Report for Broadband Stakeholder Group

The costs and capabilities of wireless and satellite technologies – 2016 snapshot

Final report

26 October 2010

Ref: 14712-432

analysys mason

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Annex A: Key inputs and assumptions

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Foreword

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CEO, Broadband Stakeholder Group

This report aims to inform rather than conclude a debate. The question the Broadband Stakeholder Group asked of Analysys Mason was a simple one: what role could terrestrial wireless and satellite technologies play in delivering ubiquitous next-generation broadband across the UK by 2016? As is the case with most simple questions, developing an answer would prove quite complex. It would require a detailed evaluation of a range of technologies, using different radio frequencies, under a number of different usage scenarios. This in turn would require the development of a complex model underpinned by many detailed technical assumptions that would need to be debated and refined by a BSG steering group comprising industry experts.

The result is a detailed and comprehensive report that we hope provides a significant step forward in helping to understand how fixed and wireless technologies can best be utilised to deliver a truly ubiquitous next-generation broadband Britain. The report does not provide definitive answers about the best technology choices, and indeed we would caution against any such conclusions being drawn. The findings are also very sensitive to the assumptions made about service capabilities, usage levels and technology performance. Finally we should also stress that the report reflects the views of the authors, Analysys Mason, and does not necessarily reflect the views of individual BSG members.

Nevertheless, despite these caveats, a number of important conclusions can be drawn from this important study.

- Firstly, terrestrial wireless and satellite technologies will have an important role to play in delivering ubiquitous next-generation broadband across the UK and should be incorporated into policy thinking about the evolution of the UK's broadband network.

- Secondly, it is likely that they can be deployed more cost-effectively than alternative, fixed-line technologies in some rural areas whilst delivering a quality of service that will address the growing demand for capacity from households and small businesses in the decade ahead.

- Thirdly, the release of additional spectrum and the use of smart technologies to reduce busy-hour traffic, in particular by caching popular video content on digital video recorders (so called 'side-loading') can further reduce deployment costs and increase service capabilities.

I would like to thank Analysys Mason for the considerable time and effort that they have dedicated to this work and the many industry experts who have participated in the BSG Steering Group and given detailed technical input to the project. Whilst it is the oft-stated intent of public policy to be technology neutral, this does not mean that policy should be technology blind. It is the BSG's hope that, as was the case with our earlier work on the costs and capabilities of fibre, this report will help to advance thinking about the evolution of broadband in the UK. Careful reading of this report should help to raise awareness about the many factors that impact upon the cost and performance of wireless and satellite technologies; provide a basis for a more informed comparison of different technologies; and help stimulate a more detailed and nuanced policy debate.

That terrestrial wireless and satellite technologies have an important role to play alongside fixed-line fibre-based technologies should not be a surprise. However, creating an environment that enables this to happen will not be easy. We hope this report will stimulate further discussion about how it can be achieved.

Sponsors

The Broadband Stakeholder Group would like to thank the following companies for helping to fund this study: Avanti, Astrium, BT, Ericsson, Talk Talk and Three.

Steering Group

The following companies and organisations participated in the BSG Steering Group that was set up to support this project: Alcatel Lucent, Avanti, Astrium, BDUK, BT, Cisco, Ericsson, Everything Everywhere, ITV, O2, Talk Talk, Three, UK Broadband and Virgin Media. The Steering Group worked with the BSG Secretariat and Analysys Mason to define the scope of the report and to discuss and refine the major technical and cost assumptions used in the model and final report. The Steering Group members recognise that, given the complexities of modelling the cost and capabilities of wireless technologies, many of the results are highly sensitive to the various input assumptions. The Steering Group did not achieve a complete consensus on all of the modelling assumptions or output results used in the report, however the assumptions used represent the agreed compromise view of the Group for the purpose of enabling the Analysys Mason study work to proceed to closure in the timeframe available. It should be noted that the companies and organisations represented on the Steering Group do not necessarily endorse all the elements or contents of this report and that this study should be viewed as an Analysys Mason report for the Broadband Stakeholder Group.

1 Executive summary

This is the final report of our study for the Broadband Stakeholder Group (BSG) on the costs and capabilities of satellite and a range of terrestrial wireless technologies. It contains the methodology, key input assumptions, results and conclusions of the project.

This study was designed to provide an insight into how satellite and terrestrial wireless technologies can support universal broadband services and next-generation access (NGA) and to compare the costs of these technologies with the costs of fixed fibre-to-the-cabinet (FTTC) and fibre-to-the-home (FTTH) networks, which were the subject of our previous study for the BSG published in 2008[1]. It should be noted that our study did *not* consider the revenues that may be derived from providing NGA services and thus the report does not assess where the provision of satellite and terrestrial wireless services may be commercially viable.

Modelling the cost of satellite and terrestrial wireless networks is far more complex than modelling the cost of fibre networks and the results presented in this report are highly sensitive to the assumptions regarding the level of traffic to be carried. We have addressed this issue by presenting the results for three different traffic scenarios for 2016 based on our best estimates of the likely traffic per household at that time.

The results for terrestrial wireless networks are also highly sensitive to assumptions regarding the radio frequency link budgets and the relationship between typical throughput and theoretical maximum throughput for the different technologies, and also to assumptions about the coverage of areas of difficult terrain and highly variable population density.

In light of these issues, we believe that the results of this study are less clear-cut than the results of the previous fibre study and should be regarded as giving indications of the relative merits of using different technologies (and, in the case of terrestrial wireless, different frequency bands), rather than providing a definitive answer on the 'best' solution for any given situation.

While this report has been prepared on the basis of input from the members of the BSG steering group for this study, the conclusions of the report do not necessarily represent the views of steering group members.

1.1 Basis for terrestrial wireless and satellite costs

Our terrestrial wireless results are based on the cost for a hypothetical operator in the UK deploying a network to provide fixed wireless connectivity. The network has been designed to provide a fixed (rather than mobile) wireless service using high-gain outdoor antennas because this

1 "The costs of deploying fibre-based next-generation broadband infrastructure", Analysys Mason for BSG, September 2008, available at: http://www.broadbanduk.org/component/option,com_docman/task,doc_view/gid,1036/Itemid,63/

allows it to deliver much higher data rates throughout each cell. This is quite a different service proposition to existing mobile broadband services which are designed to work with laptop dongles indoors (albeit with lower data rates and more limited geographical coverage). The network has been designed to serve 99% of the population with a 90-95% probability of fixed wireless coverage (we assume that the remaining homes will be served by other technologies). We assume that our hypothetical operator has a 25% market share of broadband homes within the coverage area.

We have modelled the cost of deploying a hypothetical satellite system covering 100% of the UK land area and thus able to provide service in any location where a clear line of sight is available. The type of satellite under consideration is a high-throughput multi-spotbeam geostationary satellite operating in the Ka band. Avanti Communications and Eutelsat have each announced their intentions to launch such a satellite providing coverage of the UK before the end of 2010 and we understand that both are contemplating launching larger second-generation Ka-band satellites with UK coverage before 2016. Since no other satellite operators have so far announced plans to provide service in the UK, we have assumed that our hypothetical satellite operator has a 50% market share of broadband homes, although to serve this many homes nationwide our hypothetical operator would need to deploy a very large number of satellites.

1.2 Methodology

We have adopted a top-down approach to the modelling, in which we first of all divide the UK into a number of area types (referred to as 'geotypes') on the basis of their population density. We then derive the total deployment costs required to meet a certain level of demand from each geotype with each of the technologies under consideration.

1.2.1 Approach to geotyping

Our geotyping approach is based on a scheme developed for Ofcom by Analysys Mason based on population density (since this typically determines the way that terrestrial wireless networks are planned). The distribution of our geotypes is mapped in Figure 1.1.

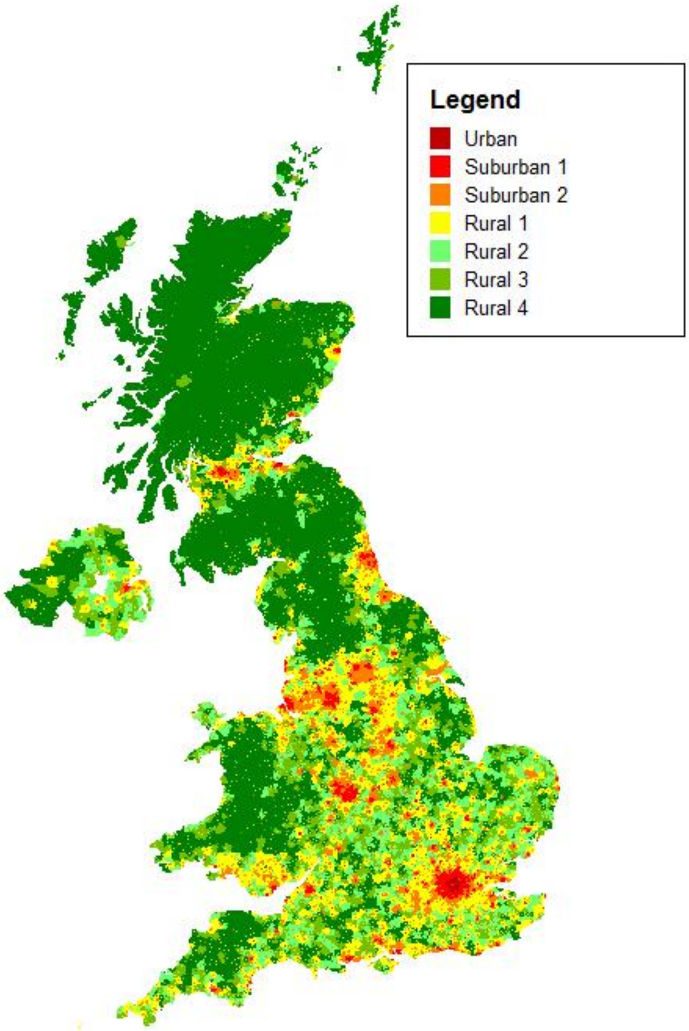

Figure 1.1: UK distribution of geotypes used in this study [Source: Analysys Mason for BSG]

Our earlier fibre costing work used a set of geotypes defined on the basis of BT local exchange size and distance from the local exchange, considerations that are not relevant to the implementation of a terrestrial wireless or satellite network. We have however, compared the way in which the UK area and population are split between the geotypes in the current study against the approach taken in the earlier fibre costing study and there is a good fit, especially in rural areas. Consequently, we believe that the results from the current study provide a meaningful comparison with the results from the previous fibre costing study.

1.2.2 Demand calculation and usage scenarios

To calculate the total demand from each geotype, we aggregate the usage by household and apply a margin calculated to reflect the level of over-dimensioning that will be required in order to achieve satisfactory quality of service.

We have modelled scenarios of low, medium and high usage per household, which we refer to as Scenarios A, B and C respectively. Video traffic accounts for a rapidly rising share of residential broadband traffic, reflecting the popularity of web-based catch-up TV services (like the BBC iPlayer) and video-sharing websites (such as YouTube) and the fact that it requires considerably more bandwidth than most other forms of Internet traffic. We believe that IP-delivered video will be the main constituent of demand by 2016 but we also consider the use of other Internet applications such as Web browsing and email. Note that the resulting usage patterns are highly asymmetric, with far more traffic in the downlink direction than in the uplink direction. As the next section shows, this has implications for the relative cost of deployment using different terrestrial wireless technologies.

Our three usage scenarios can be characterised as follows:

- *Scenario A (mobile broadband evolution)* represents demand in a world in which the retail business model for satellite and terrestrial wireless broadband access is similar to mobile broadband today. Demand is constrained by the existence of prepaid subscriptions and relatively stringent usage caps in monthly pricing plans. The scenario represents our lowest forecast for growth in fixed internet traffic, and also includes reductions to reflect the constraints of the mobile broadband business model (together resulting in annual growth of 28% from 2010 to 2016). Under Scenario A, performance of satellite and terrestrial wireless technology is sufficient to:
  - watch good-quality (i.e. low level of interruption) standard-definition streamed video content (such as YouTube and iPlayer) most of the time
  - enable acceptable, basic, current-technology video conferencing (such as Skype) most of the time
  - provide a good, responsive web browsing experience
  - support email services.

- *Scenario B (fixed broadband evolution)* represents demand in a world in which the retail business model is similar to fixed broadband today. Demand is less constrained than in Scenario A due to large (or unlimited) usage caps and predominantly pay-monthly subscriptions. Scenario B represents our view of the most likely evolution of fixed broadband traffic (including around 40% annual traffic growth from 2010 to 2016), and includes an increasing consumer preference for viewing on-demand content over IP networks (often in high definition). The growth implicit in this scenario appears to be in line with Cisco's Visual Networking Index[2], which is forecasting 39% annual growth in consumer IP traffic in Western Europe from 2009 to 2014 and much faster growth in video traffic.

- *Scenario C (accelerated IP-video evolution)* also represents demand in a world in which the retail business model is similar to fixed broadband today. However, Scenario C considers the impact of an even greater change in consumer behaviour, with a large proportion of the content viewed being on-demand video delivered over IP networks. Almost all TV content is delivered in high definition. Annual traffic growth is around 50% from 2010 to 2016.

[2] Cisco Visual Networking Index: Forecast and Methodology, 2009–2014, available at http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-481360.pdf

1.2.3 Technologies and spectrum bands considered

Figure 1.2 below lists the technologies that we have assumed our hypothetical terrestrial wireless operator can use to provide data services and the amount of spectrum that can be made available for that technology in each frequency band.

Evolved high-speed packet access (HSPA+) is another step in the evolution of the 3G mobile broadband networks that are deployed in the UK. Long-term evolution (LTE) – which is not yet being deployed commercially in the UK but is being rolled out in some other European countries – is a bridge to 4G mobile technologies, and is available in both frequency-division duplex (FDD) and time-division duplex (TDD) variants. IEEE 802.16m WiMAX is the next step in the evolution of today's WiMAX networks (which are mostly based on the IEEE 802.16e standard).

	800MHz	*900MHz*	*1800MHz*	*1800/ 2100MHz*	*2.6GHz*	*3.5GHz*
HSPA+		2×10MHz		2×20MHz		
FDD-LTE	2×10MHz		2×20MHz		2×20MHz	
TDD-LTE					40MHz	50MHz
WiMAX (802.16m)					40MHz	50MHz

Figure 1.2: Assumptions on spectrum usage for terrestrial wireless operator [Source: Analysys Mason for BSG]

Dual-frequency deployments are a possibility in 2016. In the case of HSPA+ we assume that both 900MHz spectrum and 2100MHz spectrum can be used simultaneously. In the case of FDD-LTE we assume that the 800MHz spectrum can be used simultaneously with the 1800MHz or the 2.6GHz spectrum. In the case of TDD-LTE and WiMAX we assume that either the 2.6GHz or the 3.5GHz spectrum is used, but not both together. Dual-frequency deployments may also be able to use other spectrum pairings in practice.

Due to the requirement for different antennas to make use of the different bands, our modelling of dual-frequency deployments assumes that each property only accesses one of the two frequency bands. In practice however, there may be scope to increase the bandwidth for some properties by using both bands simultaneously, but this would bring an associated increase in customer premises equipment (CPE) costs.

Our satellite modelling has focused on the Ka band. We assume that 1GHz will be available in total for the forward link of each satellite and 900MHz in total for the return link.

1.2.4 Network/system dimensioning

Terrestrial wireless networks are typically dimensioned by considering the minimum number of base stations necessary to provide the required degree of geographical coverage, then calculating how much traffic the coverage network can support and comparing this with the expected level of traffic. From this it is possible to determine the number of additional base stations necessary to provide sufficient traffic-carrying capacity. If the coverage network is able to support the expected level of traffic then the network is said to be coverage-driven. If additional capacity base stations are required the network is said to be capacity-driven.

We have used a top-down approach based on link budgets to calculate the coverage and capacity capabilities of each terrestrial wireless technology with adjustments to the required number of coverage sites to take into account difficult terrain and population dispersal.

The dimensioning of our hypothetical satellite system is simpler than the dimensioning of our hypothetical terrestrial wireless networks because each satellite is assumed to deliver a fixed amount of throughput in the downlink and uplink directions, spread across a pre-determined number of spotbeams. We have calculated the coverage and capacity capabilities of the satellite system based on the performance of each spotbeam.

1.2.5 Costs

Having dimensioned our hypothetical terrestrial wireless network and satellite system, we then calculate the total cost of deployment based on information about unit costs that we have derived from equipment vendors and network operators (and supplemented, where necessary, with our own estimates). Deployment costs are based on the expected unit pricing in 2016 but presented in real 2010 terms. We note that in practice procurement will have to take place in advance of deployment.

We have also given some consideration to the ongoing operating costs. Our analysis focuses on the cost of network operation since other costs (such as customer acquisition, customer support, billing and general management overheads) are heavily dependent on the business model adopted by our hypothetical terrestrial wireless or satellite operator. Further details are given in Section 1.3.6.

1.3 Results

1.3.1 Upfront deployment cost per home connected for terrestrial wireless

The average cost per home connected with terrestrial wireless broadband technology is shown in Figure 1.3 below. The results are based on the use of outdoor patch antennas at the customer premises, and at this stage the TDD technologies are assumed to have a downlink to uplink ratio of 2:1, meaning that they provide twice as much capacity on the downlink as they do on the uplink (in theory the FDD technologies provide equal amounts of capacity in each direction).

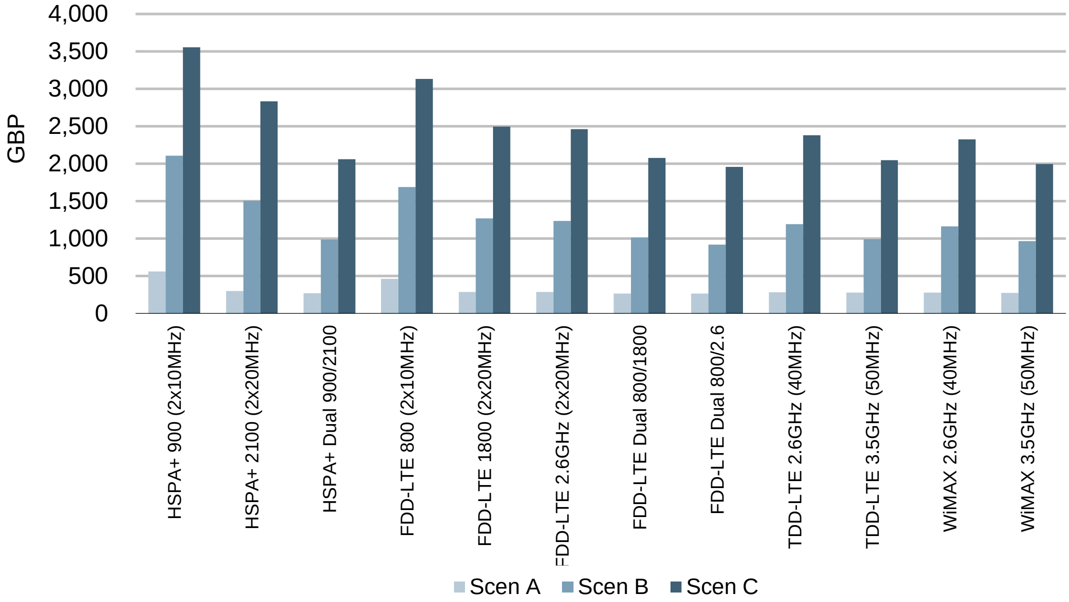

Figure 1.3: Average deployment cost per home connected for terrestrial wireless [Source: Analysys Mason for BSG]

The average cost per home connected ranges from GBP260 to GBP560 in Scenario A, and from GBP920 to GBP2100 in Scenario B. The results at this stage suggest that the lowest-cost technology/spectrum combination is, by a small margin, FDD-LTE deployed on a dual-frequency basis at 800MHz/2.6GHz (although we note this is dependent on a number of key assumptions, as evidenced in the sensitivity testing detailed in the following sections).

Impact of TDD ratio

The results above assume that the TDD technologies have a downlink to uplink ratio of 2:1 but the TDD costs can be reduced by optimising this ratio to more closely match the balance of traffic assumed in our demand scenarios.

Figure 1.4 below shows the upfront deployment cost per home connected with TDD downlink to uplink ratios of 2:1, 3:1, 5:1 and 8:1 under in Scenario B. Results are given for WiMAX at 3.5GHz as our modelling shows that this is the TDD technology with the lowest costs.

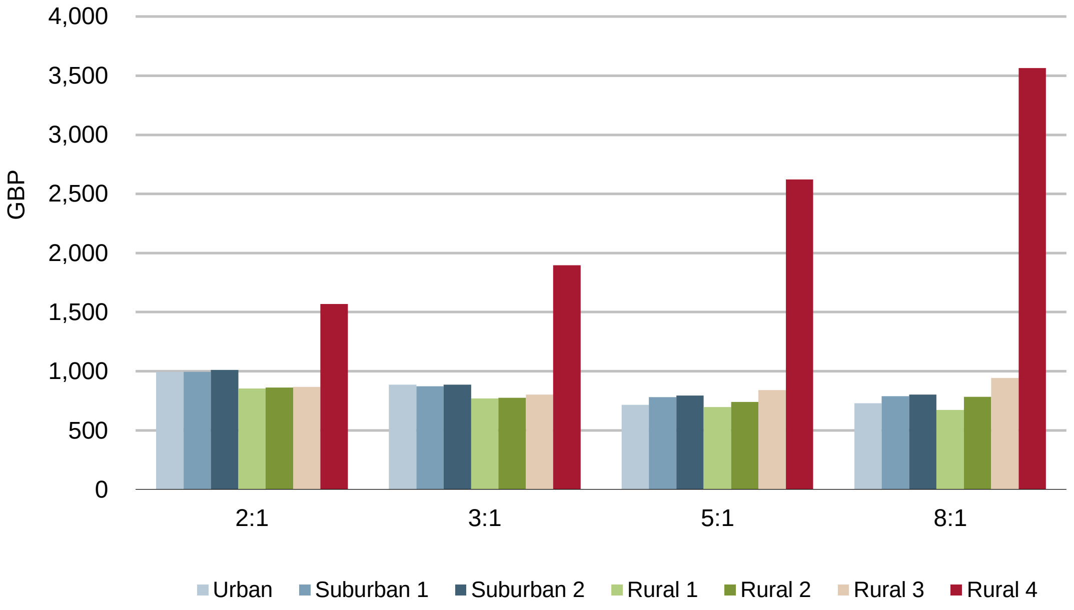

Figure 1.4: *Impact of TDD ratio on deployment cost per home connected for WiMAX at 3.5GHz, Scenario B [Source: Analysys Mason for BSG]*

The results above show that increasing the ratio of downlink to uplink bandwidth reduces the cost per home connected in most geotypes, although in the final geotype (Rural 4) the cost rises markedly as the ratio is increased. Despite the increase in the final geotype the overall TDD deployment cost is reduced by increasing the downlink to uplink ratio and with an 8:1 ratio the cost for WiMAX at 3.5GHz is lower than for FDD-LTE deployed on a dual-frequency basis at 800MHz/2.6GHz.

It should be noted that in terms of technological performance, our modelling suggests that TDD-LTE and WiMAX will be very similar. Our cost data suggests that base station costs for WiMAX may be slightly lower than those for TDD-LTE, which is why the modelling shows WiMAX to be the lower-cost option. However, the two sets of costs are sufficiently similar, and the future demand for both types of equipment is sufficiently uncertain, that in reality either technology could turn out to be the lowest-cost TDD option in 2016.

It should further be noted that if IP traffic flows were to become more symmetric by 2016, then TDD networks may lose some of their advantage. However, we do expect a high level of traffic asymmetry to continue for the foreseeable future.

Impact of type of customer premises equipment

So far our results assume the use of the same fixed wireless CPE in every home comprising a desktop wireless router connected (using multiple co-axial cables) to an outdoor multiple-input, multiple-output (MIMO) patch antenna around 0.3m square that is mounted as high as possible on the roof of the house and pointed towards the nearest base station. Although this CPE configuration gives good performance, the installed cost per home is quite high: the outdoor patch antenna costs more than the router and because it is mounted on the roof we include the cost of professional installation.

