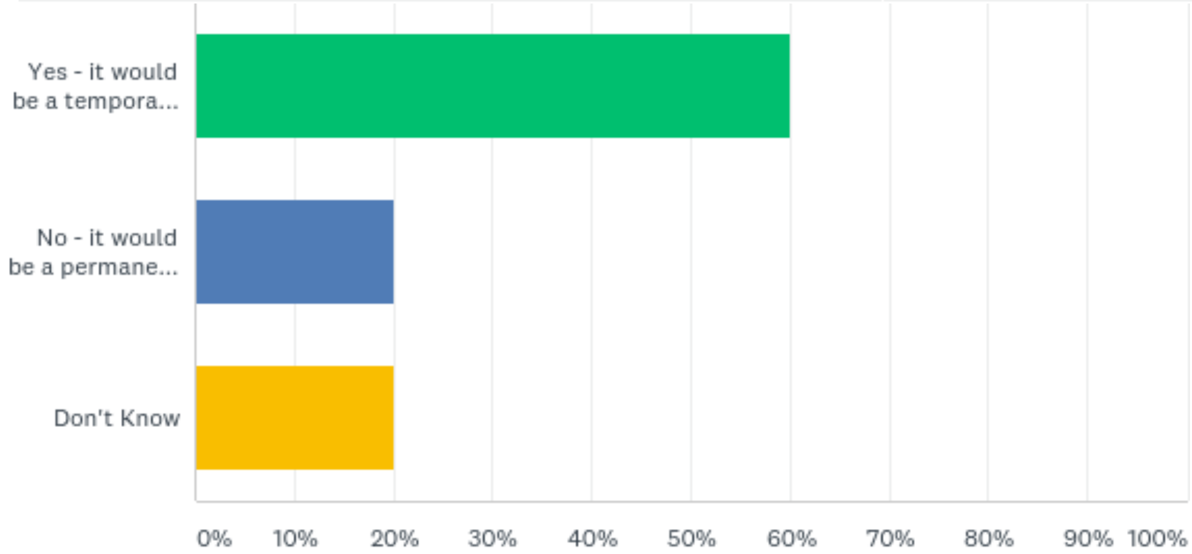


Q121: 5G Access: temporary or permanent solution

Question
Would this be a temporary solution to be replaced by FTTP when economics permit or capacity requires it?

Answered: 10 Skipped: 5

ANSWER CHOICES	RESPONSES	
Yes - it would be a temporary solution	60.00%	6
No - it would be a permanent solution	20.00%	2
Don't Know	20.00%	2
TOTAL		10



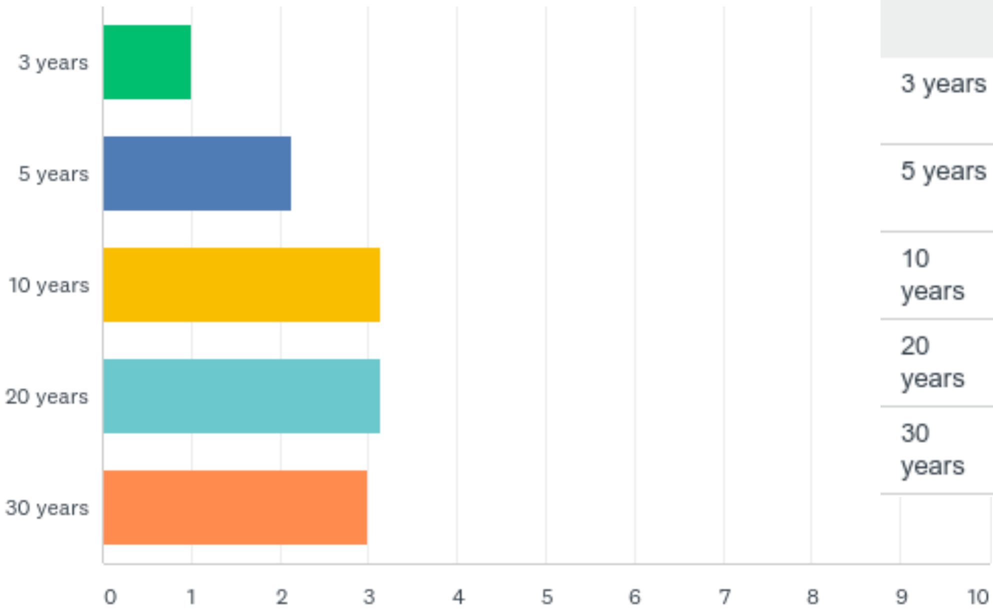
Q122: 5G fixed/mobile convergence: probable timescales- urban

Question

Finally, please give us your opinion on when 5G as a converged mobile-fixed communications technology will have the greatest benefit on infrastructure costs?