We have therefore considered whether the deployment costs can be reduced through the use of alternative CPE offering a different trade-off between installed cost and performance. The other types of CPE considered are:

- *Integrated outdoor*. The active electronics are mounted immediately behind the outdoor antenna in a watertight enclosure and a single Ethernet cable is run from the roof to an indoor Ethernet port. The installed cost for integrated outdoor CPE is even higher than for the standard configuration but the performance is better than our baseline configuration because the radio frequency signal attenuation in the cable between the antenna and the desktop unit is eliminated.

- *Window-mount*. The outdoor patch antenna in the baseline CPE is replaced by indoor patch antenna which is fastened to a window facing the nearest base station using a suction-mount. We assume that this type of CPE can be self-installed so the installed cost is considerably lower. However, the performance is lower than the baseline configuration because the glass attenuates the signal and we assume that the antenna may be mis-pointed by up to 45 degrees because of the orientation of the window relative to the base station.

- *Desktop*. Instead of using an outdoor patch antenna, there are two or four (depending on the frequency band) omni-directional antennas attached directly to the desktop unit. This type of CPE is less expensive than the window-mount but has lower performance so can only achieve the required peak throughput if the subscriber is close to the base station.

- *Dongle*. A USB modem that plugs directly into the subscriber's PC or WiFi router. This type of CPE is the least expensive of all and also has the benefit of being easily portable but can only achieve the required peak throughput if the subscriber is very close to the base station.

- *Yagi*. The outdoor patch antenna is replaced by an outdoor Yagi antenna, similar in design to a terrestrial TV aerial. A Yagi antenna can have higher gain than a patch antenna but we assume that there is no MIMO operation, since this would require multiple antennas with a precise separation which could be difficult to achieve.

Figure 1.5 compares the costs by geotype for the lowest-cost technology option using our baseline CPE ('all outdoor') with the equivalent costs using all integrated outdoor CPE, all window-mounted CPE and several combinations of CPE types. The lowest-cost option is a combination of dongles, desktop CPE and integrated outdoor CPE. A separate calculation shows that the best cost/performance trade-off is obtained by deploying dongles in premises up to 400m from the base station, desktop CPE in premises between 400m and 500m from the base station, and integrated outdoor CPE in the rest of the cell.

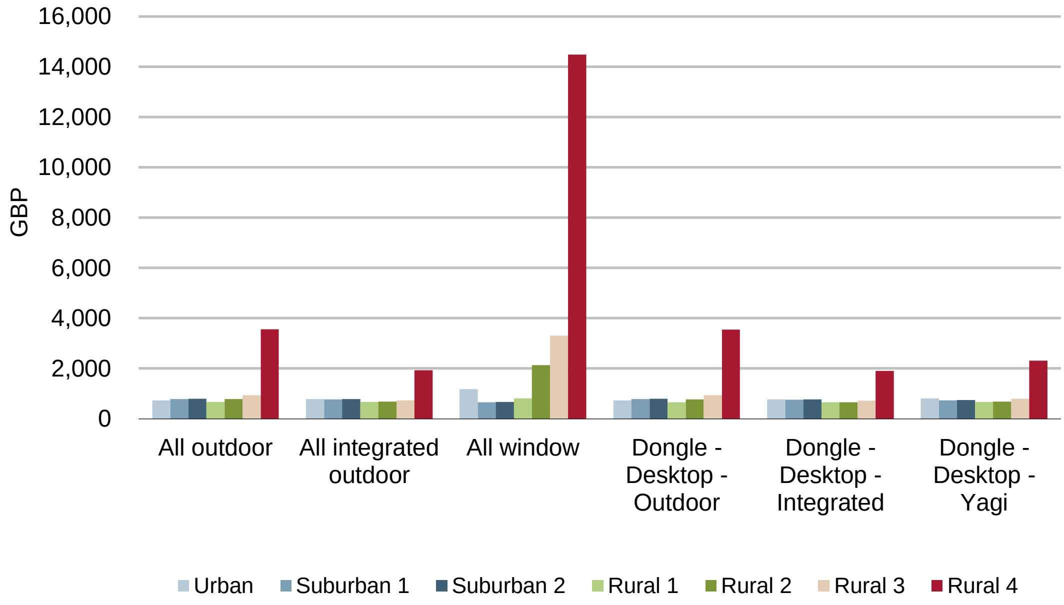

Figure 1.5: Impact of different types of CPE for terrestrial wireless on deployment cost per home connected (Scenario B, WiMAX 3.5GHz 8:1) [Source: Analysys Mason for BSG]

1.3.2 Upfront deployment cost per home connected for satellite networks

The upfront deployment cost per home connected for satellite under the three demand scenarios is shown in Figure 1.6 below. As satellite operators consider deployment business cases on a national basis, we have averaged the cost across all geotypes.

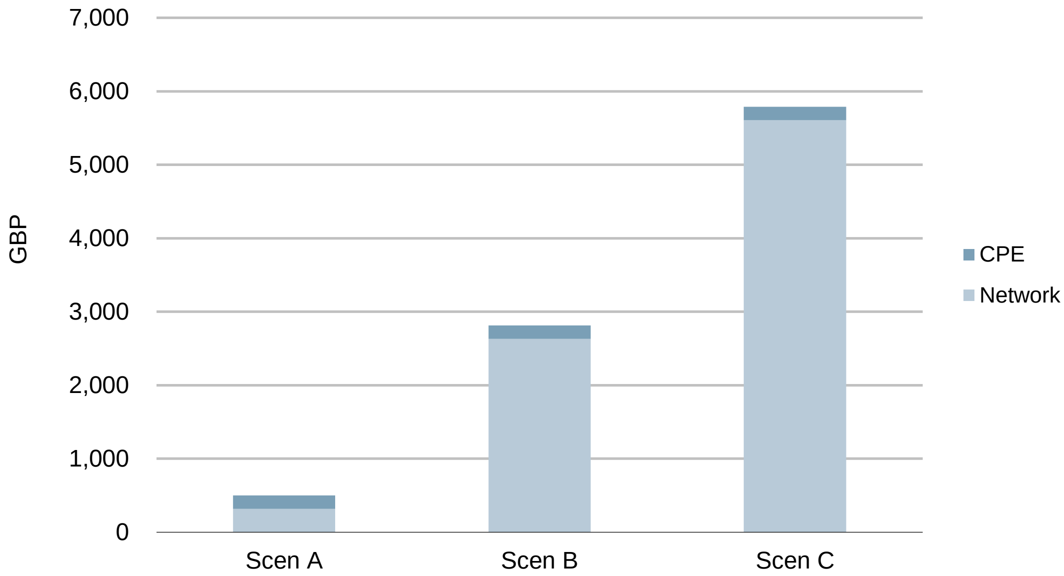

Figure 1.6: Deployment cost per home connected for satellite [Source: Analysys Mason for BSG]

The cost per home connected for satellite is GBP500 in Scenario A, GBP2800 in Scenario B and GBP5800 in Scenario C. In Scenarios B and C the costs are dominated by the network costs, of which the principal component is the cost of building and launching the satellites.

1.3.3 Total deployment requirements in the 'final third'

In order to consider realistic deployment scenarios for both terrestrial wireless and satellite networks, we have modelled the total deployment costs for different combinations of the rural geotypes, which add up to roughly the 'final third' of UK homes (i.e. those areas where fixed NGA appears unlikely to be provided without some form of public intervention).

We have considered the cost of deploying a terrestrial wireless network and a satellite network on a standalone basis. We have assumed that those homes served by wireless have a choice of four operators and those homes served by satellite have a choice of two operators and we have further assumed that the competing operators achieve equal market shares. This means that our hypothetical terrestrial wireless operator serves 25% of broadband homes but our hypothetical satellite operator serves 50% of broadband homes. To ensure a like-for-like comparison, the results in this section are scaled up to show the cost for each type of operator to serve all broadband homes in the final third.

The total deployment costs for different combinations of geotypes in the final third for a hypothetical terrestrial wireless operator using the lowest-cost technology option are shown in Figure 1.7 (percentages in brackets show the proportion of the total UK population in each combination of geotypes).

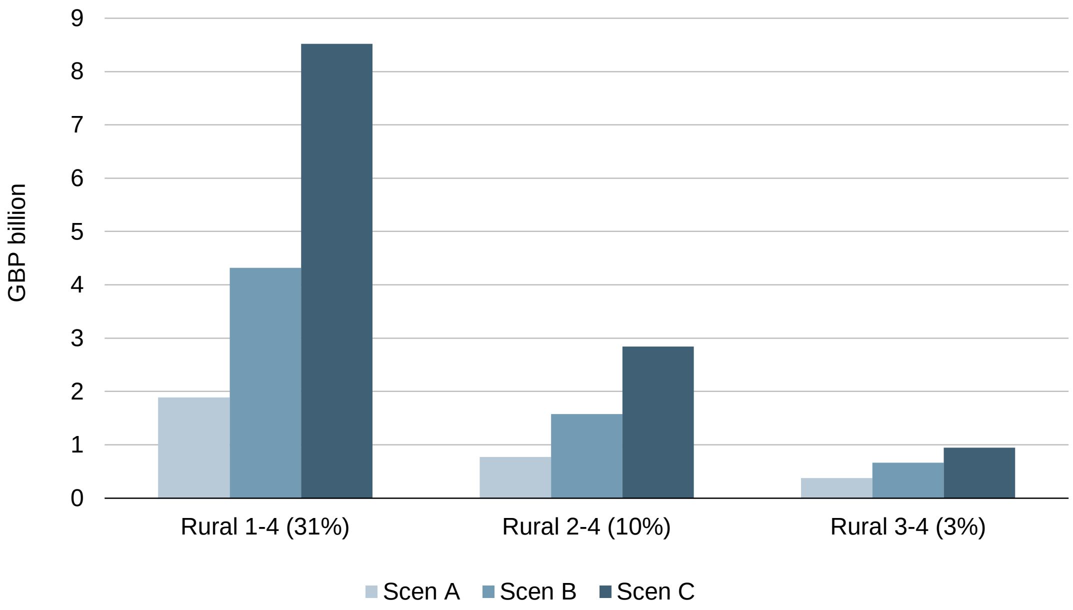

Figure 1.7: Total upfront terrestrial wireless deployment costs for the final third (WiMAX 3.5GHz 8:1, dongle/desktop/integrated outdoor CPE) [Source: Analysys Mason for BSG]

The deployment costs follow a similar profile to the required number of sites. For a terrestrial wireless operator to support the demand from all rural geotypes would cost between GBP1.9 billion and GBP8.5 billion depending on the demand scenario. Supporting the final 10% of homes would cost GBP0.8 billion to GBP2.8 billion, while supporting the final 3% of homes would cost GBP0.4 billion to GBP0.9 billion (again depending on demand scenario).

The equivalent costs for a hypothetical satellite operator are shown in Figure 5.20.

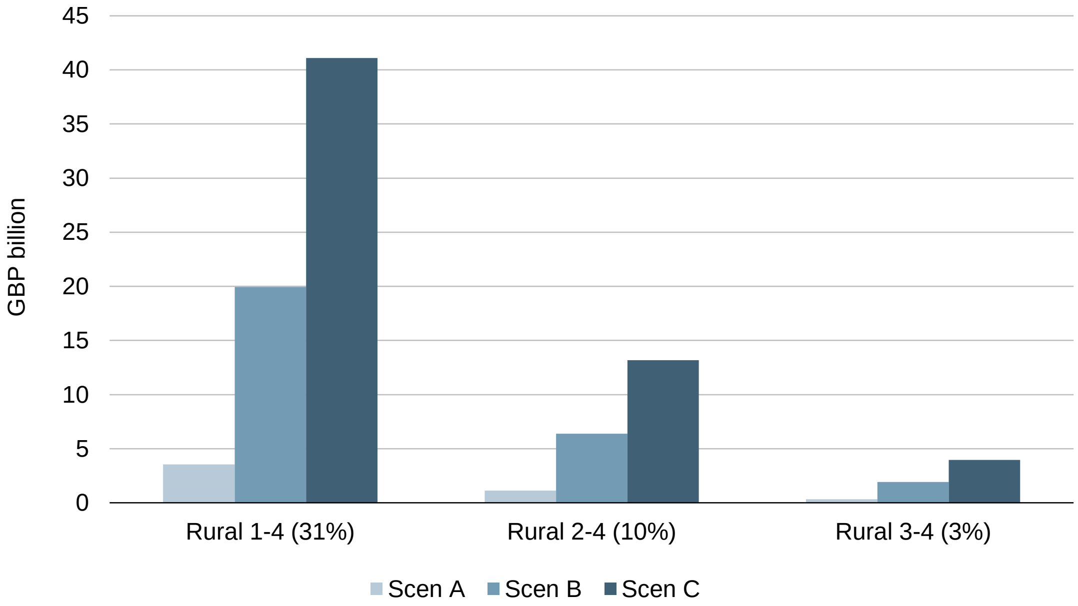

Figure 1.8: *Total upfront satellite deployment costs for the final third [Source: Analysys Mason for BSG]*

For a satellite operator to support the demand from all rural geotypes would cost between GBP3.6 billion and GBP41.1 billion depending on the demand scenario. Supporting the final 10% of homes would cost GBP1.1 billion to GBP13.2 billion, while supporting the final 3% of homes would cost GBP0.3 billion to GBP4.0 billion (again depending on demand scenario). It should however, be noted that with our baseline satellite configuration a very large number of satellites would be required to support all the rural geotypes in Scenario A, or any combination of the rural geotypes in Scenarios B and C and it would, in practice, be difficult or impossible to deploy this many satellites. In reality, if satellite technology were chosen to support a large level of demand in the rural geotypes, then higher-capacity satellites incorporating a larger number of smaller spotbeams would almost certainly be developed. Such higher-capacity satellites could be expected to have a lower cost per spotbeam than we have modelled.

1.3.4 Assessment of deployment costs

The preceding results suggest that WiMAX at 3.5GHz with a downlink to uplink ratio of 8:1 and dongle/desktop-integrated CPE is the lowest-cost technology option. In practice, however, we do not believe it is possible to state categorically that there is a clear winner among the terrestrial wireless technologies that we have considered. As previously noted, the cost and performance of TDD-LTE and WiMAX technologies appear to be very similar, and dual-frequency FDD technologies may also be able to deliver equivalent broadband services at broadly similar cost. Satellite appears to be uniformly more expensive than terrestrial wireless in terms of cost per home connected, but we believe it still has a useful role to play in serving the areas where we assume terrestrial wireless will not be deployed and also serving premises located in 'notspots' within the terrestrial wireless coverage area.

1.3.5 Spectrum costs

We have not included the cost of spectrum in any of our calculations since it is difficult to determine an appropriate set of costs with accuracy and confidence. At present there are two distinct pricing regimes for terrestrial wireless spectrum in the UK depending on whether or not the spectrum was originally allocated by auction:

- For spectrum that has been auctioned there are no additional fees to pay during the initial period of the licence, which is typically 20 years.
- For spectrum that has not been auctioned an annual fee is payable based on an administrative incentive pricing (AIP) calculation determined by Ofcom, based on the opportunity cost of spectrum.

The 2100MHz and 3.5GHz bands have already been auctioned. The 2100MHz licensees paid a total of GBP22.5 billion in 2000 for licences lasting until 2021, while the 3.5GHz licensees paid GBP7 million in 2003 (with a further GBP7 million payable in 2008 and 2013 for two available five-year extensions). These are however, sunk costs and it is not clear how they should be allocated (if at all) to future services. The 800MHz and 2.6GHz bands will be released for commercial use by means of an auction, but this is not expected to take place before 2011 and it is difficult to predict what the outcome will be in advance.

The 900MHz and 1800MHz bands are subject to the AIP regime but in July 2010 the Government proposed to direct Ofcom to determine revised AIP fees for these bands and thus the future level of charges is unclear at the time of writing.

As a potential indicator, an FDD spectrum auction was concluded in Germany in May 2010. We have calculated the cost of the spectrum used in our model if the price per MHz per head of population in the UK was the same as in the German auction.

The indicative spectrum cost per home connected is around GBP10 in the case of 1800MHz and 2.6GHz spectrum (which would have a negligible impact on total deployment costs), around

GBP50 in the case of 2100MHz FDD spectrum (which would have some impact, though not enough to significantly alter our results) and around GBP150 in the case of 800MHz spectrum (which would make the use of 800MHz spectrum look even less attractive than it does in our base case results).

Terrestrial wireless operators will also have to pay for the spectrum used to provide microwave backhaul but we have also ignored these costs because they are not large enough to have a material impact on our results.

Satellite operators do not currently pay for their spectrum in the same way that terrestrial wireless operators do (although there is a small annual administrative charge for the spectrum used by a satellite gateway). We do not expect this situation to change in the foreseeable future and therefore we do not believe that spectrum costs are relevant to the deployment costs for satellite.

1.3.6 Operating costs

Our study is focused mainly on the costs of deploying communications networks, but we have also undertaken a high-level analysis of the ongoing cost of network operation. We have not considered operating costs for customer acquisition, customer support, billing and general management overheads.

For consistency, Figure 1.9 shows our estimate of the annual network operating cost per home connected for the terrestrial wireless technology which had the lowest deployment costs in our model (a WiMAX network at 3.5GHz) although we note that the dual-frequency FDD LTE option requires slightly fewer sites and thus has slightly lower operating costs.

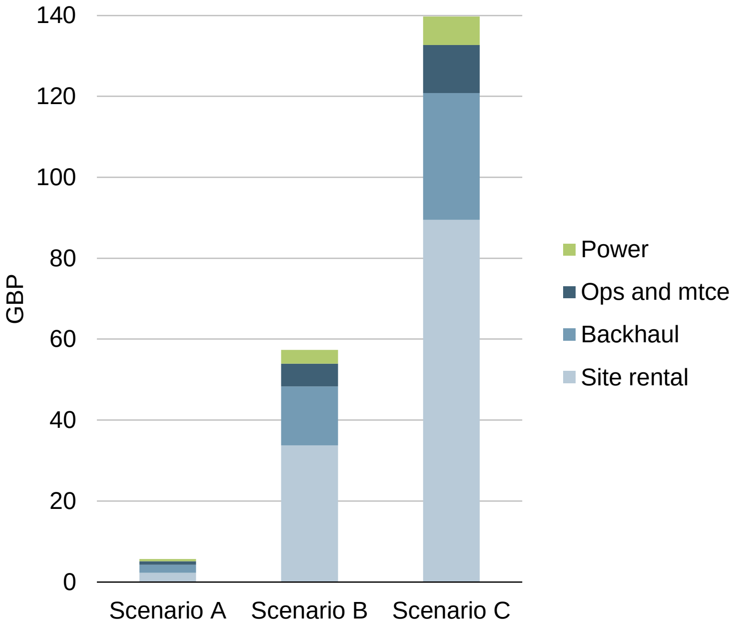

Figure 1.9: Annual network operating cost per home connected for WiMAX 3.5GHz 8:1, dongle/desktop/ integrated outdoor CPE [Source: Analysys Mason for BSG]

We estimate the annual operating cost per home connected to be around GBP6 in Scenario A, GBP57 in Scenario B and GBP140 in Scenario C.

Our estimated annual operating cost per home connected for satellite is considerably lower at around GBP3 in Scenario A, GBP18 in Scenario B and GBP38 in Scenario C (see Figure 1.10). The annual operating cost for satellite is 46% of the equivalent cost for terrestrial wireless in Scenario A, 31% in Scenario B and 27% in Scenario C.

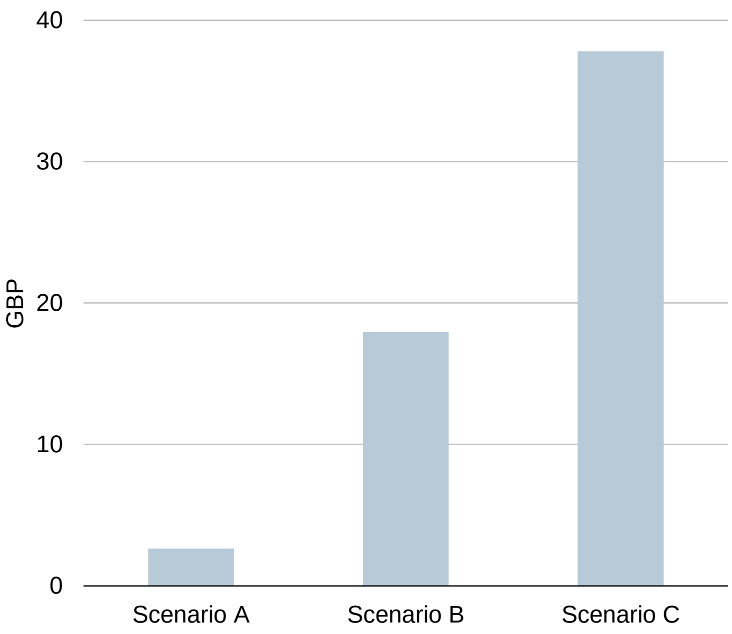

Figure 1.10: Annual network operating cost per home connected for satellite [Source: Analysys Mason for BSG]

Over a ten-year period the operating costs for satellite (without taking any account of the time value of money) would be around GBP30 lower per home connected than terrestrial wireless in Scenario A, GBP400 lower in Scenario B and GBP1000 lower in Scenario C. This partially offsets the additional deployment costs of satellite but the saving is not sufficient to make satellite a less expensive option overall.

1.4 Conclusions

1.4.1 Economics of terrestrial wireless and satellite broadband networks

While the costs of the fibre networks considered in our previous study remain broadly unchanged for a wide variation in the level of traffic per subscriber, the costs of terrestrial wireless and satellite broadband networks are highly dependent on the peak traffic loading. At the levels of demand being considered in this study, throughput factors (such as the amount of spectrum available and the MIMO schemes that can be used) have a much larger impact on the cost of terrestrial wireless networks than the coverage factors (such as the improved propagation at lower frequencies). Satellite technology is inherently capable of providing wide geographical coverage at relatively low cost per home so the overall cost per home connected for a satellite system is almost invariably determined by throughput factors.

1.4.2 Bandwidth required per home

There are large differences in the *average* busy-hour bandwidth required per home in our three scenarios: Scenario A requires 85kbit/s, Scenario B requires 700kbit/s while Scenario C requires 1.5Mbit/s. These differences reflect the current uncertainty over future demand that exist within the broadband community.

However, the *peak* bandwidth demand per home in all of our scenarios is assumed to be driven by the number of simultaneous video streams that a household may consume. We have assumed that the maximum average bandwidth requirement per home is that which is needed to deliver 2.3 video streams. Scenario A assumes that all streamed services are in standard definition (SD) which gives a maximum bandwidth of 4.6Mbit/s per household. Scenarios B and C assume that viewing is in high definition (HD), which gives a maximum bandwidth of 18.9Mbit/s per home. We therefore believe this that, despite the uncertainty over the *average* bandwidth required per home, there is no pressing need to implement technologies that can deliver significantly in excess of 20Mbit/s *peak* bandwidth per home before 2016.

Another consequence of assuming that video streaming will be the main driver of demand is that the bandwidth requirement is highly asymmetric. The trend in ADSL since its launch has undoubtedly been towards more asymmetric services: whereas the original 512kbit/s ADSL services typically offered headline upstream speeds of 128kbit/s (a downstream to upstream ratio of 4:1), the latest 20Mbit/s services typically offer headline upload speeds of 1Mbit/s (a downstream to upstream ratio of 20:1). Among existing residential applications, only HD video calling and some forms of online gaming require high upstream bandwidth. If these applications become very popular in the future then it is conceivable that residential demand may be more symmetric in the future, but we believe that this is highly unlikely. Our modelling therefore assumes that fully symmetric services will not be required by more than a small minority of residential users.

1.4.3 Cost of deploying terrestrial wireless in different frequency bands

In Scenarios B and C the network dimensioning is almost entirely capacity-driven in all geotypes, i.e. the size of the cells is determined by the amount of traffic that each cell needs to carry, rather than the maximum coverage that can be achieved with the chosen technology.

In our model the 800/900MHz technologies have much lower capacity per cell. This is mostly because we assume that our hypothetical operator only has access to 2×10MHz of spectrum at 800/900MHz (compared with 2×20MHz at the higher frequencies) but also, to a lesser extent, because we assume that physical constraints will limit the use of MIMO to two antennas per CPE device in this band (compared with four at the higher frequencies)[3]. Consequently, the 800/900MHz deployment costs look high compared to the costs for the higher frequency bands.

The conventional wisdom in the wireless industry is that low-frequency spectrum is much more valuable than high-frequency spectrum. While this is undoubtedly true when networks are predominantly coverage driven (since the extra range of low-frequency spectrum allows a given area to be covered with fewer base stations), our study suggests that for capacity-driven networks the relative abundance of high-frequency spectrum means that the latter may be a better choice. This is especially true if our assumption that more sophisticated forms of MIMO can be deployed at the higher frequencies is correct. If the demand for wireless data in 2016 does, in fact, approach the levels implied in our Scenario B then we believe the amount of spectrum available for broadband services will prove to be more important than the band in which it is available, and we might therefore expect to see a reduction in the premium attached to low-frequency spectrum. It should be noted that this study has been based on deployment of a fixed wireless network using outdoor antennas, and that the results for value of spectrum for a network focused on mobile indoor coverage may be different.

As discussed above, our assumption that the traffic profile is highly asymmetric results in lower costs per home connected for TDD technologies than for FDD technologies. Historically, TDD spectrum has tended not to be valued as highly as FDD spectrum but if there is high demand for terrestrial wireless data traffic in 2016 and the profile is as asymmetric as our analysis indicates, this discount may be eroded in the future.

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3 While a four-antenna array designed for the 800/900MHz bands could, in principle, be deployed at customer premises, we believe that size constraints could limit the available gains and therefore we have assumed that that modelling the use of two-antenna arrays at 800/900MHz is a suitable approach. We note that MIMO is a complex area that would benefit from further advanced simulations and trials.

1.4.4 Cost of deploying satellite

Figure 1.11 shows that the deployment cost per home connected is significantly higher for satellite than for terrestrial wireless although this is partially offset by lower operating costs.

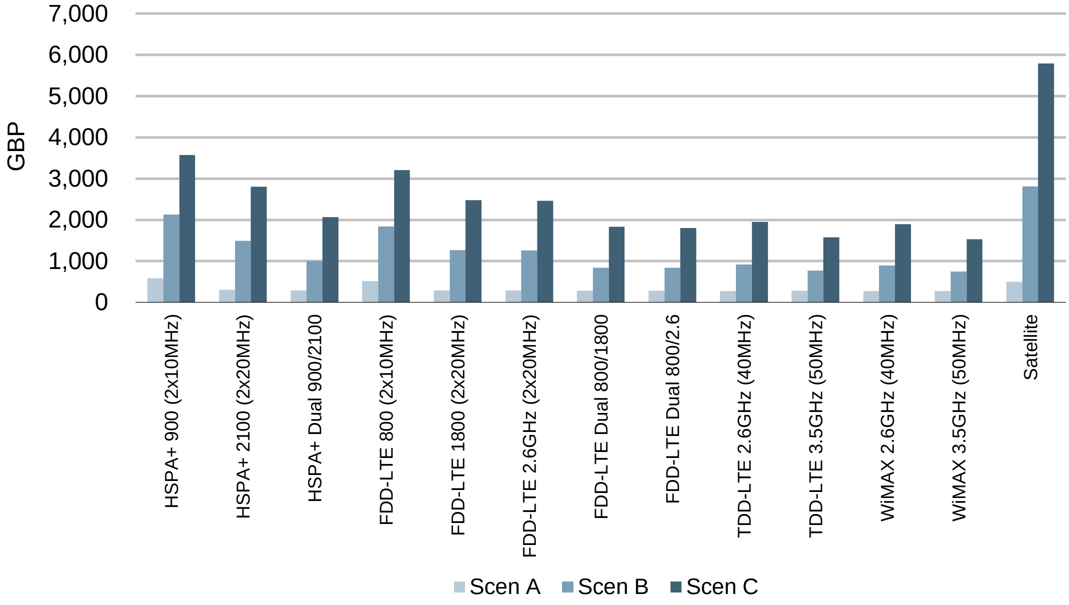

Figure 1.11: Comparison between terrestrial wireless and satellite deployment costs per home connected [Source: Analysys Mason for BSG]

It should however, be noted that even in a largely terrestrial wireless network some premises will still need to be served by other means for two reasons:

- First, it is unlikely to be economically viable to build a terrestrial wireless network that covers 100% of the UK land area (our model assumes 100% coverage of the urban geotypes, 99% population coverage of the suburban geotypes and 98% population coverage in the rural geotypes).
- Secondly, even within the planned coverage area of the terrestrial wireless network some premises will be in dead zones where the wireless signal is not available (sometimes referred to as 'notspots'). These notspots can result from natural features (e.g. dips in the terrain) or man-made obstructions (e.g. tall buildings which prevent the signal from reaching premises in their shadow) and are found throughout the UK. Mobile wireless networks are typically planned to offer 90% probability of coverage (i.e. no more than 10% of premises are in notspots). The probability of coverage for a fixed wireless network of the type we are considering is likely to be higher due to the ability to site CPE in the optimum location and use outdoor antennas where necessary. We believe it would be reasonable to assume that a single network would provide service to a maximum of 95% of premises within its coverage area, although this proportion is likely to rise a little if there are two or more competing infrastructures using different base station sites.

Within the context of this study, we assume that satellite will be used to serve the premises that cannot be served by terrestrial wireless. Taking both coverage and notspots into account, our model assumes that satellite will be used to serve 6% of premises nationally and 7% of premises in rural areas.

1.4.5 Comparison of terrestrial wireless and satellite deployment costs with fibre

Figure 1.12 and Figure 1.13 compare the deployment cost per home connected for satellite and the lowest-cost TDD and FDD terrestrial wireless technologies identified in this study (all based on 80% take-up among homes covered) with the equivalent results for the lowest-cost fibre technology in our previous study.

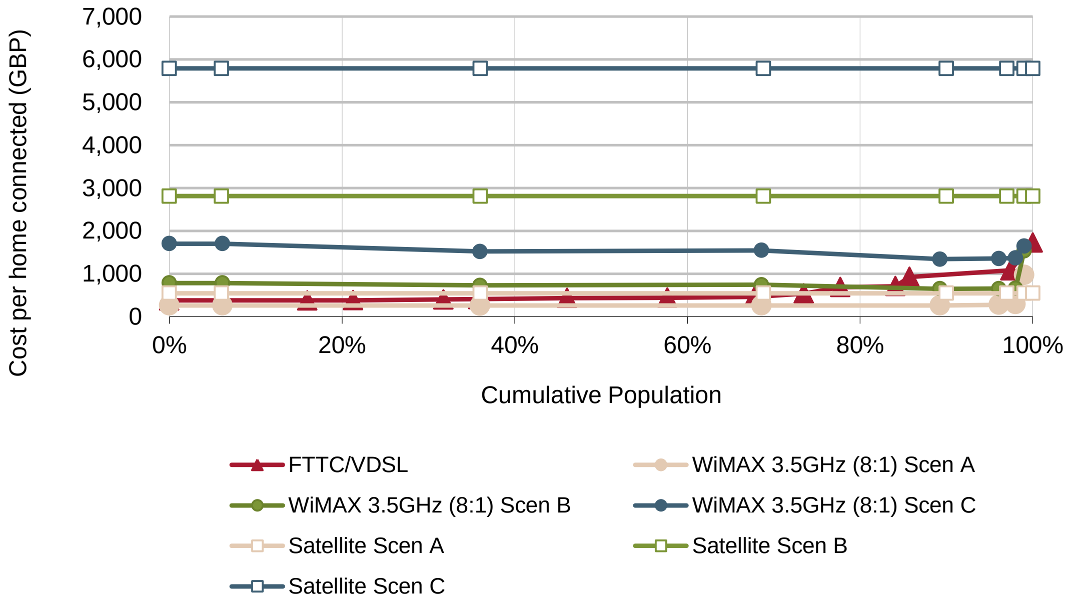

Figure 1.12: Comparison between TDD terrestrial wireless and satellite deployment costs per home connected and the equivalent fibre costs [Source: Analysys Mason for BSG]

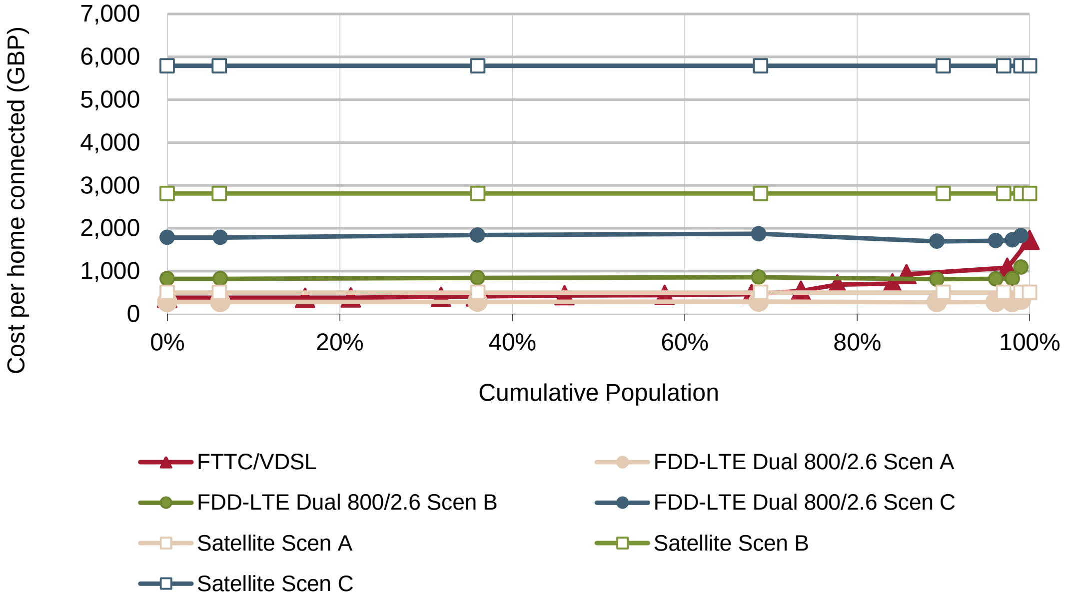

Figure 1.13: Comparison between FDD terrestrial wireless and satellite deployment costs per home connected and the equivalent fibre costs [Source: Analysys Mason for BSG]

Figure 1.14 and Figure 1.15 present the same comparisons, but focusing on the final third and deployment costs of up to GBP3000 per home connected.

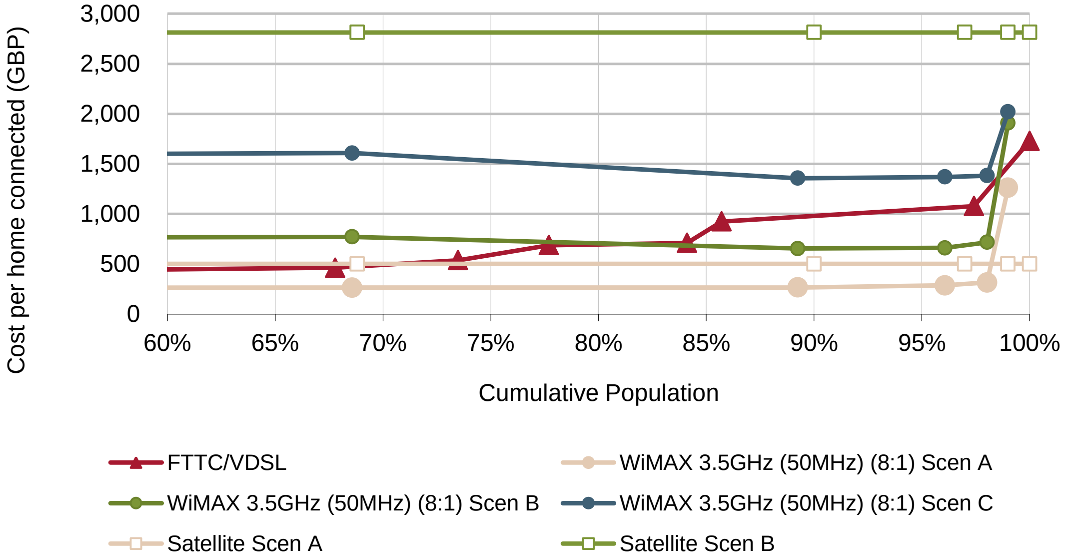

Figure 1.14: Comparison between TDD terrestrial wireless and satellite deployment costs per home connected and the equivalent fibre costs [Source: Analysys Mason for BSG]

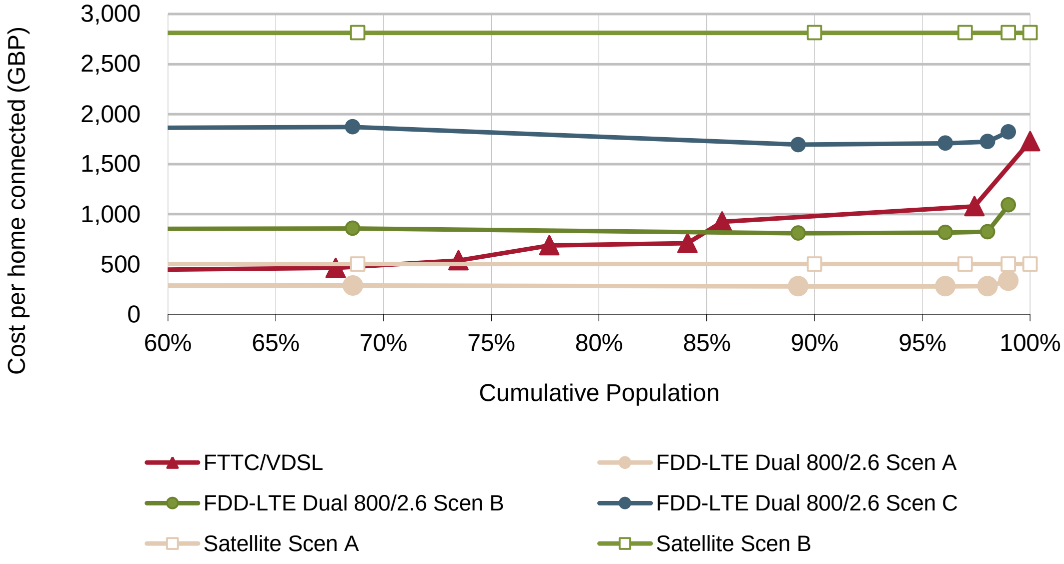

Figure 1.15: Comparison between FDD terrestrial wireless and satellite deployment costs per home connected and the equivalent fibre costs [Source: Analysys Mason for BSG]

Whereas the fibre costs rise quite steeply for the final third of UK homes, the terrestrial wireless costs remain broadly similar across all but the most rural geotype (Rural 4) and the satellite costs are identical. TDD terrestrial wireless technologies are less expensive than FDD technologies in most geotypes but FDD technologies are less expensive in the most rural geotype. Our modelling shows that in Scenario A terrestrial wireless is cheaper to deploy than FTTC/VDSL, but this result must be interpreted carefully since in this scenario the terrestrial wireless network is dimensioned to support peak download rates of 4.6Mbit/s per home, which is significantly lower than that offered by FTTC/VDSL.

Scenario B, with its peak download rate of 18.9Mbit/s per household can more reasonably be compared with FTTC/VDSL and here our modelling suggests that terrestrial wireless may generally be less expensive for the final 15% of homes (although TDD technologies appear more expensive than FTTC/VDSL in the most rural geotype). It also suggests that terrestrial wireless is more expensive than FTTC/VDSL across almost all geotypes in Scenario C (in each case, the two most rural wireless geotypes are slightly cheaper than the most rural fibre geotype). For any given scenario, the cost per home connected for satellite is always higher than the equivalent cost for terrestrial wireless but, as discussed in the previous section, our model assumes that satellite is still used in areas not covered by terrestrial wireless and notspots within the coverage area of terrestrial wireless.

It is important to note that, although in Scenario B the cost of deploying terrestrial wireless technology in rural areas looks attractive compared to FTTC/VDSL, the latter may provide a greater degree of future-proofing. Our hypothetical terrestrial wireless networks have been dimensioned to support exactly the amount of traffic expected in each scenario in 2016. If the bandwidth required by each household continues to grow then new base stations would need to be added continuously to keep up with demand. A network based on FTTC/VDSL, by contrast, is likely to offer a certain amount of headroom to support future traffic growth depending on the lengths of the VDSL sub-loops. If the sub-loops are capable of supporting higher speeds than the 20Mbit/s peak bandwidth required in Scenarios B and C it may be that once FTTC/VDSL has been deployed in a particular area, further investment will not be required for a considerable number of years. If this is the case, it may be more cost-effective in the long term to deploy FTTC/VDSL in some areas where our 2016 snapshot implies that terrestrial wireless is a lower-cost option.

1.4.6 Implications for multiple infrastructures

In our previous fibre costing work, we concluded there are likely to be large areas of the UK where there is a single provider of fibre-based NGA but we believe that the economics of terrestrial wireless deployment (particularly in Scenarios B and C) may be such that two or more infrastructure-based players can continue to co-exist.

There are large economies of scale in *coverage-driven* wireless networks, where the lowest-cost option is clearly to have a single network of base stations shared by all operators. It is this logic that has driven T-Mobile and Three to implement network sharing in the UK and O2 and Vodafone to set up a pan-European network sharing programme called Cornerstone.

However, the results from our modelling suggest that by 2016 terrestrial wireless networks may be almost entirely *capacity-driven*. The economies of scale in capacity-driven networks are much more limited than they are in coverage-driven networks since the total number of base stations needed is independent of the number of operators, so long as each operator has sufficient spectrum to operate the maximum channel bandwidth defined in the relevant standards.

Since Orange is now merging with T-Mobile, it appears as if there may only be two distinct FDD wireless infrastructures in the UK by 2016: one used by Orange, T-Mobile and Three and a second used by O2 and Vodafone. If terrestrial wireless networks are largely capacity-driven in 2016 (as our model suggests), the savings that could be achieved by subsequently moving from two infrastructures to one appear to be quite small. Indeed, from a consumer perspective, these cost savings may be outweighed by the increased efficiency that results from competition between the two operators.

With fewer terrestrial wireless infrastructures in the future, the level of churn between infrastructures will also be reduced. We understand that in the past high level of churn by mobile broadband subscribers has been one of the factors that has discouraged operators from rolling out wireless broadband coverage faster in rural areas. If churn between infrastructures is reduced we believe that the terrestrial wireless operators may have a greater incentive to extend their rural broadband coverage.

With regard to competition between Ka-band satellite operators, so long as Hylas-1 and KA-SAT are both launched successfully, the UK is likely to see Avanti Communications competing with Eutelsat from 2011 onwards.

1.4.7 Opportunities for reducing deployment costs

We see two major opportunities for reducing the deployment costs from the levels in our base case:

- release of additional spectrum for terrestrial wireless and satellite communications
- reducing demand in the busy hour, especially by caching popular video content on digital video recorders (so-called ‘sideloading’).

Access to additional spectrum

The deployment cost in a capacity-constrained terrestrial wireless network is highly dependent on the amount of spectrum available to the network. As such, for a given demand scenario, an increase in the amount of spectrum allocated to a network in a given frequency band can be expected to reduce the deployment cost per home connected, even when additional spectrum fees are taken into account. Although the UK’s five mobile licensees already have substantial paired spectrum holdings at 900MHz, 1800MHz and 2100MHz, they are constrained in their ability to use them to support new high-speed terrestrial wireless broadband services by the need to support existing services.

The planned allocation of the new 800MHz and 2.6GHz frequencies will alleviate the shortage of terrestrial wireless spectrum to some extent; however if additional spectrum were to be made available then costs could be reduced below the level that we have estimated in our base case. Similarly, if a satellite itself is not power-limited then for a given demand scenario increasing the size of the spectrum block allocated to satellite will reduce costs.

Figure 1.16 illustrates the effect of increasing the amount of spectrum allocated for broadband services by showing the reduction in the cost per home that would result from a doubling of the spectrum allocated to each technology. As before, the results in the figure are based on a dongle/desktop/integrated outdoor CPE scheme and those for TDD technologies assume an 8:1 downlink to uplink ratio.

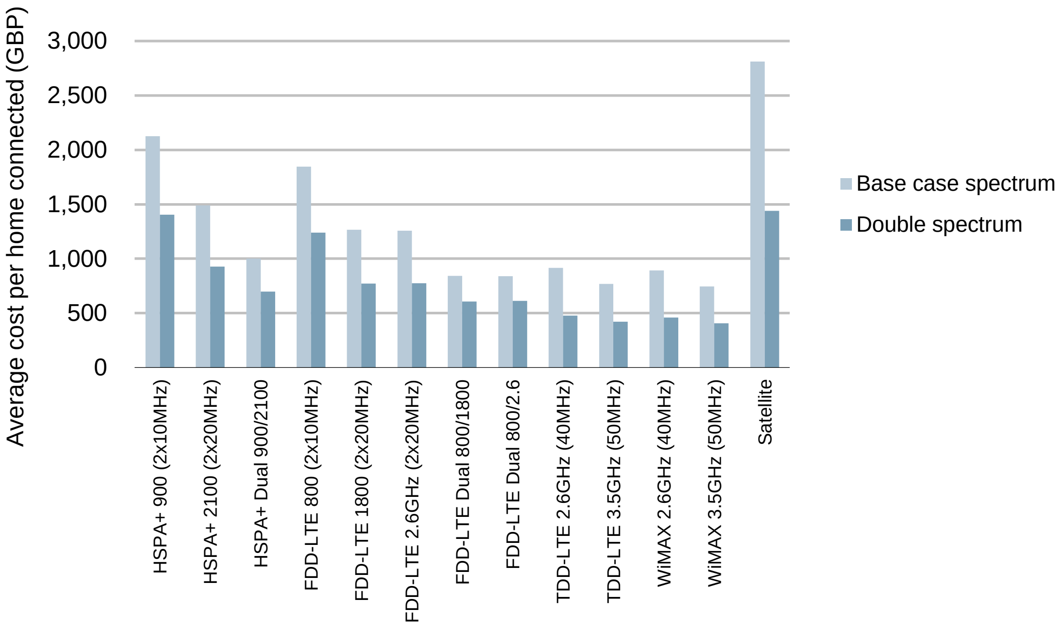

Figure 1.16: Impact of doubling spectrum availability [Source: Analysys Mason for BSG]

The availability of additional spectrum leads to a reduction in cost for terrestrial wireless ranging between 27% and 39% for the FDD technologies and between 45% and 48% for the TDD technologies. The reduction in cost for satellite is 49%. UK Broadband already has access to more than twice as much spectrum at 3.5GHz as we assume in the base case. It is also conceivable that a single operator could end up with 2×40MHz of FDD spectrum at 2.6GHz, or 2×20MHz of FDD spectrum at 800MHz at the conclusion of the forthcoming auction. It would however, be difficult to provide 80MHz of TDD spectrum at 2.6GHz or any more spectrum in the 900MHz, 1800MHz and 2100MHz bands so these results should be regarded as indicative. It may also be difficult to double the size of the spectrum blocks that we have assumed will be available for satellite.

Figure 1.17 shows that with double the amount of spectrum at 3.5GHz (where there is definitely more spectrum available) the cost of TDD terrestrial wireless technology is less than or equal to the cost of FTTC/VDSL across all but the most rural geotype in Scenario B (with the base-case spectrum allocation the cost was only lower for the final 15% of homes).