Firstly in urban areas (where 1 = No Benefit, 5 = Very Significant Benefit)

Answered: 8 Skipped: 7



	1	2	3	4	5	TOTAL	WEIGHTED AVERAGE
3 years	100.00% 7	0.00% 0	0.00% 0	0.00% 0	0.00% 0	7	1.00
5 years	12.50% 1	62.50% 5	25.00% 2	0.00% 0	0.00% 0	8	2.13
10 years	0.00% 0	14.29% 1	57.14% 4	28.57% 2	0.00% 0	7	3.14
20 years	14.29% 1	0.00% 0	42.86% 3	42.86% 3	0.00% 0	7	3.14
30 years	14.29% 1	0.00% 0	57.14% 4	28.57% 2	0.00% 0	7	3.00

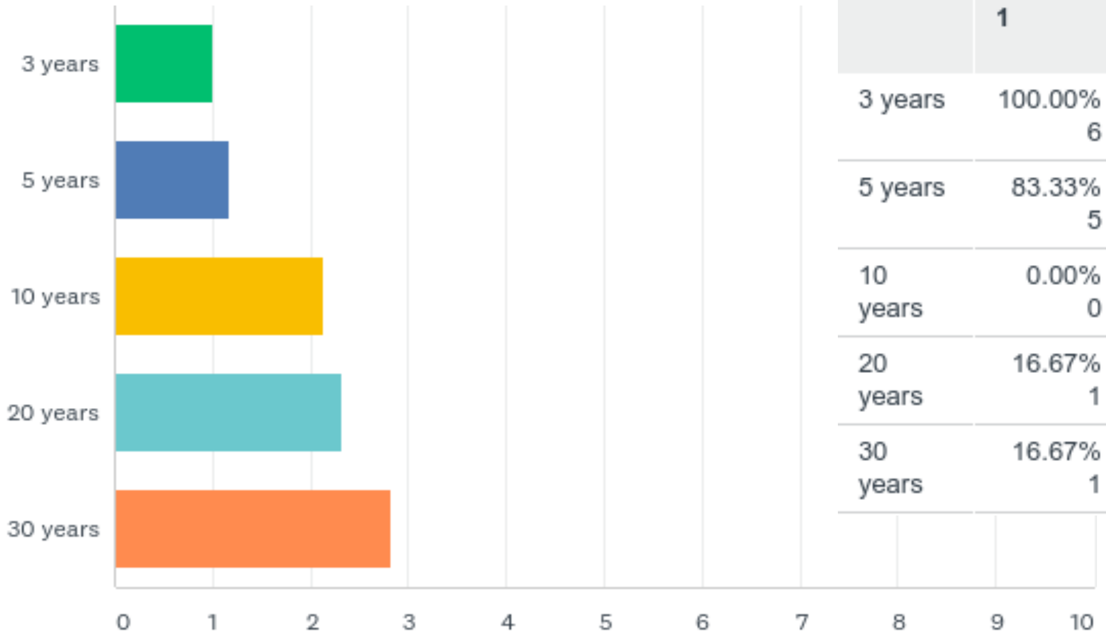
Q123: 5G fixed/mobile convergence: probable timescales- rural

Question

Finally, please give us your opinion on when 5G as a converged mobile-fixed communications technology will have the greatest benefit on infrastructure costs?

Secondly in rural areas (where 1 = No Benefit, 5 = Very Significant Benefit)

Answered: 7 Skipped: 8



	1	2	3	4	5	TOTAL	WEIGHTED AVERAGE
3 years	100.00% 6	0.00% 0	0.00% 0	0.00% 0	0.00% 0	6	1.00
5 years	83.33% 5	16.67% 1	0.00% 0	0.00% 0	0.00% 0	6	1.17
10 years	0.00% 0	85.71% 6	14.29% 1	0.00% 0	0.00% 0	7	2.14
20 years	16.67% 1	33.33% 2	50.00% 3	0.00% 0	0.00% 0	6	2.33
30 years	16.67% 1	16.67% 1	33.33% 2	33.33% 2	0.00% 0	6	2.83

Q124: General feedback

Answered: 4   Skipped: 11

Comments:

1. New commercial models- such as concession contracts for ducts, co-operative organisations for civil and fibre assets, JVs for council assets- all significantly reduce the capital costs of building infrastructure. These need to be encouraged more by policy.

2. As commented, more standardisation on global best practices for design, installation and material technologies, within fibre optic systems. It's no surprise that leaders like Japan, Korea and several northern and eastern European countries have been going full fibre (even Jersey) for decades.

3. The impact of 5G will rely on modifying spectrum policy, so the rollout is not sacrificed by the spectrum fees.

4. 5G should be considered as complementary to FTTP rather than a replacement. Neutral host models will be important - both FTTP and 5G