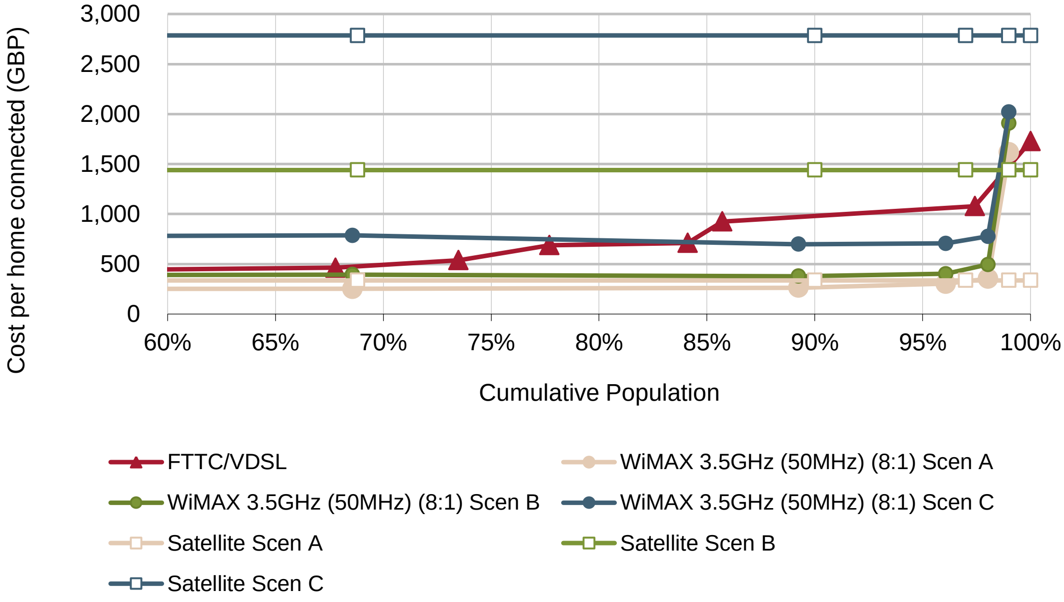

Figure 1.17: Comparison between TDD terrestrial wireless and satellite deployment costs per home connected (with increased spectrum allocation) and the equivalent fibre costs [Source: Analysys Mason for BSG]

Flattening peak traffic demand

Since the deployment costs for both terrestrial wireless and satellite networks are dependent on the busy-hour traffic per customer, and in our demand scenarios the biggest driver of busy-hour traffic is streaming of on-demand video, it follows that any steps that can be taken to reduce the amount of traffic that has to be streamed in the busy hour will significantly reduce the deployment costs.

Terrestrial wireless operators are already starting to offload some of their peak traffic on to WiFi networks and femtocells, but this strategy can only be used in areas where high-bandwidth fixed broadband services are available.

Another option, which can be implemented nationwide at relatively low incremental cost per home, is to push popular video content to customers at off-peak times and cache it locally on DVRs so that it is available for viewing on demand, a technique referred to as 'sideloading'.

Satellite technology is particularly well-suited to support sideloading since a single satellite can broadcast a large number of video channels simultaneously over the whole of the UK. Customers could, in principle, receive many SD and HD TV channels from a Ku-band satellite adjacent to the Ka-band broadband satellite using a single antenna equipped with two feeds, or the programmes to be sideloaded could be rebroadcast on the Ka-band satellite.

Sideloading could also be applied to terrestrial wireless networks (to deliver a smaller number of channels) using standards such as Digital Video Broadcasting – Handheld (DVB-H) and

Multimedia Broadcast Multicast Service (MBMS) which have already been ratified, though they are not currently being used commercially in the UK.

The impact on the deployment cost per home of sideloading 80% of the most popular on-demand content is shown in Figure 1.18.

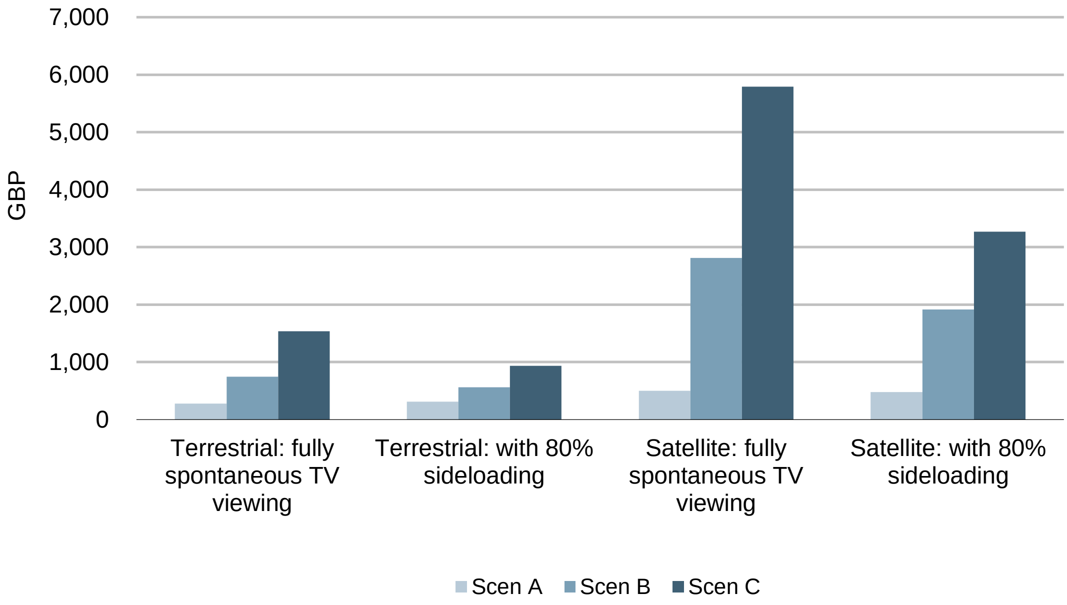

Figure 1.18: Impact of sideloading on-demand content on deployment costs per home [Source: Analysys Mason for BSG]

Sideloading reduces the cost per home connected in Scenarios B and C by between 25% and 39% for terrestrial wireless (results shown here for the lowest-cost terrestrial wireless option). For Scenario A, the cost per home actually increases by 12%, as the small reduction in base-station requirements is outweighed by the additional cost of a hard-disk drive at the customer premises. For satellite, the cost per home connected is reduced by between 4% and 44%, depending on the demand scenario.

It should be noted that sideloading of content would require some practical issues be addressed. If the content is to be stored from a live 'on-air' broadcast (e.g. Freesat, Sky), then:

- the orbital location of broadband satellite needs to be within a few degrees of that used by broadcast satellite if both services are to use the same antenna
- the user terminal will need multiple front-ends in order to receive content from multiple channels at the same time, which would increase CPE costs over and above those considered in the study.

1.4.8 Operating costs

We believe that the annual network operating cost per home connected in the current study can broadly be compared to the sum of provision/maintenance, network support and accommodation costs in the previous fibre study (which we refer to collectively as fibre 'network costs'). Figure 1.19 shows the comparison for the lowest-cost terrestrial wireless option (WiMAX at 3.5GHz), satellite and the lowest-cost fibre option (FTTC/VDSL).

	Annual operating cost per home connected (GBP)		
	Scenario A	*Scenario B*	*Scenario C*
Terrestrial wireless	6	57	140
Satellite	3	18	38
FTTC/VDSL 'network costs'	30	30	30

Figure 1.19: Estimated annual network operating costs per home connected for terrestrial wireless and satellite [Source: Openreach, Analysys Mason for BSG]

For terrestrial wireless, the annual operating cost per home connected is lower than the equivalent fibre costs in Scenario A, but higher by around GBP27 per annum in Scenario B, which means that over a ten-year period (and ignoring the time value of money) the lower deployment cost for terrestrial wireless may be entirely offset by higher operating costs. The annual operating cost per home connected is considerably higher than the equivalent fibre costs in Scenario C.

For satellite, the annual operating cost per home connected is lower than the equivalent fibre costs in Scenario A, between the cost for FTTH and FTTC/VDSL in Scenario B (but not sufficiently less than the FTTC/VDSL cost to offset the increased cost of deployment) and somewhat higher than both the FTTH and FTTC/VDSL costs in Scenario C.

In the earlier fibre study we also considered the network power consumption per customer. Figure 1.20 compares the results from the fibre study with the power consumption for terrestrial wireless (we believe that the network power consumption per customer for satellite is negligible since mains power is only required to operate a small number of satellite gateways).

	Average network power per customer (W)		
	Scenario A	*Scenario B*	*Scenario C*
Terrestrial wireless	0.7	4.9	10.3
Satellite	-	-	-
FTTC/VDSL	3.8	3.8	3.8

Figure 1.20: Estimated annual network power consumption per home connected for terrestrial wireless and satellite [Source: Openreach, Analysys Mason for BSG]

It can be see that the network power consumption per customer in our hypothetical terrestrial wireless network is significantly lower than for FTTC/VDSL in Scenario A, similar in Scenario B and considerably higher in Scenario C. We have not looked at the relative power consumption of fibre, wireless and satellite CPE in detail.

1.4.9 Universal service commitment

At the time of writing the technical definition of the universal service agreement (USC) was still being agreed by industry. Consequently, we have not considered the USC in detail. The current suggestion for a USC download service is "Access offering throughput of at least 2Mbps for 90% of the time during the busiest 3 hour period daily"[4]. We understand that this requirement refers to a 90% chance of a particular user being able to receive 2Mbit/s during the busy hour.

We believe that the performance of the networks we have modelled is likely to be commensurate with this requirement (the level of over-provisioning we included in our Erlang C calculation is sufficient to ensure a 98% probability of an on-demand video stream starting with 5 seconds). Furthermore, we believe that the average bandwidth per home in our lowest wireless demand scenario for 2016 is higher than the average bandwidth provided by a typical fixed broadband network in 2010. We believe that as the definition of USC develops, the detailed assumptions and wide range of scenarios provided in this report will provide a useful indicator of performance.

1.4.10 Impact on mobile coverage in rural areas

The provision of fixed terrestrial wireless services in rural areas is likely to lead to an improvement in mobile coverage in these areas, though our modelling suggest that it would probably not result in the availability of contiguous outdoor mobile broadband service. Moreover, the mobile broadband service may only be available to mobile handset users in the case of an FDD deployment (existing mobile handset models do not support the use of TDD).

1.4.11 Other policy considerations

As Figure 1.21 shows, the number of terrestrial wireless sites needed to support Scenarios B and C on a national basis is far higher than the 12 000 sites that we assume our hypothetical operator has today. Given that new base station sites are frequently opposed by local residents, it may be difficult for an operator to deploy this number of additional sites in practice. The problem will be exacerbated if it is not possible for the operator to re-use 100% of existing sites (e.g. because they cannot be upgraded for MIMO operation).

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4 Source: Department for Business, Innovation & Skills, http://www.bis.gov.uk/assets/biscore/business-sectors/docs/b/10-1065-bduk-usc-theoretical-exercise-request-information.pdf

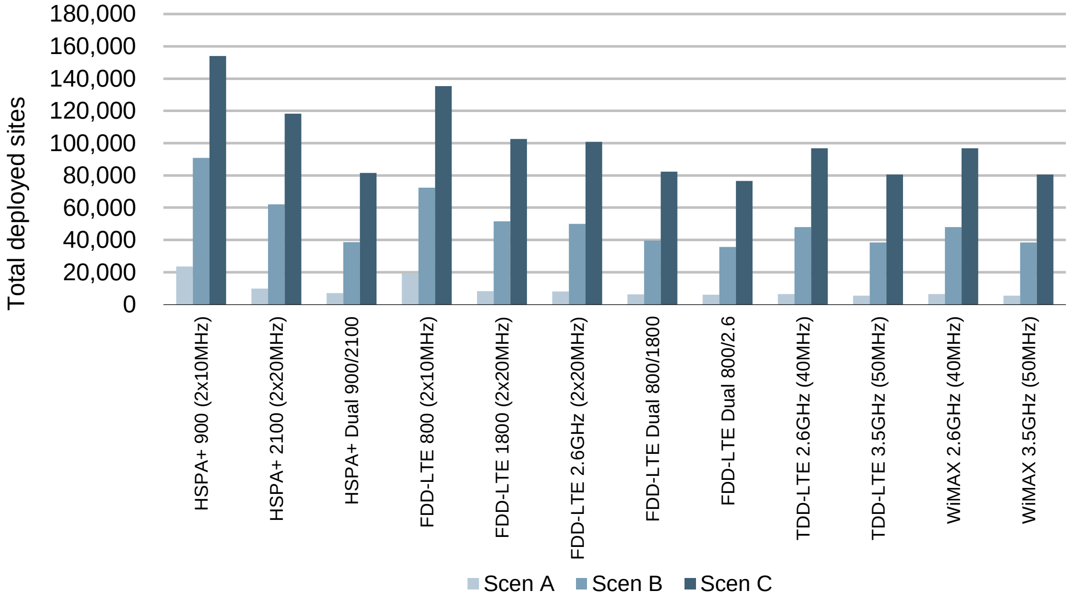

Figure 1.21: Total number of sites required per operator for terrestrial wireless broadband across the UK in 2016 [Source: Analysys Mason for BSG]

Moreover around 18% of the UK is made up of areas that have been designated as National Parks, Areas of Outstanding Natural Beauty (in England, Wales and Northern Ireland) and National Scenic Areas (in Scotland). It may be particularly difficult to find acceptable sites in these areas for the large number of new base stations that would be required for a terrestrial wireless deployment supporting the traffic envisaged in our Scenarios B and C.

At the same time there may be objections to the installation of outdoor terrestrial wireless or satellite antennas on premises in these areas.

For the reasons outlined above National Parks, Areas of Outstanding Natural Beauty and National Scenic Areas present a particular challenge with respect to the delivery of next-generation broadband. They are, almost by definition, sparsely populated and thus unlikely to be covered by fibre roll-outs unless there is some form of public intervention.

Policy-makers are therefore likely to be faced with a difficult choice between three options for such areas:

- accept the additional visual intrusion that is likely to be associated with the deployment of terrestrial wireless and/or satellite broadband in these areas
- find the funding necessary to subsidise the roll-out of less visually-intrusive fibre-based NGA in these areas
- accept that the availability and speed of broadband access in these areas will continue to lag behind other parts of the UK.

Finally, we note that the maximum permitted mean in-block transmission power for mobile and nomadic CPE operating in the 800MHz band is 23dBm[5]. This is considerably lower than the power limits for the other bands considered in this study and reduces the attractiveness of the 800MHz band relative to the other bands that can be used to provide terrestrial wireless services. The European Commission Decision states that Member States may relax the limit for specific deployments, e.g. fixed station terminals in rural areas, provided that the protection of other service, networks and applications is not compromised and cross-border obligations are fulfilled. We believe it would be helpful if Ofcom could consider permitting such a relaxation in the UK.

1.4.12 Concluding remarks

Given our base-case assumptions on spectrum availability and based on the costs identified in our study, we believe that terrestrial wireless technology could cost-effectively support a level of throughput that is similar to our predicted fixed network traffic demand in the year 2016 for the final 15% of UK homes, although this would require a large increase in the number of base stations deployed. With more spectrum devoted to the provision of broadband services than we assume in our base case, terrestrial wireless technology could deliver this level of throughput to a larger number of homes, potentially including all of the final third.

The study has also shown that satellite can play an important complementary role by delivering NGA to homes that lie outside the coverage area of terrestrial wireless and those that are located in 'notspots' within the coverage area. The cost of deploying satellite broadband could also be reduced through the allocation of additional spectrum, and it seems probable that satellite operators will further reduce the effective cost by implementing sideloading.

Although there are huge uncertainties about the level of demand in 2016, under three credible scenarios the peak demand for the average household is under 20Mbit/s. We think it unlikely that new residential applications requiring significantly in excess of 20Mbit/s will emerge before 2016. We therefore believe that the economic case for delivering higher bandwidths in the next five years is uncertain.

We believe that private-sector investment in fibre, terrestrial wireless and satellite technologies will deliver incremental increases in bandwidth over the next five years that reflect the underlying demand from consumers. Given that the lack of clarity over what the average level of demand will be in 2016, and the complex interplay of other factors which ultimately determine which technology is most cost-effective for a particular location, we believe that a cautious approach to public intervention is required.

It is however, apparent that the cost per home connected could be reduced through the release of additional terrestrial wireless and satellite spectrum and we believe this would encourage the private sector to improve the provision of broadband services in rural areas.

5 Commission Decision of 6 May 2010 on harmonised technical conditions of use in the 790-862MHz frequency band for terrestrial systems capable of providing electronic communications services in the European Union (ref 2010/267/EU)

2 Introduction

This is the final report of our study for the Broadband Stakeholder Group (BSG) on the costs and capabilities of satellite and terrestrial wireless technologies[6]. It contains the methodology, key input assumptions, results and conclusions of the project.

This study was designed to provide an insight into how satellite and terrestrial wireless technologies can support universal broadband services and next-generation access (NGA) and to compare the costs of these technologies with the costs of providing fixed fibre to the home (FTTH), and fibre to the cabinet (FTTC) used in conjunction with very-high-speed digital subscriber lines (VDSL), which were the subject of our previous study for the BSG published in 2008[7]. It should be noted that our study did *not* consider the revenues that may be derived from providing NGA services and thus the report does not assess where the provision of satellite and terrestrial wireless services may be commercially viable.

The specific objectives of the study were as follows:

- To provide a detailed comparative analysis of the costs and capabilities of different satellite and terrestrial wireless technologies that could be used to provide broadband services in the UK.
- To help address policy uncertainty about costs and capabilities of satellite and terrestrial wireless technologies and how this relates to spectrum allocation decisions.
- To identify which technologies might be best suited (in terms of their costs and capabilities) to particular locations/deployment challenges.
- To indicate how satellite and terrestrial wireless technologies should be integrated into the policy approach for universal and next-generation broadband services in rural areas.
- To make explicit the relationship between these policy goals and the ongoing debate about spectrum policy.

Key assumptions and observations

The results in this report focus on the upfront deployment costs of terrestrial fixed-wireless and satellite networks. We also present a high-level analysis of the associated spectrum and operating costs.

It should be noted that the cost of satellite and terrestrial wireless networks is far more dependent on the peak traffic loading than is the case for fibre networks. The results presented in this report are therefore

6 In this report we use the term ‘terrestrial wireless’ to refer to a variety of ground-based radio technologies such as HSPA+, LTE and WiMAX which use cellular base stations to communicate with end users; there technologies are distinguished from satellite technologies which involve a wireless connection between the end user and what is effectively a large base station in space.

7 “The costs of deploying fibre-based next-generation broadband infrastructure”, Analysys Mason for BSG, September 2008, available at: http://www.broadbanduk.org/component/option,com_docman/task,doc_view/gid,1036/Itemid,63/

very sensitive to the assumptions regarding the future development of traffic volumes. We have addressed this issue by presenting the results for three different traffic scenarios.

The results for terrestrial wireless networks are also highly sensitive to assumptions regarding the radio frequency (RF) link budgets for different types of base station and customer premises equipment (CPE). In the interests of transparency we present a number of sample link budgets in the technical annex and we believe that the final set we have used is reasonable. Nonetheless, we recognise that a case can be made for using alternative assumptions which might give significantly different results. The calculations for satellite systems are less complex and consequently the performance of next-generation satellite systems is less uncertain than the performance of next-generation terrestrial wireless systems.

Finally, the results for terrestrial wireless networks are very sensitive to assumptions regarding the relationship between typical throughput and theoretical maximum throughput for the different technologies, and also to assumptions about the number of additional base stations required to cover areas of difficult terrain and to cope with population dispersal.[8] Again neither of these issues is relevant to satellite systems.

In light of the issues described above, we believe that the results of this study are less clear-cut that the results of the previous fibre study and should be regarded as giving indications of the relative merits of using different technologies and, in the case of terrestrial wireless, different frequency bands, rather than providing a definitive answer on the ‘best’ solution for any given situation.

We should like to acknowledge the considerable support that we have received from the study’s steering group in commenting on our assumptions and providing data to support or challenge them from within their own organisations and from third-party sources. Analysys Mason is grateful for their input and we believe that our results, while still imperfect, are more robust as a consequence of the steering group’s involvement in the study. It should nevertheless be noted that the conclusions of the report do not necessarily represent the views of steering group members.

Structure of the report

The remainder of this document is laid out as follows:

- Section 3 describes the project scope and network architectures
- Section 4 describes the project methodology
- Section 5 presents the draft results
- Section 6 presents the conclusions and policy implications.

The report includes an annex presenting the key inputs and assumptions.

8 The requirement for additional base stations to provide adequate coverage in rural areas with small but fairly densely populated towns and villages separated by countryside containing very few homes is a problem that we refer to as ‘geotype fragmentation’

3 Network architectures

This section provides a summary of the different network architectures that we have modelled in the study.

The costs of broadband satellite and terrestrial wireless networks are highly dependent on the volume of traffic that is carried. Recent years have seen very rapid growth in broadband traffic generated by each household and this trend is expected to continue. In order to calculate the cost of deploying and operating broadband satellite and terrestrial wireless networks to cope with the forecast volume of traffic, we have taken a 'snapshot' of the expected situation in 2016 based on our best estimates of the likely traffic per household at that time.

The year 2016 was chosen for the snapshot because it is sufficiently far in the future for next-generation terrestrial wireless networks – based on technology such as long-term evolution (LTE) and 802.16m WiMAX standards – to have been widely deployed in the UK in all of the frequency bands under consideration, and for next-generation satellite broadband (based on high-bandwidth, Ka-band multi-spotbeam satellites) to be available from multiple providers, but not so far into the future that these technologies are likely to have been superseded by the following generation of standards.

3.1 Terrestrial wireless architecture

We have modelled the cost for a hypothetical network operator deploying a terrestrial wireless network in the UK to serve 100% of the population in urban areas, 99% of the population in suburban areas and 98% of the population in rural areas. Furthermore we expect a 90–95% probability of a household being able to receive broadband services with a fixed wireless terminal within a given coverage area (we assume that the remaining homes will be served by other technologies). The network has been dimensioned on the basis that the operator has a 25% market share of broadband homes within the coverage area, although to serve this many homes in our higher-demand scenarios, our hypothetical operator would require many more base station sites than a typical UK mobile operator has today.

The network design is based on the use of three-sector macrocell base stations throughout, i.e. we have not considered the use of single-sector macrocells, or microcells and picocells. Due to the level of demand in our model (particularly in Scenarios B and C) we believe that three-sector base stations will result in lower overall cost by maximising the capacity per site. In addition, a key aim of this study has been to assess the role that terrestrial wireless can play in delivering NGA in rural areas. In this context, the extra height of the typical macrocell mast compared to the typical microcell or picocells mast means that macrocells are better able to serve outlying properties. Also, limiting the analysis to one configuration of base station has allowed us to avoid adding further complexity to the modelling. We recognise that in real-life deployments, other base station configurations (including single sector sites, microcells and picocells) may have a role to play in delivering an optimum terrestrial wireless infrastructure solution.

The network has been designed to provide fixed (rather than mobile) wireless connectivity. This allows higher average data rates as the reception conditions in a fixed wireless network are more constant and can be optimised; the reception conditions on mobile networks, by contrast, tend to be more variable. The nature of terrestrial wireless technology is such that a small number of customers who live very close to the centre of a terrestrial wireless cell may in practice be able to obtain the target data rate indoors using a mobile broadband dongle.

The network will also provide outdoor mobile broadband coverage for dongles and smartphones, though our modelling suggests that this coverage may not be contiguous (i.e. the signal strength at the edge of each cell will be sufficient to support the target data rate using a high-gain directional antenna, but not sufficient to provide mobile broadband service to a handheld device with a low-gain omni-directional antenna). We note also that existing handset designs do not support TDD technologies.

In terms of antenna technology, we consider multiple-input multiple-output (MIMO) systems at both the base station and customer premises, again for the reason that use of MIMO makes it possible to achieve higher average data rates. We have included the impact of two types of MIMO scheme:

- MIMO A (space time block coding) involves sending multiple parallel streams of the same data. This increases the chance that the receiver can identify a strong signal and so increases the data rate at the cell edge.
- MIMO B (spatial multiplexing) involves splitting the data between different streams. This creates a direct increase in the available throughput for a given amount of spectrum. However, the benefits of MIMO B can only be fully realised where there is a relatively high signal-to-noise ratio (i.e. close to the centre of the cell).

Both MIMO A and MIMO B schemes can be employed in the same cell, delivering benefits to both cell radius and average throughput. We assume the use of 4×2 MIMO (four antennas on the base station and two on the CPE) at 800 and 900MHz and 4×4 MIMO[9] at the higher frequencies.

The study assumes the use of a standard terrestrial wireless architecture comprising CPE, base stations and backhaul from the base stations to the terrestrial wireless operator's nearest switch node. As Figure 3.1 illustrates, in our earlier fibre costing study, the cost of backhaul from the local exchange to the nearest metro node was *not* included. We have opted to include the first leg

9 HSPA+ does not currently support 4×4 MIMO but we assume that this option will be available by 2016. We note that while a four-antenna array designed for the 800/900MHz bands could, in principle, be deployed at customer premises, we believe that size constraints could limit the available gains and therefore we have assumed that that modelling the use of two-antenna arrays at 800/900MHz is a suitable approach. We note that MIMO is a complex area that would benefit from further advanced simulations and trials.

of backhaul towards the core of the network in this study, because it accounts for a greater proportion of overall costs than in a typical fixed fibre network.

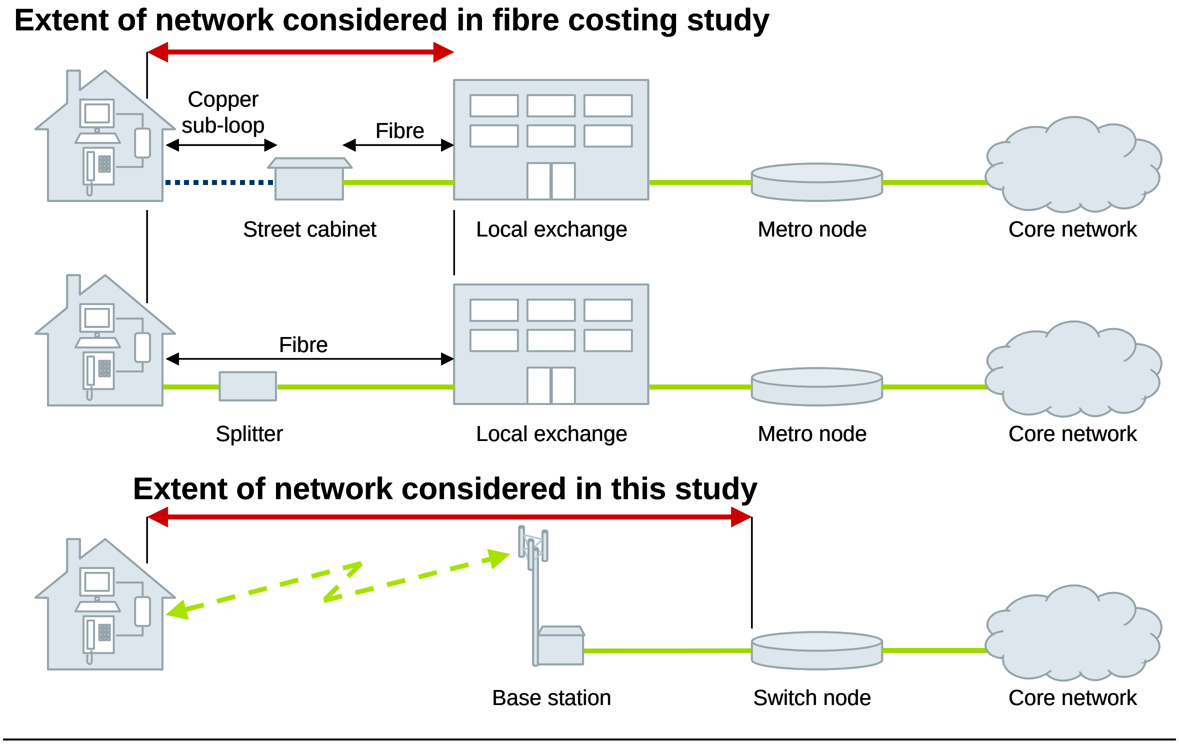

Figure 3.1: *Comparison of terrestrial wireless network elements considered in this study and elements considered in the earlier fibre costing study [Source: Analysys Mason based on an original by Ofcom]*

Terrestrial wireless CPE

The baseline configuration in this study is a desktop unit with WiFi (see Figure 3.2 below for an example of an existing commercial LTE product designed for the US market) used in conjunction with an outdoor directional antenna measuring approximately 30cm by 30cm (see Figure 3.3 below for an example), or else an outdoor modem of similar size which also contains the CPE electronics and is wired back to an Ethernet socket indoors, thereby eliminating the RF signal loss in the cable linking the antenna to the desktop unit (see Figure 3.4 for an example).

Figure 3.2: Desktop LTE router with WiFi [Source: ZyXEL Communications Corp.]

Figure 3.3: Outdoor antenna [Source: Mars Antennas and RF Systems]

Figure 3.4: Outdoor terrestrial wireless broadband modem [Source: Aviat]

As mentioned above, it is likely that a small proportion of customers who live very close to the centre of a cell will be able to obtain the target data rate with a mobile broadband dongle (similar to the one illustrated in Figure 3.5) rather than a desktop unit; while customers who live just too far away from the base station to use a dongle will be able to use a desktop unit with indoor omnidirectional antennas, rather than an outdoor antenna. We assume that by 2016 MIMO technology can be incorporated within a single outdoor antenna or outdoor modem casing, although an outdoor MIMO antenna will need to be connected using multiple co-axial cables. Rather like a terrestrial TV aerial, the outdoor antenna will need to be mounted as high as possible and pointed towards a nearby base station. Our costings are based on the assumption that desktop units and dongles will be installed by the subscriber, but that CPE requiring an outdoor component will be professionally installed. We recognise however, that it may be possible to arrange for an outdoor component to be installed by the subscriber just as some terrestrial TV aerials are self-installed.

Figure 3.5: Mobile broadband dongle [Source: Analysys Mason]

We also consider the use of window-mounted CPE, whereby an internal patch antenna is affixed to the inside of a window (to reduce in building penetration losses) using a suction-mount. Although a window antenna is unlikely to achieve the same signal gain as an external antenna, it is easier for subscribers to install this type of CPE themselves and thus it is a lower-cost solution.

For base stations, we consider the cost of both the active electronics and civil works elements, adjusting the cost of these according to whether the site is a new build or an upgrade (we assume that our hypothetical operator has 12 000 existing sites – which we believe to be typical for UK mobile operators – and that all of these can be re-used). We assume that a mix of leased fibre and self-provided microwave will be used for backhaul (this ratio varies by geotype: we assume that there will be a higher ratio of leased fibre in urban areas than in rural areas).

3.2 Satellite architecture

We have modelled the cost of deploying a hypothetical satellite system covering 100% of the UK land area and thus able to provide service in any location where a clear line of sight is available. The type of satellite under consideration is a high-throughput multi-spotbeam geostationary satellite operating in the Ka band. For modelling purposes we have assumed that the satellite operator has a 50% market share of broadband homes[10], although to serve this many homes nationwide our hypothetical operator would need to deploy a very large number of satellites.

The capacity of each satellite is determined by three factors:

10 We assume a 50% market share for the satellite operator, as opposed to 25% for the terrestrial wireless operator, because only two satellite operators (Avanti Communications and Eutelsat) have announced plans to provide Ka-band service in the UK

- the total amount of spectrum available, which governs the capacity of each spotbeam (a multi-spotbeam satellite re-uses the spectrum allocated to it in the same way as a terrestrial cellular network does; a four 'cell' re-use pattern is the norm)
- the diameter of each spotbeam, which governs the number of spotbeams that can be used to cover a given area
- the total amount of power generated by the satellite, which governs the total number of spotbeams that it can operate simultaneously.

The components of the satellite system that we consider are shown in Figure 3.6. The space segment deployment costs comprise the cost of building and launching the satellite and the cost of launch insurance. The ground segment deployment costs comprise the cost of procuring and installing satellite gateways and the cost of providing connectivity between gateways (for the purposes of resilience) and connections to the Internet.

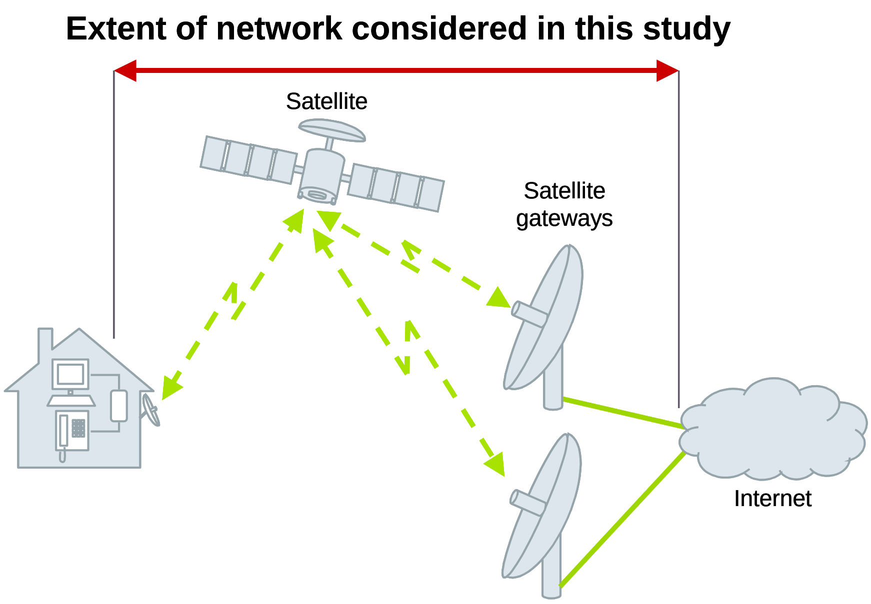

Figure 3.6: Elements considered as part of the satellite system [Source: Analysys Mason for BSG]

Expected satellite deployments

Avanti Communications plans to launch two Ka-band satellites providing UK coverage: Hylas-1 is due to be launched in 4Q 2010 and will place two Ka-band spotbeams over the British Isles. Hylas-2 is due to be launched in 2Q 2012 and will place a further two Ka-band spotbeams over the British Isles.

Avanti is also undertaking planning for a next-generation Ka-band system called Hercules under a European Space Agency programme. Hercules will comprise two high-power Ka-band satellites (Hercules-1 and Hercules-2) to be operated in different orbital locations. Avanti states that the Hercules system could be in operation by 2016 and that the entire capacity of one or both satellites could be directed at the UK. Each Hercules satellite is intended to provide a minimum total capacity of around 15Gbit/s on its forward link and around 3.5–4Gbit/s (25% of the forward link capacity) on its return link. It is assumed that each spotbeam will provide at least 1Gbit/s of throughput on its forward link.

Eutelsat also intends to launch a Ka-band multi-spotbeam satellite called KA-SAT in 4Q 2010. KA-SAT has been designed to cover the whole of Europe together with parts of North Africa and Western Asia using 83 spotbeams, of which five are expected to provide UK coverage. KA-SAT has been designed to provide 70Gbit/s total throughput. We understand that the capacity of each UK spotbeam will be approximately 0.5Gbit/s on the forward link and 0.4Gbit/s on the return link. We understand that Eutelsat is also considering whether to launch a second Ka-band multi-spotbeam satellite before 2016 which would provide significantly greater capacity over the UK.

In North America, ViaSat is procuring a satellite called ViaSat-1 for launch in 2011 which is similar to KA-SAT but has been designed to provide total throughput of 130Gbit/s, while Hughes Network Systems is procuring a Ka-band multi-spotbeam satellite called Jupiter-1 for launch in 2012 with a design throughput in excess of 100Gbit/s.

Given the significant variation in total capacity of the satellites discussed above, we have chosen to model the cost per spotbeam for a hypothetical satellite with 1Gbit/s capacity on the forward link and 300Mbit/s capacity on the return link of each spotbeam. Based on the discussion of forthcoming satellites above, we believe that it is reasonable to assume that systems with this amount of capacity per spotbeam could be made available over the UK by 2016.

Satellite CPE

The satellite CPE comprises a small indoor unit about the same size as a desktop unit for the terrestrial wireless network (see Figure 3.7 for an example) connected to an outdoor satellite antenna which is likely to be around 65-70cm in diameter (see Figure 3.8 for an example). The antenna will need to be mounted in a location that affords a clear line of sight to the satellite (i.e. to the south) but does not necessarily need to be mounted as high up on the premises as an outdoor antenna for terrestrial wireless. We assume that the satellite CPE will be professionally installed in all cases, although we note that self-install schemes are currently available in Europe and may be more widely available by 2016.

Figure 3.7: Ka-band indoor satellite unit [Source: Eutelsat]

Figure 3.8: Ka-band outdoor satellite unit [Source: Eutelsat]

Whereas in the case of the terrestrial wireless network, customers need different types of CPE to achieve the target data rate depending on how far they are from the nearest base station, and there will inevitably be some variation in performance between different connections using the same type of CPE, a satellite system delivers the same service to all customers using a single type of CPE.

The Ka band is however, more affected by attenuation in adverse weather conditions (so-called 'rain fade') than the spectrum bands used for terrestrial wireless networks. Modern Ka-band satellite systems cope with this by using adaptive coding and modulation to adjust the data rate in real time for any customers suffering rain fade. This means that customers are highly unlikely to lose their satellite broadband connection altogether in wet weather but will probably notice that it slows down during periods of heavy rain.

The latency of the satellite system will be approximately 250ms, while the latency of the terrestrial wireless systems is expected to be less than 20ms. For both systems, latency is unlikely to cause problems in streaming applications and any effects on interactive web browsing can be mitigated through techniques such as pre-fetching. However, the additional latency suffered in satellite systems could be noticeable if the system is used for VoIP or videoconferencing applications (especially if both ends of the connection use satellite broadband) and it may not be possible to use the satellite system for other latency-intolerant applications such as highly-interactive online gaming.

4 Methodology

We have adopted a top-down approach to the modelling, in which we first of all divide the UK into a number of area types (referred to as 'geotypes') on the basis of their population density. We then derive the total deployment costs required to meet a certain level of demand from each geotype with each of the technologies under consideration. An overview of our methodology is shown in Figure 4.1.

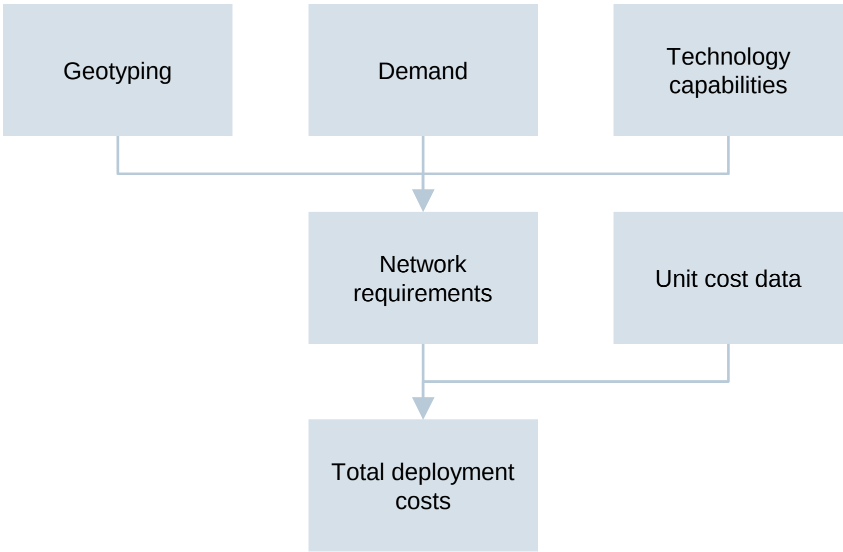

Figure 4.1: Overview of methodology [Source: Analysys Mason for BSG]

The remainder of this section explains our approach to geotyping and demand estimation and then goes on to explain how we have dimensioned terrestrial wireless networks and satellite systems to support this level of demand.

4.1 Geotyping

Our geotyping approach is based on a scheme developed for Ofcom by Analysys Mason for a wholesale mobile cost termination review model based on long-run incremental costing (LRIC). This scheme is based on population density since this typically determines the way that terrestrial wireless networks are planned. The Ofcom approach provides nine geotypes which are described in Figure 4.2.

Geotype	*Minimum population density (people per km^2)*	*Percentage of UK population in geotype*	*Percentage of UK area in geotype*	*Percentage of all traffic in geotype (Ofcom LRIC study)*
Urban	7959	6.0%	0.1%	12.8%
Suburban 1	3119	30.0%	1.5%	56.2%
Suburban 2	782	32.8%	4.6%	16.0%
Rural 1	112	21.2%	18.4%	6.1%
Rural 2	47	7.0%	22.1%	2.0%
Rural 3	25	2.0%	13.0%	0.6%
Rural 4	0	1.0%	35.1%	0.3%
Highways	N/A	0.0%	4.4%	3.5%
Railways	N/A	0.0%	0.8%	3.3%

Figure 4.2: Distribution of population, area and traffic by geotype [Source: Ofcom mobile call termination consultation, 2010, from Analysys Mason]

As our model is considering a broadband network designed to provide fixed wireless and fixed satellite services, we have redistributed the area contained in the *highways* and *railways* geotypes back amongst the *rural* geotypes[11]. Figure 4.3 shows the distribution of geotypes across the UK.

[11] We understand that in the Ofcom model the area occupied by urban and suburban highways and railways is included within the urban and suburban geotypes.

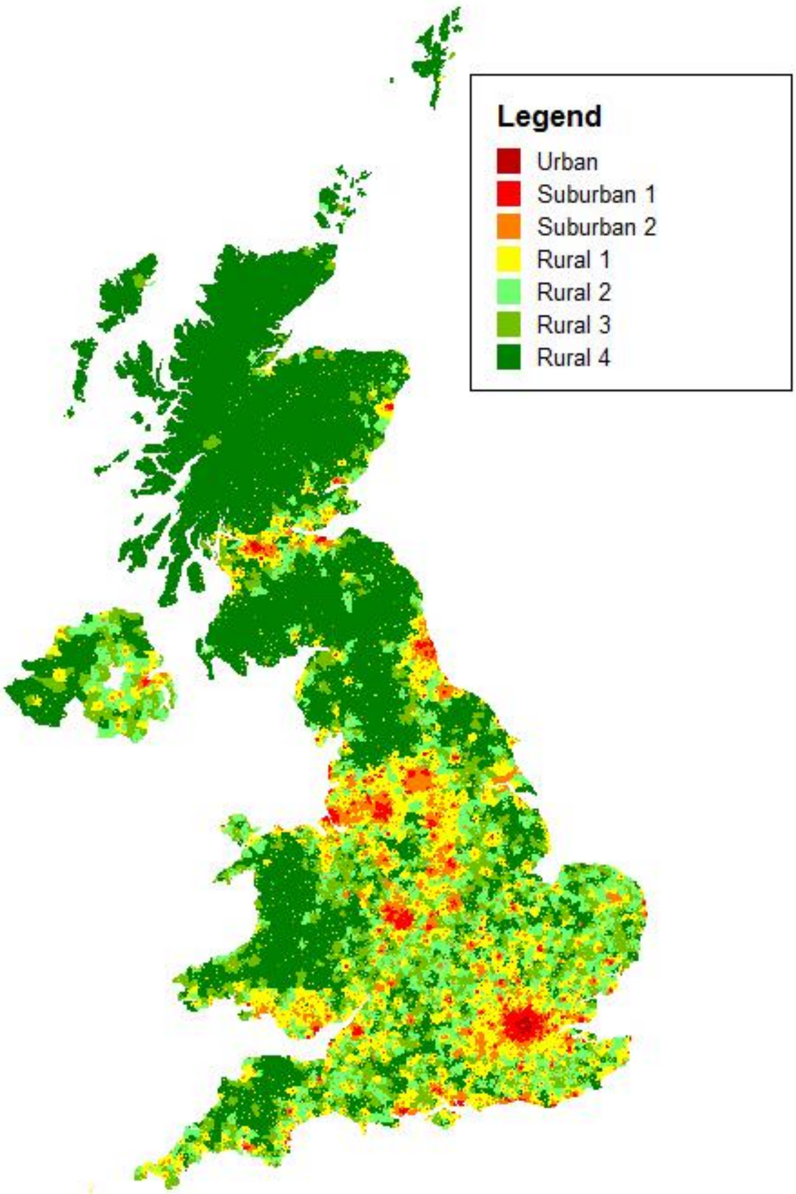

Figure 4.3: UK distribution of geotypes used in this study [Source: Analysys Mason for BSG]

Our earlier fibre costing work used a set of geotypes defined on the basis of BT local exchange size and distance from the local exchange, considerations that are not relevant to the implementation of a terrestrial wireless or satellite network. We have however, compared the way in which the UK area and population are split between the geotypes in the current study against the approach taken in the earlier fibre costing study and there is a good fit, especially in rural areas (see Figure 4.4). Consequently, we believe that the results from the current study provide a meaningful comparison with the results from the previous fibre costing study.

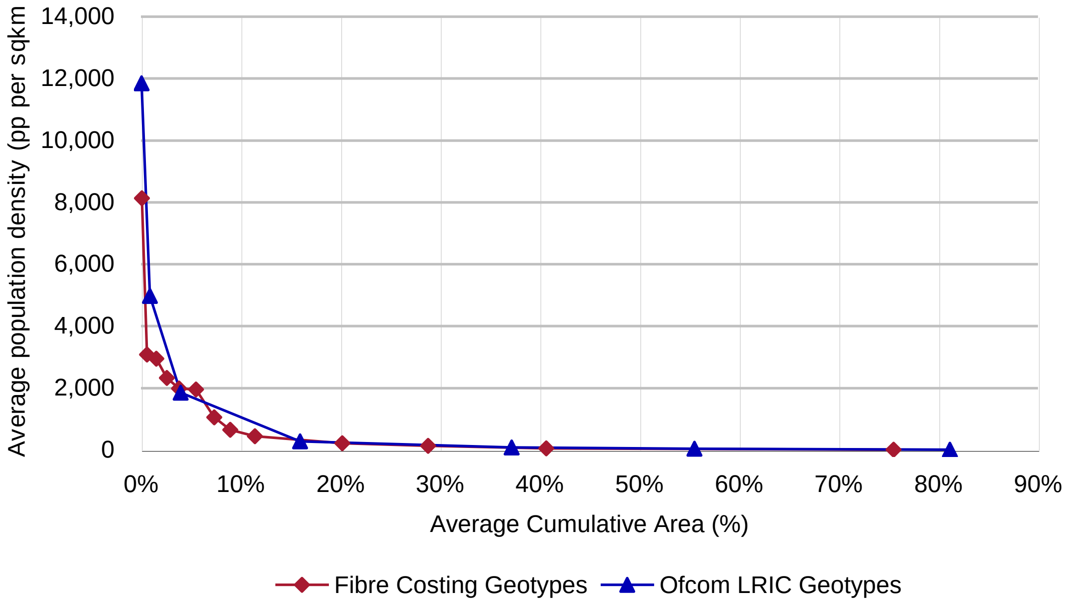

Figure 4.4: Comparison of geotyping approaches [Source: Analysys Mason for BSG]

In order to calculate the number of households served by the satellite and terrestrial wireless broadband service in each geotype, we have taken into account broadband take-up, network coverage and market share of our hypothetical operator. This process is shown in Figure 4.5.

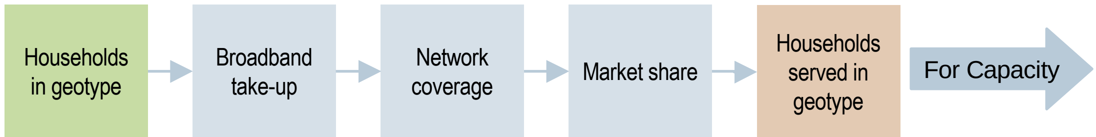

Figure 4.5: Calculation of households served by geotype [Source: Analysys Mason for BSG]

4.2 Demand estimation

To calculate the total demand from each geotype, we calculate the demand per household using the process shown in Figure 4.6. Video traffic requires considerably more bandwidth than most other forms of Internet traffic and the popularity of web-based catch-up TV services (like the BBC iPlayer) and video sharing websites (such as YouTube) has resulted in video traffic accounting for a rapidly-rising share of residential broadband traffic. We believe that IP-delivered video will be the main constituent of demand by 2016 and hence our demand calculation starts with IP viewing minutes. We also consider the use of other Internet applications such as Web browsing and email.

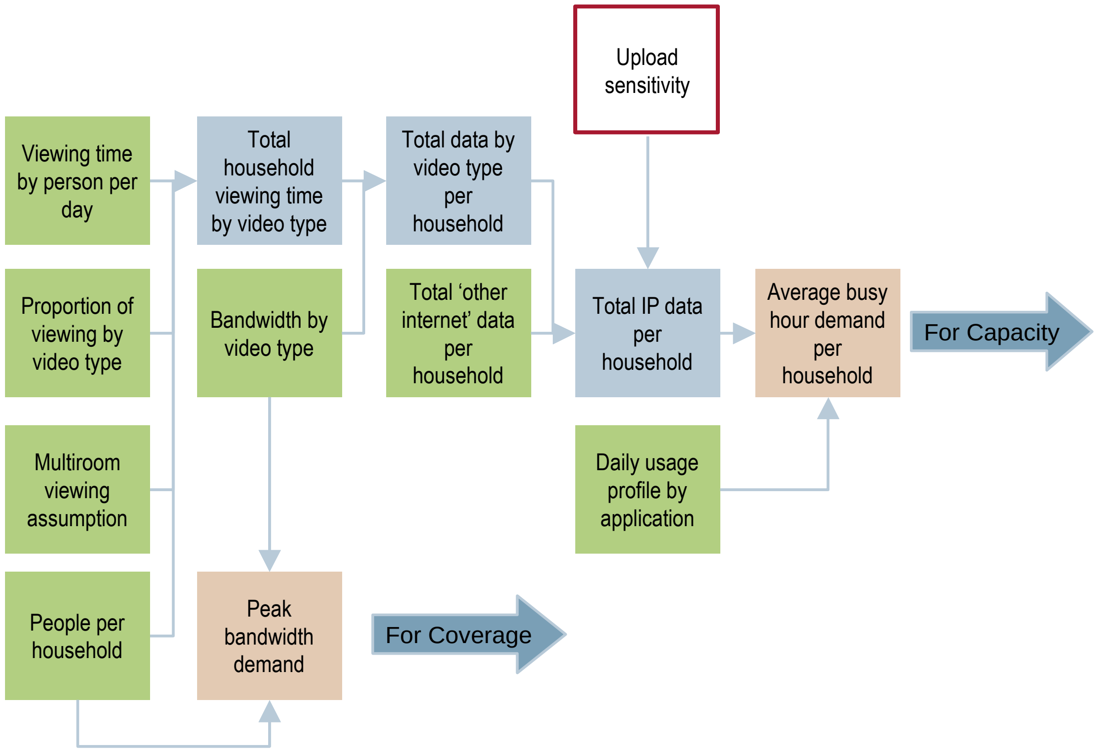

Figure 4.6: Demand methodology [Source: Analysys Mason for BSG]

As the costs of satellite and terrestrial wireless broadband networks are highly dependent on the volume of traffic to be carried, assumptions for the evolution of traffic will have a significant effect on the conclusions. In reflection of this, we have modelled three different scenarios for the evolution of demand: low, medium and high usage which we refer to as Scenarios A, B and C respectively. Note that because we assume that IP-delivered video is the main component of demand, the traffic in all three scenarios is highly asymmetric, with far more traffic in the downlink direction than in the uplink direction:

- *Scenario A (mobile broadband evolution)* represents demand in a world in which the retail business model for satellite and terrestrial wireless broadband access is similar to mobile broadband today. Demand is constrained by the existence of prepaid subscriptions and relatively stringent usage caps in monthly pricing plans. The scenario represents our lowest forecast for growth in fixed internet traffic, and also includes reductions to reflect the constraints of the mobile broadband business model (together resulting in annual growth of 28% from 2010 to 2016). The reductions have been calibrated against existing mobile broadband traffic data, and we have taken into account the fact that existing mobile broadband users will also often have a fixed broadband subscription, which most will opt to use during the busy hour: either via a desktop or laptop, or via a WiFi connection from their mobile device. Under Scenario A, performance of satellite and terrestrial wireless technology is sufficient to:
  - watch good-quality (i.e. low level of interruption) standard-definition streamed video content (such as YouTube and iPlayer) most of the time
  - enable acceptable, basic, current-technology video conferencing (such as Skype) most of the time

  - provide access to current online government services (e.g. tax self-assessment form)
  - provide a good, responsive web browsing experience
  - support email services.

- *Scenario B (fixed broadband evolution)* represents demand in a world in which the retail business model is similar to fixed broadband today. Demand is less constrained than in Scenario A due to large (or unlimited) usage caps and predominantly pay-monthly subscriptions. Scenario B represents our view of the most likely evolution of fixed broadband traffic (including around 40% annual traffic growth from 2010 to 2016), and includes an increasing consumer preference for viewing on-demand content over IP networks, often in high definition (HD). The growth implicit in this scenario appears to be in line with Cisco's Visual Networking Index, which is forecasting 39% annual growth in consumer IP traffic in Western Europe from 2009 to 2014 and much faster growth in video traffic.

- *Scenario C (accelerated IP-video evolution)* also represents demand in a world in which the retail business model is similar to fixed broadband today. However, Scenario C considers the impact of an even greater change in consumer behaviour, with a large proportion of the content viewed being on-demand video delivered over IP networks. Almost all TV content is delivered in HD. Annual traffic growth is around 50% from 2010 to 2016.

It should be noted that although the three scenarios represent three different evolutions of IP traffic consumption to 2016, the scenarios could also be interpreted as representing traffic consumption at different points in time. For example, if terrestrial wireless broadband services look like Scenario B in 2016, Scenario C could represent the level of traffic consumption five or ten years later. This is an important concept for understanding how continued investment would be needed in the network to meet the ongoing demand.

Further detail on the input assumptions for the demand methodology can be found in Section A.1.2.

For network dimensioning it is also important to consider the impact of random traffic peaks. When there are many hundreds or thousands of users the total traffic profile should be a good match to the average user. In Figure 4.7, we have shown a random distribution of traffic from different numbers of users (with an average demand represented by 100).

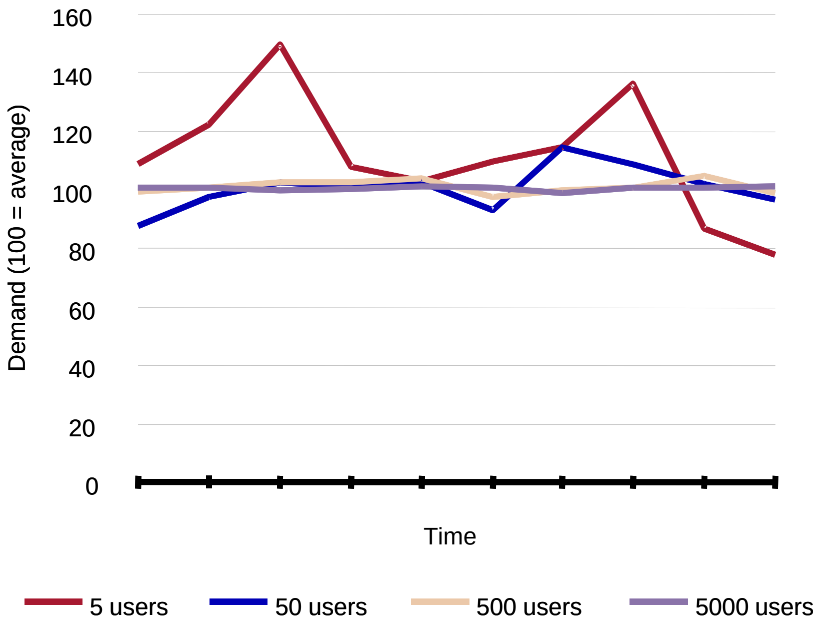

Figure 4.7: Impact of users upon size of traffic peaks [Source: Analysys Mason for BSG]

It can be seen that with only five users the peak usage is about 50% greater than the average, while with 5000 users the peak usage is only 1% more than the average. To ensure that there is a good quality of service it is necessary to allow appropriate additional capacity for these variations in demand. In our modelling this is known as over-dimensioning.

We have used an Erlang C calculation as a way to approximate the over-dimensioning that would be necessary to support the type of traffic that we have modelled. Erlang C is typically applied to call-centre dimensioning. The inputs include: average demand (calls per hour); average duration of calls; total number of call-centre agents. Outputs include: average time to wait before a call is answered; proportion of calls answered within a specified time.

We have used an iterative approach to modify the calculation so that it can be applied to video streaming. The inputs are the average number of concurrent video streams and the average duration of a video stream. The parameters are the average delay from the time a video is requested to the time that the stream starts, and proportion of streams that start within a specified time of requesting. The output is the total capacity required to the specified inputs given the specified parameters (which we use as an estimate of the over-dimensioning factor).

We have assumed the following parameters for acceptable quality of services

- average time to wait before a stream starts is 1 second
- 98% of streams start within 5 seconds of requesting.

An increase in either take-up or node[12] size leads to a fall in the degree of over-dimensioning required. This is shown in Figure 4.8:

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12 A node is an aggregation in a communications network. In the context of this study, "node" refers to a terrestrial wireless base station or a satellite spotbeam.

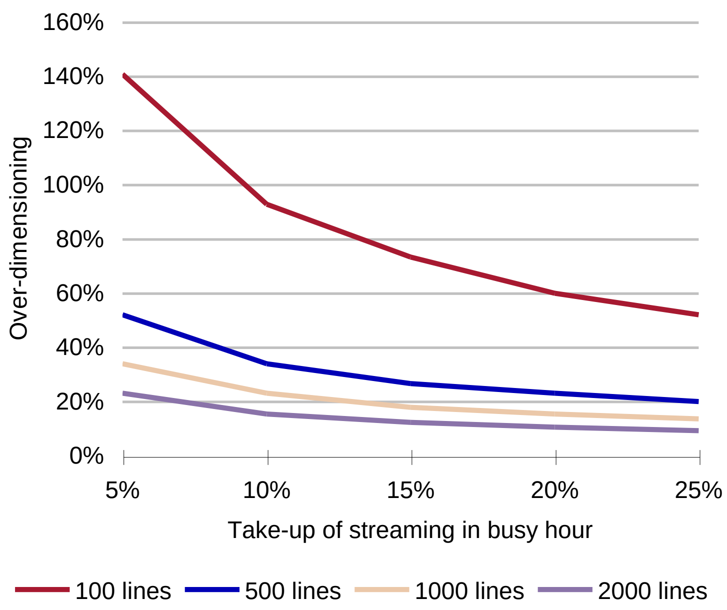

Figure 4.8: Impact of take-up and number of lines per node on over-dimensioning [Source: Analysys Mason for BSG]

It can be seen in Figure 4.8 that as the number of lines at the node decreases, a larger amount of over-dimensioning is required: at 25% take-up the over-dimensioning for 100 lines is over 50% (compared to under 10% for 2000 lines). As take-up increases, the amount of over-dimensioning falls: for 1000 lines, the over-dimensioning falls from 34% at 5% take-up to 14% at 25% take-up.

4.3 Technology capabilities

4.3.1 Technologies and spectrum bands considered

The combination of technologies and spectrum bands that we have considered is shown in Figure 4.9 below.

- Evolved high-speed packet access (HSPA+) is another step in the evolution of the 3G mobile broadband networks that are deployed in the UK.
- LTE – which is not yet being deployed commercially in the UK but is being rolled out in some other European countries – is a bridge to 4G mobile technologies.
  - LTE is available in both frequency-division duplex (FDD)…
  - …and time-division duplex (TDD) variants.
- IEEE 802.16m WiMAX is the next step in the evolution of today's WiMAX networks (which are mostly based on the IEEE 802.16e standard).
- The Ka band is a portion of the microwave spectrum in which future broadband communications satellites will operate.

	800MHz	*900MHz*	*1800MHz*	*2100MHz*	*2.6GHz*	*3.5GHz*	*Ka band*
HSPA+		✓		✓			
FDD-LTE	✓		✓		✓		
TDD-LTE					✓	✓	
WiMAX (802.16m)					✓	✓	
Satellite							✓

Figure 4.9: Combinations of technologies and frequency bands [Source: Analysys Mason for BSG]

The upper end of the 800MHz 'digital-dividend' band is only separated from the lower end of the 900MHz EGSM band by 18MHz (albeit with a larger separation between the downlink frequencies) so we have considered these two bands together in the modelling. Similarly the upper end of the 1800MHz GSM (DCS) band is only separated from the lower end of the 2100MHz IMT band by 40MHz so we have considered these two bands together in the modelling as well. The current ownership and availability of spectrum in the UK is shown in Figure 4.10.

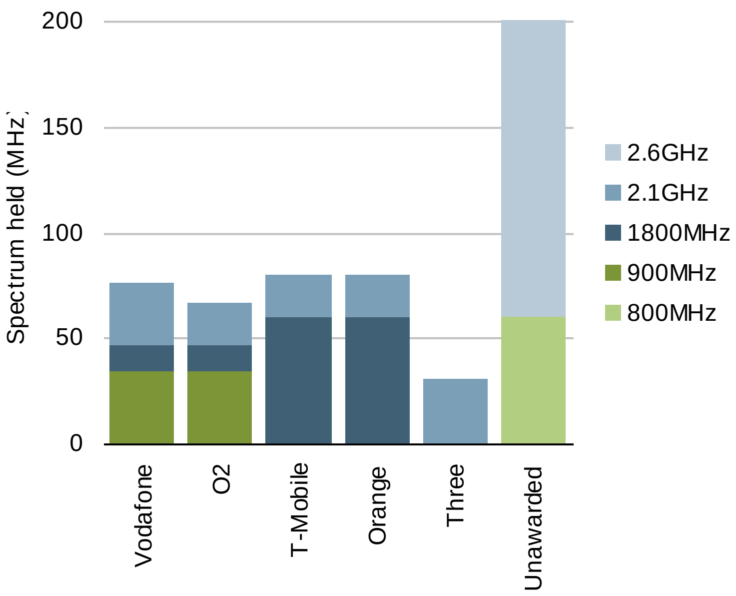

Figure 4.10: Distribution of paired spectrum [Source: Independent Spectrum Broker's Report, 2009]

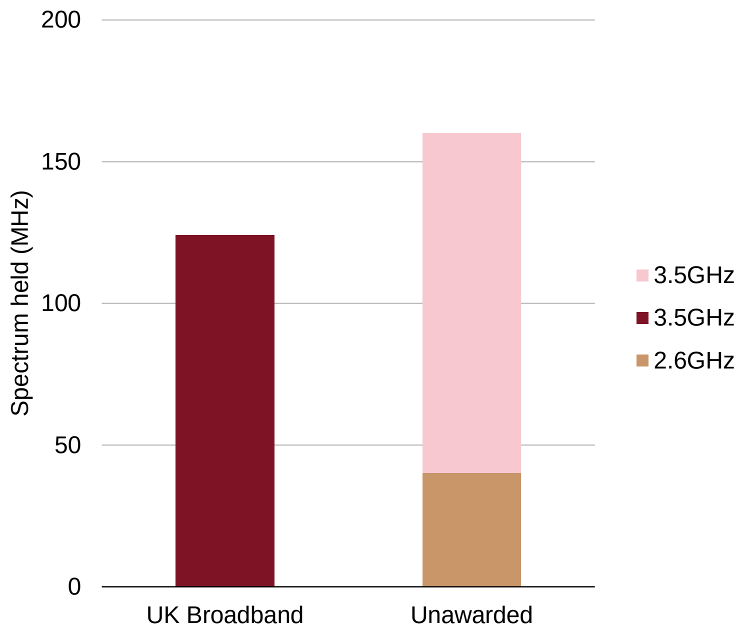

Figure 4.11: Distribution of unpaired spectrum (note: Unawarded spectrum at 3.5GHz refers to maximum amount of spectrum between 3.4 and 3.6GHz that could be released in the short term by the Ministry of Defence) [Source: Analysys Mason for BSG]

HSPA+ is expected to be deployed in the 2100MHz band in the UK and could potentially be deployed in the 800/900MHz band; however given the late availability of the 800MHz band in the UK, we believe that this band is more likely to be used for LTE. We note that the market is already being seeded with terminals that support 900MHz HSPA+. We believe there is little vendor support for HSPA+ at 2.6GHz so we have only considered LTE (both FDD and TDD) and WiMAX in this band. We have considered TDD-LTE and WiMAX in the 3.5GHz band.

Figure 4.12 below shows our assumptions on the spectrum options available to our hypothetical terrestrial wireless operator for the provision of data services.

	800MHz	*900MHz*	*1800MHz*	*1800/2100 MHz*	*2.6GHz*	*3.5GHz*	*Ka band*
HSPA+		2×10MHz		2×20MHz			
FDD-LTE	2×10MHz		2×20MHz		2×20MHz		
TDD-LTE					40MHz	50MHz	
WiMAX (802.16m)					40MHz	50MHz	

Figure 4.12: Assumptions on spectrum usage for terrestrial wireless operator [Source: Analysys Mason for BSG]

It should be noted that in the case of 2.6GHz, only 40MHz of spectrum may be usable for wide-area deployments as two 5MHz guard bands (or restricted blocks) may be required to minimise interference between TDD and FDD systems.

Dual-frequency deployments are a possibility in 2016. In the case of HSPA+ we assume that both 900MHz spectrum and 2100MHz spectrum can be used simultaneously. In the case of FDD-LTE we assume that the 800MHz spectrum can be used simultaneously with the 1800MHz or the 2.6GHz spectrum. In the case of TDD-LTE and WiMAX we assume that either the 2.6GHz or the 3.5GHz spectrum is used, but not both together. Dual-frequency deployments may also be able to use other spectrum pairings in practice.

Due to the requirement for different antennas to make use of the different bands, our modelling of dual-frequency deployments assumes that each property only accesses one of the two frequency bands. In practice there may be scope to increase the bandwidth for some properties by using both bands simultaneously, but this would bring an associated increase in CPE costs.

Our satellite modelling has focused on the Ka band. We assume that 1GHz will be available in total for the forward link[13] and 900MHz in total for the return link[14]. Assuming a re-use pattern based on clusters of four spotbeams, this implies that the spectral efficiency will need to be 4bit/Hz on the forward link and 1.33bit/Hz on the return link.

4.3.2 Terrestrial wireless network dimensioning

Wireless network dimensioning is typically estimated by considering the minimum number of base stations necessary to provide the required degree of geographical coverage, then calculating how much traffic the coverage network can support and comparing this with the expected level of traffic. From this it is possible to determine the number of additional base stations necessary to provide sufficient traffic-carrying capacity. If the coverage network is able to support the expected level of traffic then the network is said to be coverage-driven. If additional capacity base stations are required the network is said to be capacity-driven.

We have used a comprehensive link budget-based approach to calculate the coverage and capacity capabilities of the terrestrial wireless technologies under consideration. Details of the input assumptions can be found in Section A.2.

Terrestrial wireless coverage

For coverage, our cell radii are calculated from a link budget driven by the required cell-edge data rate. This is shown in Figure 4.13 below.

---

[13] Forward link frequencies: 19.7-20.2GHz and 17.3-17.7GHz and a further 100MHz elsewhere in the Ka-band

[14] Return link frequencies: 27.5-27.8125GHz, 28.4545-28.8265GHz and 29.4625-30GHz

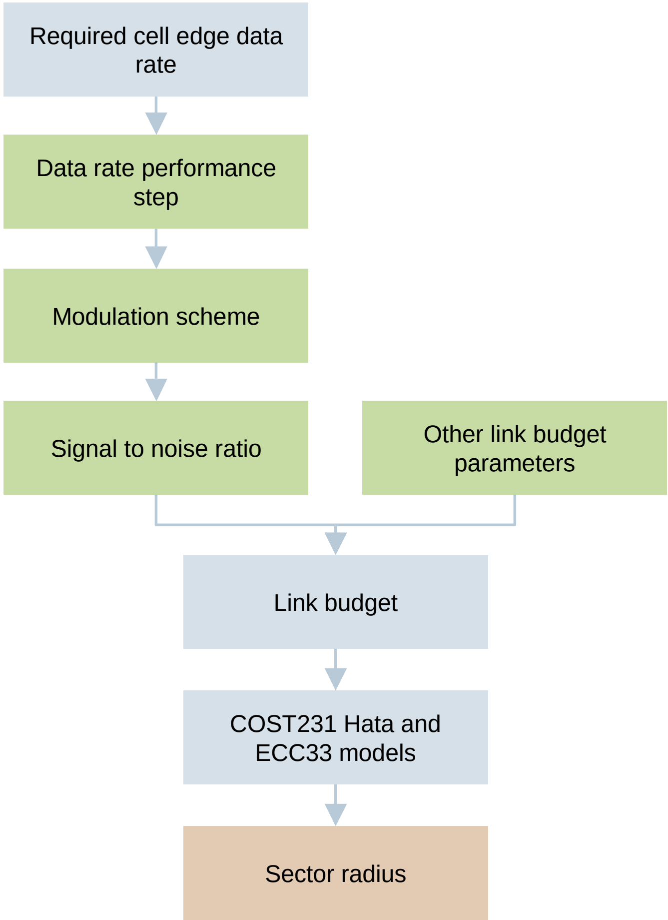

Figure 4.13: Sector radii calculation [Source: Analysys Mason for BSG]

We use the required cell-edge data rate (dictated by multi-room video streaming) to determine the required throughput performance. This performance drives a minimum signal-to-noise ratio, which we combine with other link budget parameters to create a maximum allowable path loss. We then use this path loss with a suitable propagation model to generate the cell radius.[15]

We use the cell radii along with a hexagonal area factor (in place of Pi) to calculate the number of cells required to cover a given area with a certain technology at a certain frequency. For a three-sector site, the area factor is assumed to be 1.95 (see Figure 4.14 below).

15 For frequencies up to 3GHz, we use the COST231 Hata model, which generates separate radii for urban, suburban and rural areas. For frequencies over 3GHz, we use the ECC33 model. Unfortunately, this model only generates radii for urban areas. Therefore we have used the COST231 Hata correction factors for suburban and rural areas with the ECC33 model in order to generate non-urban radii. In the absence of a suitable model for generating suburban and rural radii at 3GHz and above, we believe that this approach represents a good compromise and should produce results which provide a reasonable comparison across frequencies. We have further adapted the ECC33 model below 2km to have a near-distance path-loss profile similar to COST231 Hata. This allows us to use ECC 33 with the low path-loss link budgets generated by using indoor CPE such as dongles and desktop units.

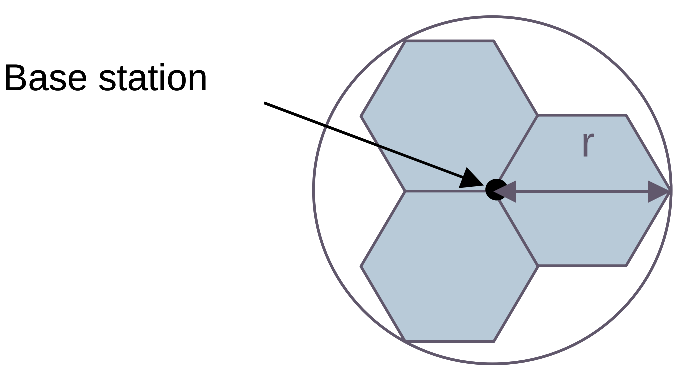

Figure 4.14: Explanation of area factor for three-sector cell: the area is the shaded hexagons is approximately 1.95r^2 [Source: Analysys Mason for BSG]

The overall process of calculating the number of terrestrial wireless coverage sites is shown in the Figure 4.15 below.

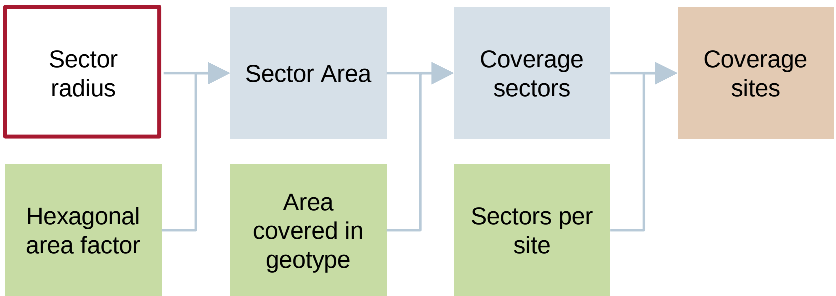

Figure 4.15: Terrestrial wireless coverage methodology [Source: Analysys Mason for BSG]

However, the top-down approach requires an adjustment to take account of additional coverage sites. This adjustment is to take account of the additional sites required to account for hilly terrain and fragmentation of geotypes. These issues are illustrated in Figure 4.16 below.

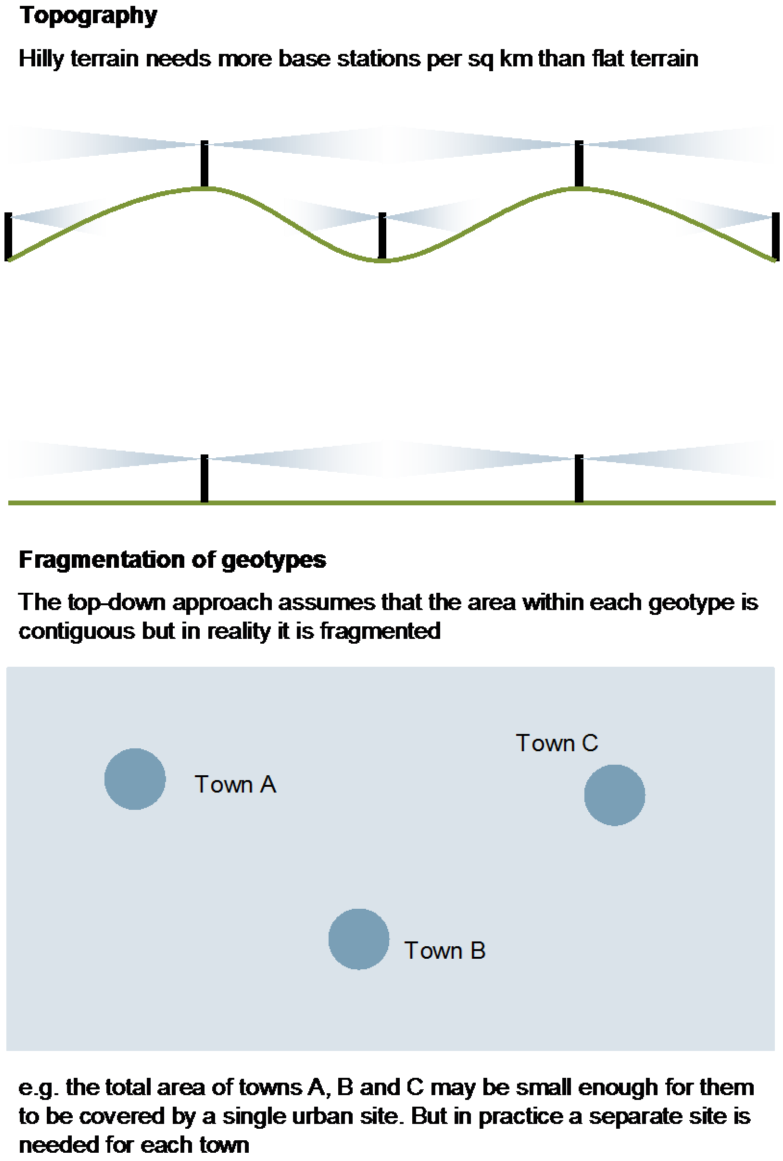

Figure 4.16: Impact of hilly terrain and fragmented geotypes [Source: Analysys Mason for BSG]

The cell radii outputs of our propagation model for various technologies under Scenario A (with the lowest cell-edge data rate requirement) are shown in Figure 4.17. Results are shown below for outdoor antennas at the customer premises and with TDD technologies having a 2:1 downlink to uplink ratio.

Technology	*Urban*	*Suburban 1*	*Suburban 2*	*Rural 1*	*Rural 2*	*Rural 3*	*Rural 4*
HSPA+ 900	6.75	12.00	12.00	34.50	34.50	34.50	34.50
HSPA+ 2100	3.00	6.75	6.75	23.75	23.75	23.75	23.75
HSPA+ Dual 900/2100	6.75	12.00	12.00	34.50	34.50	34.50	34.50
FDD-LTE 800	7.75	13.50	13.50	37.50	37.50	37.50	37.50
FDD-LTE 1800	4.25	9.25	9.25	29.00	29.00	29.00	29.00
FDD-LTE 2.6GHz	3.50	7.25	7.25	25.00	25.00	25.00	25.00
FDD-LTE Dual 800/1800	7.75	13.50	13.50	37.50	37.50	37.50	37.50
FDD-LTE Dual 800/2.6	7.75	13.50	13.50	37.50	37.50	37.50	37.50
TDD-LTE 2.6GHz	2.50	5.25	5.25	20.50	20.50	20.50	20.50
TDD-LTE 3.5GHz	2.00	4.50	4.50	15.50	15.50	15.50	15.50
WiMAX 2.6GHz	2.50	5.25	5.25	20.50	20.50	20.50	20.50
WiMAX 3.5GHz	2.00	4.50	4.50	15.50	15.50	15.50	15.50

Figure 4.17: Cell radii output (km) from propagation model (Scenario A) [Source: Analysys Mason for BSG]

We then apply a factor to each radius to account for the hilliness within each geotype. This topographical factor is derived from detailed analysis of the terrain in the UK. The resultant cell radii for various technologies in Scenario A are shown in Figure 4.18.

Technology	*Urban*	*Suburban 1*	*Suburban 2*	*Rural 1*	*Rural 2*	*Rural 3*	*Rural 4*
HSPA+ 900	5.84	9.40	9.04	21.82	20.62	19.91	16.25
HSPA+ 2100	2.75	5.66	5.50	15.80	15.03	14.56	12.16
HSPA+ Dual 900/2100	5.84	9.40	9.04	21.82	20.62	19.91	16.25
FDD-LTE 800	6.62	10.49	10.08	23.45	22.14	21.35	17.34
FDD-LTE 1800	3.80	7.45	7.20	18.72	17.74	17.15	14.13
FDD-LTE 2.6GHz	3.20	5.99	5.81	16.45	15.63	15.13	12.57
FDD-LTE Dual 800/1800	6.62	10.49	10.08	23.45	22.14	21.35	17.34
FDD-LTE Dual 800/2.6	6.62	10.49	10.08	23.45	22.14	21.35	17.34
TDD-LTE 2.6GHz	2.36	4.48	4.37	13.89	13.24	12.85	10.81
TDD-LTE 3.5GHz	1.89	3.93	3.84	10.90	10.44	10.16	8.69
WiMAX 2.6GHz	2.36	4.48	4.37	13.89	13.24	12.85	10.81
WiMAX 3.5GHz	1.89	3.93	3.84	10.90	10.44	10.16	8.69

Figure 4.18: Cell radii (km) adjusted for hilliness (Scenario A) [Source: Analysys Mason for BSG]

Finally, we further adjust the cell radii to account for fragmentation of the geotypes. We have calibrated our adjustment factors against Ofcom’s LRIC model for mobile termination. The resultant cell radii for Scenario A are shown in Figure 4.17.

Technology	*Urban*	*Suburban 1*	*Suburban 2*	*Rural 1*	*Rural 2*	*Rural 3*	*Rural 4*
HSPA+ 900	3.25	5.28	8.32	12.99	14.66	16.69	16.25
HSPA+ 2100	1.53	3.18	5.06	9.41	10.69	12.21	12.16
HSPA+ Dual 900/2100	3.25	5.28	8.32	12.99	14.66	16.69	16.25
FDD-LTE 800	3.68	5.90	9.27	13.97	15.74	17.90	17.34
FDD-LTE 1800	2.11	4.19	6.62	11.15	12.62	14.38	14.13
FDD-LTE 2.6GHz	1.78	3.37	5.34	9.80	11.11	12.68	12.57
FDD-LTE Dual 800/1800	3.68	5.90	9.27	13.97	15.74	17.90	17.34
FDD-LTE Dual 800/2.6	3.68	5.90	9.27	13.97	15.74	17.90	17.34
TDD-LTE 2.6GHz	1.31	2.52	4.02	8.27	9.42	10.77	10.81
TDD-LTE 3.5GHz	1.05	2.21	3.53	6.49	7.42	8.52	8.69
WiMAX 2.6GHz	1.31	2.52	4.02	8.27	9.42	10.77	10.81
WiMAX 3.5GHz	1.05	2.21	3.53	6.49	7.42	8.52	8.69

Figure 4.19: Cell radii (km) adjusted for hilliness and fragmentation (Scenario A) [Source: Analysys Mason for BSG]

The cell-edge data rate requirements are higher in Scenarios B and C, and this requires a reduction in cell radius for some of the technology/frequency combinations. This effect is most significant in the sub-1GHz band, where the small available bandwidth requires a large increase in the signal-to-noise ratio. This also affects the average throughput of the cell, as discussed below and in more detail in Section A.1.4. The cell radii for Scenarios B and C, adjusted for hilliness and fragmentation, are shown in Figure 4.20.

Technology	*Urban*	*Suburban 1*	*Suburban 2*	*Rural 1*	*Rural 2*	*Rural 3*	*Rural 4*
HSPA+ 900	1.53	2.52	4.02	7.36	8.39	9.61	9.71
HSPA+ 2100	1.05	2.21	3.53	7.01	8.00	9.16	9.28
HSPA+ Dual 900/2100	1.53	2.52	4.02	7.36	8.39	9.61	9.71
FDD-LTE 800	1.31	2.21	3.53	6.49	7.42	8.52	8.69
FDD-LTE 1800	1.31	2.52	4.02	8.02	9.14	10.46	10.53
FDD-LTE 2.6GHz	1.18	2.33	3.73	7.57	8.63	9.88	9.98
FDD-LTE Dual 800/1800	1.31	2.52	4.02	8.02	9.14	10.46	10.53
FDD-LTE Dual 800/2.6	1.31	2.33	3.73	7.57	8.63	9.88	9.98
TDD-LTE 2.6GHz	1.18	2.40	3.83	7.82	8.91	10.19	10.26
TDD-LTE 3.5GHz	1.05	2.21	3.53	6.49	7.42	8.52	8.69
WiMAX 2.6GHz	1.18	2.40	3.83	7.82	8.91	10.19	10.26
WiMAX 3.5GHz	1.05	2.21	3.53	6.49	7.42	8.52	8.69

Figure 4.20: Cell radii (km) adjusted for hilliness and fragmentation (Scenarios B and C) [Source: Analysys Mason for BSG]

Terrestrial wireless average throughput

We have also used a link budget approach to calculate the average throughput available in each cell. This approach is shown in Figure 4.21 below.

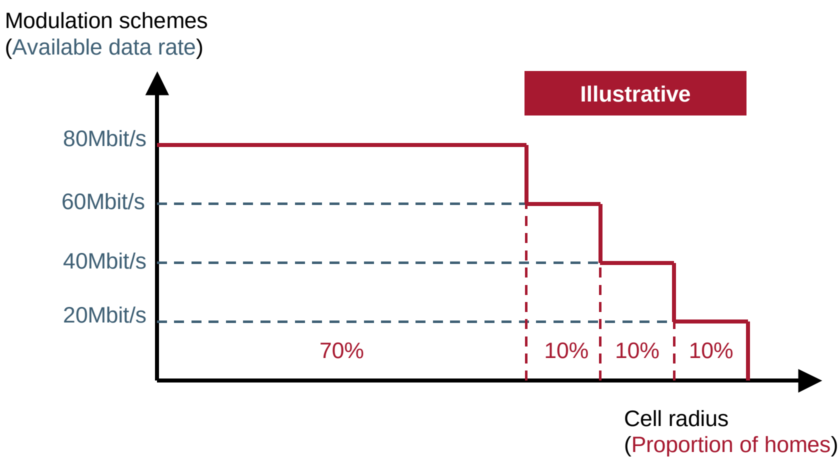

Figure 4.21: Calculation of average sector throughput [Source: Analysys Mason for BSG]

Based on the link budget, we calculate the available data rate at different distances from the cell centre. This then allows us to calculate the overall average throughput of the cell, based on the average of the maximum available data rates, weighted according to the number of homes covered. We assume that homes are evenly distributed within a geotype. If homes are in reality more tightly clustered, a greater number of households would have access to higher data rates and therefore the throughput would be higher. Therefore, the costs of capacity-driven geotypes may be lower in reality than our modelling suggests. However, it should be noted that the average downlink throughput is affected by the size of the cell, which is in turn limited by the uplink performance. This concept is illustrated in Figure 4.22 below.

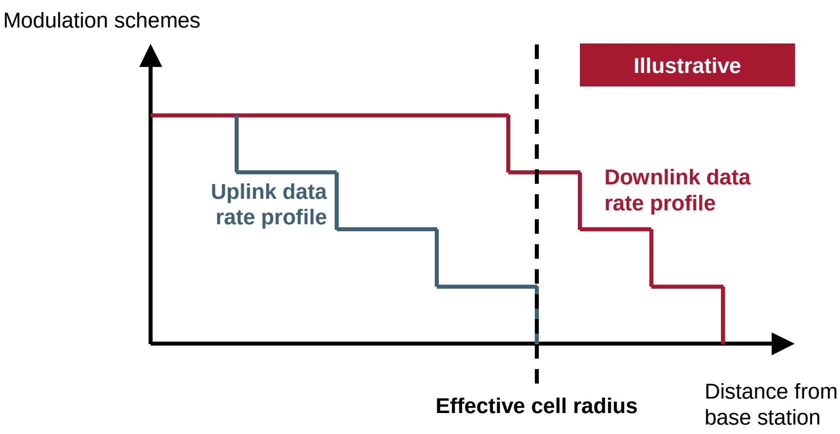

Figure 4.22: Impact of cell radius on cell average throughput [Source: Analysys Mason for BSG]

The downlink average throughput of the cell is the weighted average of the available data rates within the radius dictated by the uplink performance. Any downlink signal available beyond the effective cell radius will create interference with other cells. This interference could be reduced by decreasing the output power of the base station but this will reduce the distance over which higher modulation schemes can be received and so decrease the average downlink throughput for the cell. Therefore, there is a trade-off between maximising average downlink throughput and minimising interference with other cells.

It should further be noted that (based on the methodology described above) the average downlink throughput of a technology is significantly affected by the difference in the downlink and uplink link budgets. If a technology has a relatively high link budget for the downlink and a much smaller link budget for the uplink, the edge of the cell (which is dictated by the uplink) will coincide with a high modulation scheme (downlink data rate). Therefore the weighted average of the available downlink data rates (which drives average downlink throughput) will also be high. If however, the link budgets for the uplink and downlink are more similar, then the cell edge will coincide with a low modulation scheme (downlink data rate). In this second case, the weighted average of the downlink data rates will be lower (as more, lower modulation schemes are included) and therefore the downlink average throughput will be lower. In recognition of the fact that link budget overlap will be limited by the interference created between adjacent cells, and to ensure a fair comparison between the average throughput performance of different technologies, we limit the link budget overlap to a fixed number of decibels for all technologies.

We use the above methodology to create a parameterised average throughput calculation which allows us to compare average cell throughput with different technologies at different frequencies. However, the actual average throughput is affected by more than the available data rate (including the number of customers trying to use the cell at any given time) and therefore we apply an additional reduction factor to the calculated cell average throughput. We have calibrated this factor against published results for cell throughput from theoretical simulations. The resultant average cell throughput values are given in Figure A.21 of the annex.

Once we have calculated the capacity of each sector, we use the total demand per geotype to calculate the number of capacity sectors required to meet the demand. This is shown in Figure 4.23 below.

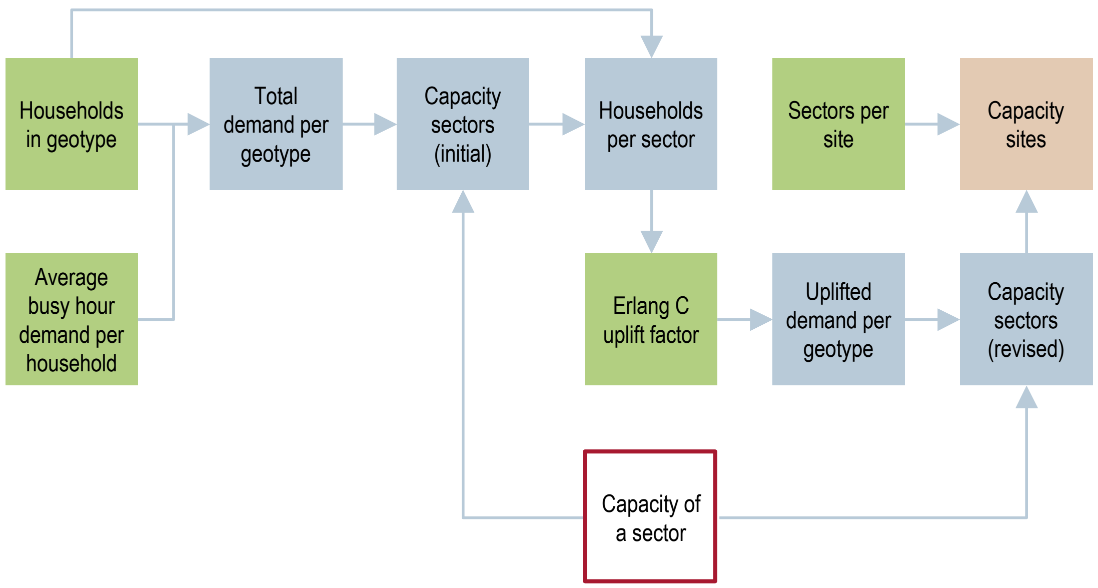

Figure 4.23: Terrestrial wireless capacity methodology [Source: Analysys Mason for BSG]

In order to apply the Erlang C over-provisioning calculation, we must first calculate the number of capacity sectors for an 'ideal' network (which gives the number of households per node). We can then calculate the required over-provisioning factor to derive the 'revised' number of capacity sectors for the over-provisioned network.

Once we have calculated the coverage and capacity sites for each geotype, we assume that the total sites needed in a geotype will be the larger of the two site counts (i.e. that the network is either coverage- or capacity-driven in each geotype).

4.3.3 Satellite system dimensioning

The dimensioning of our hypothetical satellite system is considerably simpler than the dimensioning of our hypothetical terrestrial wireless networks because each satellite is assumed to deliver a fixed amount of throughput in the downlink and uplink directions, spread across a pre-determined number of spotbeams. We have calculated the coverage and capacity capabilities of the satellite system based on the performance of each spotbeam.

- For the coverage of a spotbeam, we calculate the area covered from the angle of spread of the spot beam and the height of the satellite (assumed to be geostationary orbit).
- For the capacity of a spotbeam, we have used industry benchmarks for the total capacity of Ka-band multi-spotbeam satellite, divided by the number of spotbeams that each satellite provides.

We have also applied the Erlang C calculation in determining the actual number of homes that can be served using a single spotbeam.

There is no explicit provision in the satellite system dimensioning for additional satellites to provide redundancy in case of system failure.

More detail on the input assumptions for our satellite calculations, along with a more detailed example of how we calculate the coverage and capacity of a satellite is included in Sections A.2.6 and A.3.2.

5 Results

This section summarises the results of the study, focusing on the upfront deployment costs of terrestrial fixed wireless and satellite networks. We also provide a discussion around the costs for spectrum and operating costs at the end of the section.

Where possible, we have tried to maintain a base set of assumptions to aid comparison of the results. Unless otherwise stated, the results below assume:

- upload traffic demand is 10% of download traffic
- high-gain outdoor antennas are used at customer premises
- spectrum costs are not included
- costs are for 2016[16], but are presented in real 2010 values.

In addition, the terrestrial wireless results assume:

- no capex costs for using existing fibre to backhaul
- 100% re-use of 12 000 existing sites
- an overall population coverage of 99% (note: satellite is assumed to provide 100% population coverage).

5.1 Terrestrial wireless networks

5.1.1 Total UK site count

The total number of sites that a hypothetical terrestrial wireless operator with 25% market share would need to deploy to cover the whole of the UK is shown in Figure 5.1 below. Results are shown for each of the technology and spectrum combinations that we have modelled and each of the three demand scenarios.

16 We recognise that in reality, procurement would take place in advance of the deployment and so the associated costs would be for a date before 2016. However, we have assumed that this would have a limited impact on the output of the study and have not considered prior procurement explicitly in the modelling.

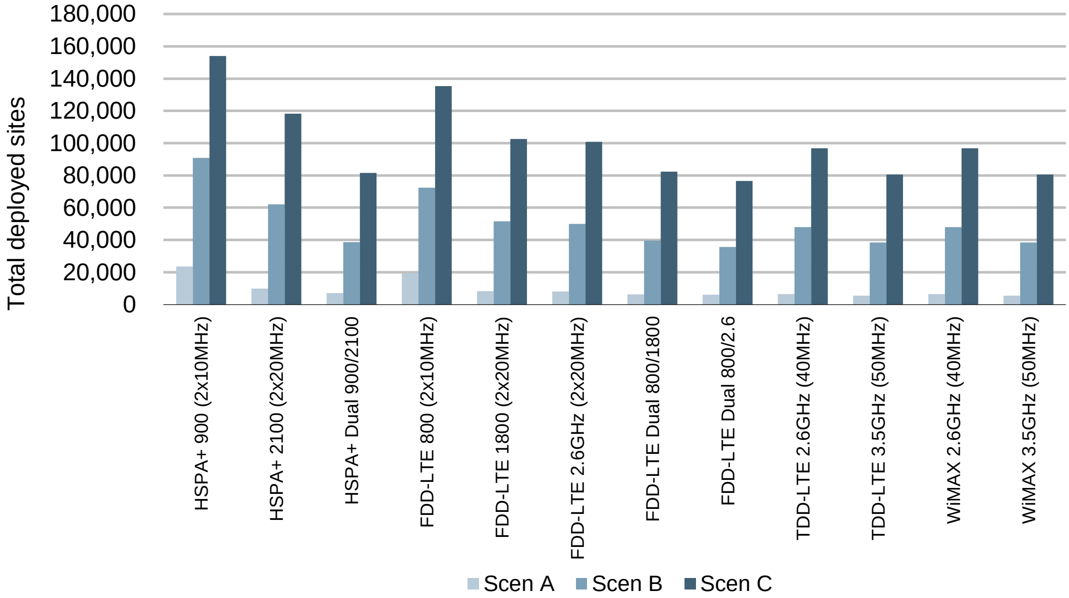

Figure 5.1: *Total number of sites required per operator for terrestrial wireless broadband across the UK in 2016 [Source: Analysys Mason for BSG]*

The results above assume that the TDD technologies have a downlink to uplink ratio of 2:1.

Across all scenarios and technologies, the deployment of sites is driven by capacity requirements rather than coverage requirements. Consequently, the infrastructure needed to meet the forecast demand under each of the three scenarios differs significantly. The relatively high capacity of the technologies being considered means that to meet the demand forecast in Scenario A using frequencies above 1GHz, our hypothetical terrestrial wireless operator needs to upgrade between 5000 and 10 000 of its existing sites. It can be seen that the restrictions that we have assumed in the sub-1GHz bands (only 2×10MHz of bandwidth, and only 2×4 MIMO due to antenna size constraints) mean that an operator using the low frequencies needs to deploy a larger number of sites in Scenario A.

The restrictions in the sub-1GHz bands have a larger impact on the number of sites required in Scenarios B and C with site counts ranging from 72 000 sites for FDD-LTE at 800MHz in Scenario B to 150 000 sites for HSPA+ at 900MHz in Scenario C, which would clearly pose a major deployment challenge. For other frequencies (above 1GHz), the total site count is still very large, at 35 000 to 62 000 sites for Scenario B and 77 000 to 118 000 sites for Scenario C. We assume that the hypothetical operator’s 12 000 existing sites could be upgraded, but the remainder would need to be deployed as new sites.

In terms of the technologies, the dual-frequency FDD technologies and the TDD technologies (under a 2:1 downlink to uplink ratio) deliver similar results, as each can provide similar amounts of bandwidth for the downlink capacity[17]. It should be noted that our model assumes an even distribution of households within the cell, when in reality there is likely to be some degree of clustering around the centre. Clustering would give a greater proportion of users access to higher data rates, improving the average throughput of the cell and reducing the required cell count. Therefore, an actual deployment may require slightly fewer sites than the results above suggest.

5.1.2 Upfront deployment cost per home connected

The average cost per home connected with terrestrial wireless broadband technology is shown in Figure 5.2 below. Results for TDD technologies are again shown with a downlink to uplink ratio of 2:1, meaning that they provide twice as much capacity on the downlink as they do on the uplink (in theory the FDD technologies provide equal amounts of capacity in each direction).

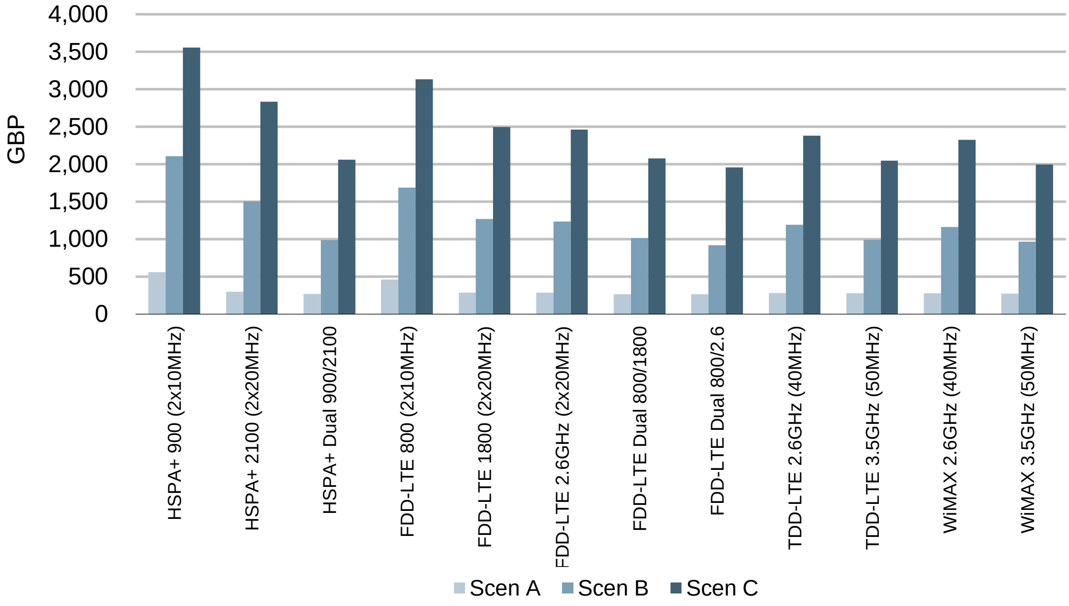

Figure 5.2: Average deployment cost per home connected for terrestrial wireless [Source: Analysys Mason for BSG]

The average cost per home connected ranges from GBP260 to GBP560 in Scenario A, and from GBP920 to GBP2100 in Scenario B. The results at this stage suggest that the lowest-cost technology/spectrum combination is, by a small margin, FDD-LTE deployed on a dual-frequency basis at 800MHz/2.6GHz (although we note this is dependent on a number of key assumptions, as evidenced in the sensitivity testing detailed in the following sections).

17 Under dual-frequency scenarios, we assume that the higher-frequency CPE is deployed as far out as possible to maximise the available throughput for the users within the cell. However to ensure that the overall average throughput of the cell benefits from the capacity both sets of spectrum, we assume that there is always at least a small area covered by the lower frequency.

The cost per home connected by geotype for each technology and frequency is shown for Scenarios A, B and C in Figures 5.3 to 5.5. Once again TDD technologies are assumed to have a downlink to uplink ratio of 2:1.

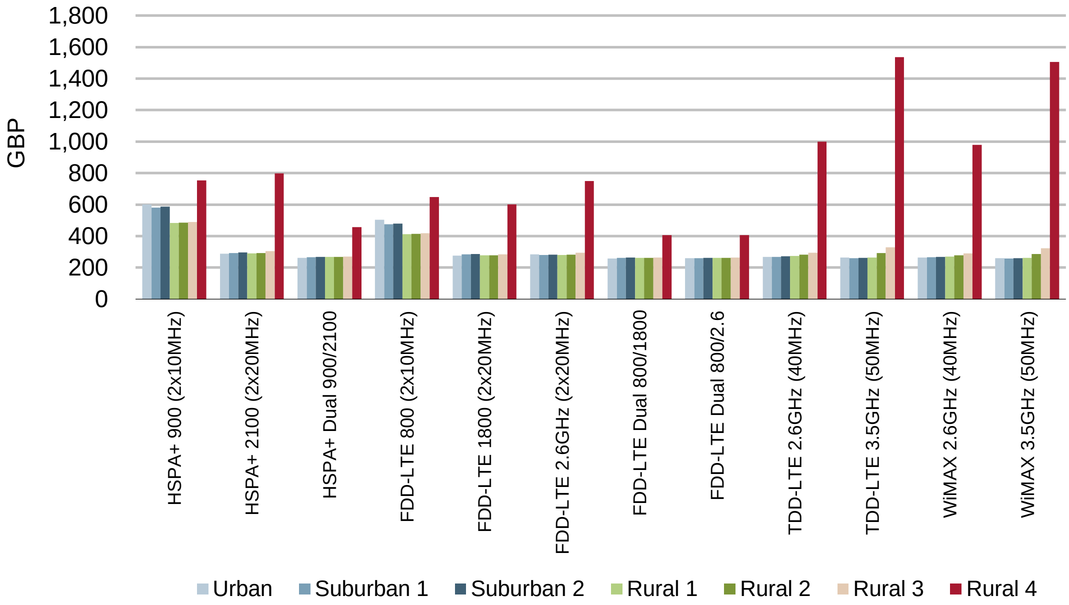

Figure 5.3: *Deployment cost per home connected by geotype (Scenario A) [Source: Analysys Mason for BSG]*

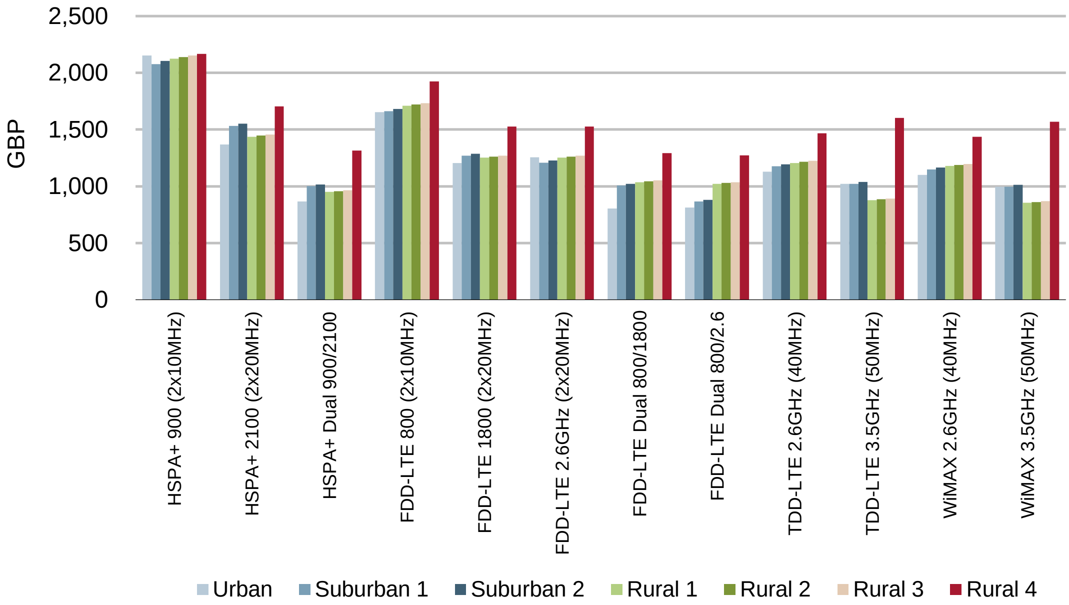

Figure 5.4: *Deployment cost per home connected by geotype (Scenario B) [Source: Analysys Mason for BSG]*

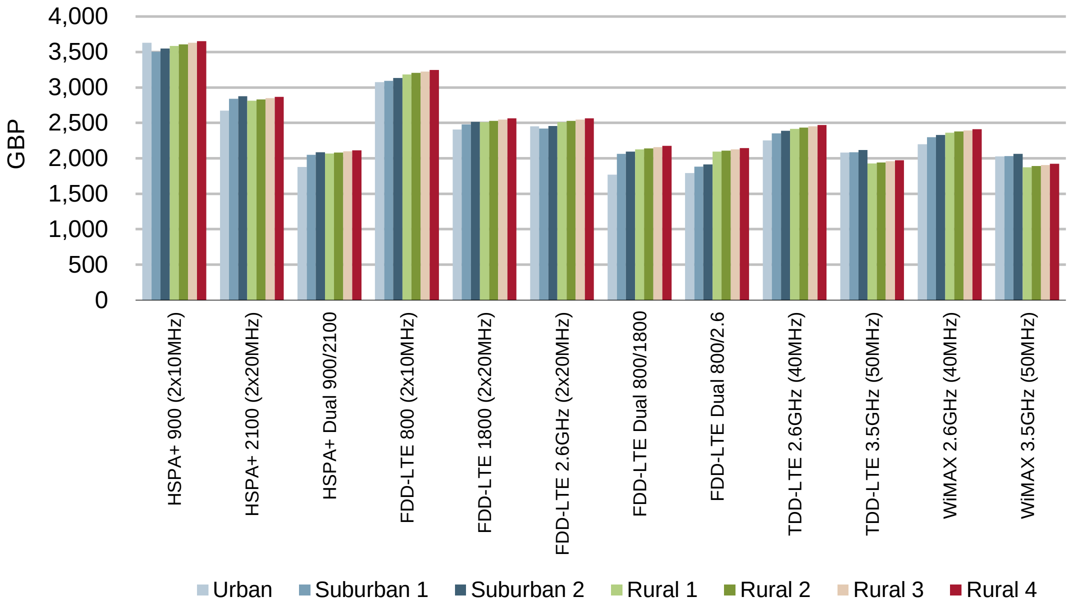

Figure 5.5: *Deployment cost per home connected by geotype (Scenario C) [Source: Analysys Mason for BSG]*

In Scenarios A and B, the cost per home connected for the final geotype (Rural 4) is consistently higher than to the other geotypes due to the fact that the final geotype is coverage-driven under many of the technology/frequency combinations. For some technology/frequency combinations, the costs in urban and suburban areas are higher than some rural areas. This is due to the fact that our model shows slightly better signal propagation in rural areas since there is less clutter to cause reflections of the radio waves.

Impact of TDD ratio

While the results above assume that the TDD technologies have a downlink to uplink ratio of 2:1, the TDD costs can be reduced by optimising this ratio to more closely match the balance of traffic assumed in our demand scenarios.

Figures 5.6 to 5.8 below show the upfront deployment cost per home connected by geotype with TDD downlink to uplink ratios of 2:1, 3:1, 5:1 and 8:1. Results are given for WiMAX at 3.5GHz as our modelling shows that this TDD technology has the lowest costs.

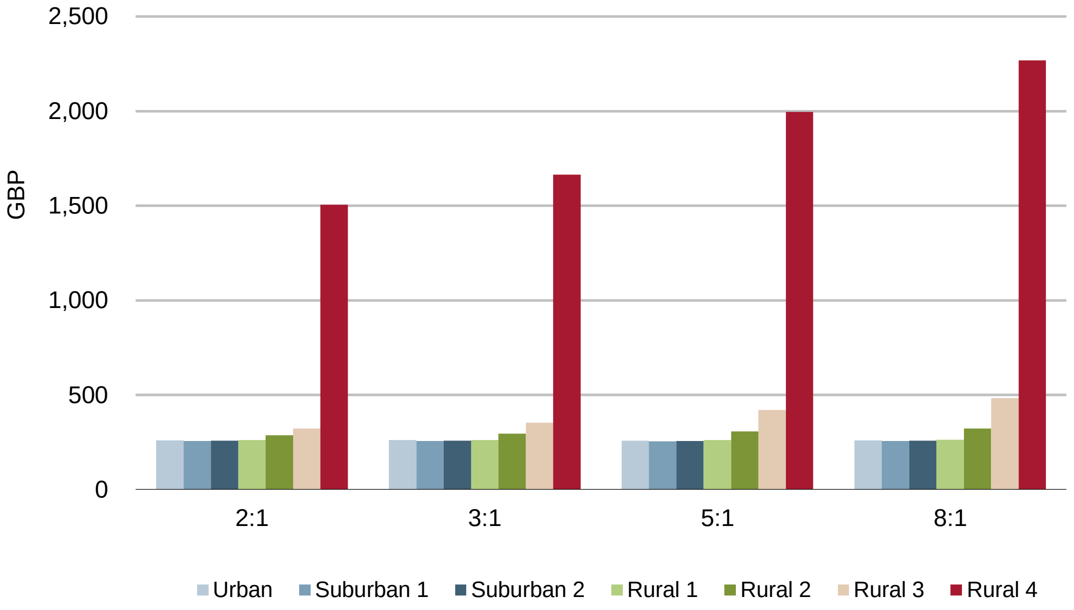

Figure 5.6: *Impact of TDD ratio on deployment cost per home connected for WiMAX at 3.5GHz, Scenario A [Source: Analysys Mason for BSG]*

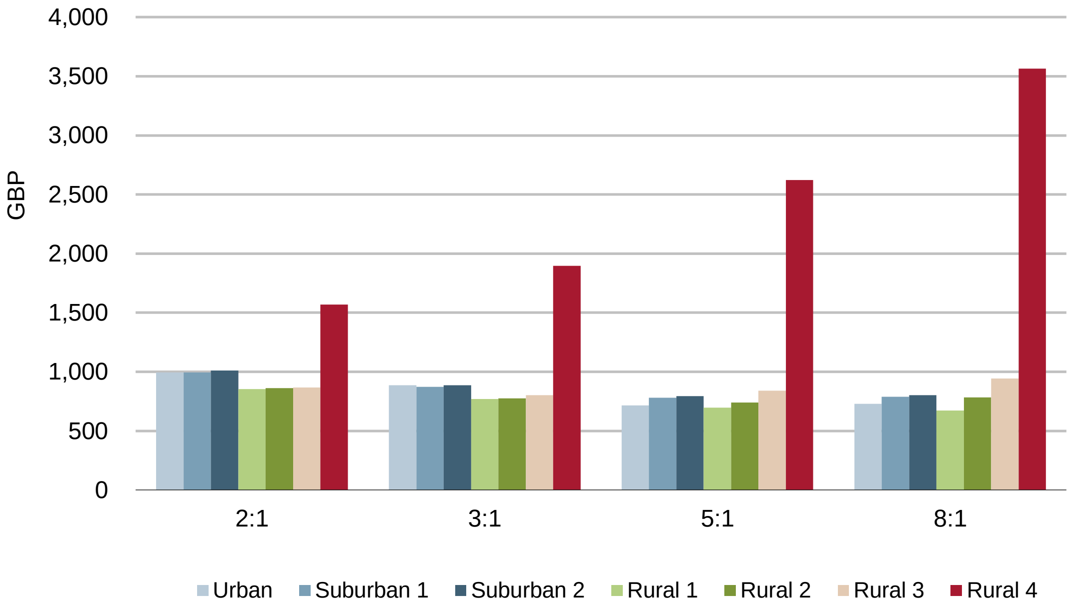

Figure 5.7: *Impact of TDD ratio on deployment cost per home connected for WiMAX at 3.5GHz, Scenario B [Source: Analysys Mason for BSG]*

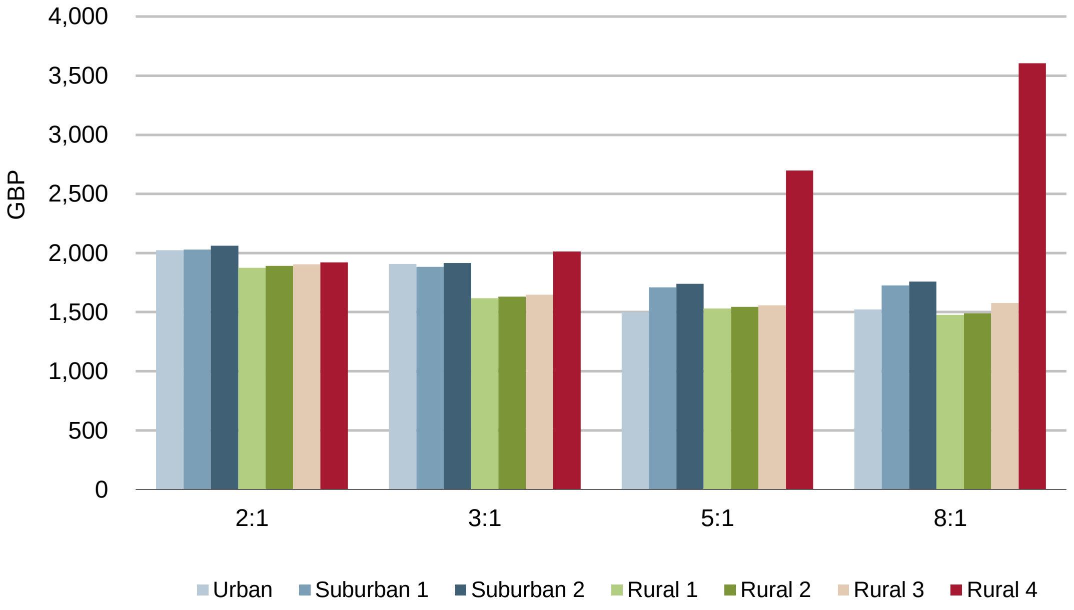

Figure 5.8: *Impact of TDD ratio on deployment cost per home connected for WiMAX at 3.5GHz, Scenario C [Source: Analysys Mason for BSG]*

The results above show that, across the demand scenarios, increasing the ratio of downlink to uplink bandwidth reduces the cost per home connected in most geotypes, but there is a marked increase in the cost per home connected for the final geotype (Rural 4). This is because, for WiMAX at 3.5GHz, costs in the final geotype are driven by coverage (not capacity). Decreasing the proportion of bandwidth used for the uplink reduces the uplink power and therefore reduces cell radius, driving up costs. However, it should be noted that the Rural 4 geotype contains just 1% of the UK population, so by increasing the downlink to uplink ratio and with an 8:1 ratio the cost for WiMAX at 3.5GHz is lower than for FDD-LTE deployed on a dual-frequency basis at 800MHz/2.6GHz.

It should be noted that in terms of technological performance, our modelling suggests that TDD-LTE and WiMAX will be very similar. Our cost data suggests that base station costs for WiMAX may be slightly lower than those for TDD-LTE, which is why the modelling shows WiMAX to be the lower-cost option. However, the two sets of costs are sufficiently similar, and the future demand for both types of equipment is sufficiently uncertain, that in reality either technology could turn out to be the lowest-cost TDD option in 2016.

It should further be noted that if IP traffic flows were to become more symmetric by 2016, then TDD networks may lose some of their advantage. However, we do expect a high level of traffic asymmetry to continue for the foreseeable future.

Impact of type of CPE

The deployment costs can be further reduced through the use of more sophisticated CPE schemes. We have considered the impact of using different types of CPE on our lowest-cost terrestrial wireless technology (i.e. WiMAX at 3.5GHz with a downlink to uplink ratio of 8:1). The results are shown in Figures 5.9 to 5.11 below.

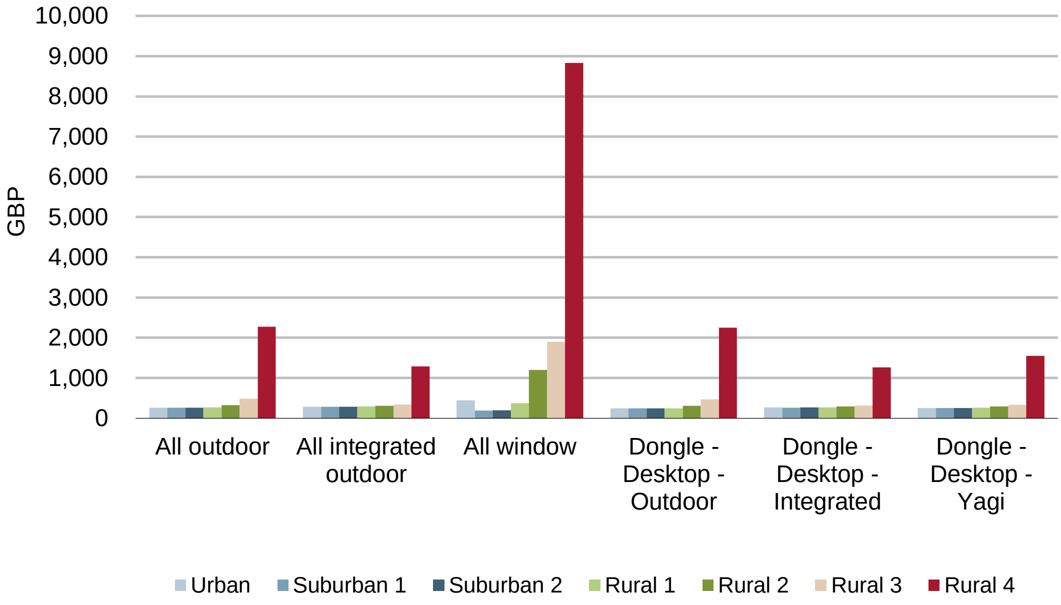

Figure 5.9: *Impact of different types of CPE for terrestrial wireless on deployment cost per home connected (Scenario A, WiMAX 3.5GHz 8:1) [Source: Analysys Mason for BSG]*

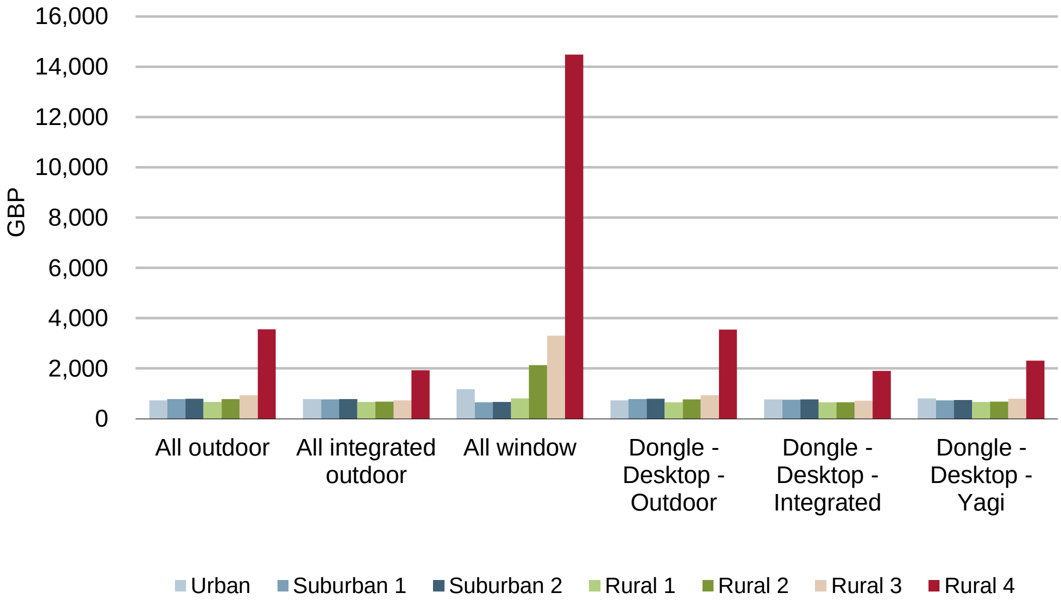

Figure 5.10: Impact of different types of CPE for terrestrial wireless on deployment cost per home connected (Scenario B, WiMAX 3.5GHz 8:1) [Source: Analysys Mason for BSG]

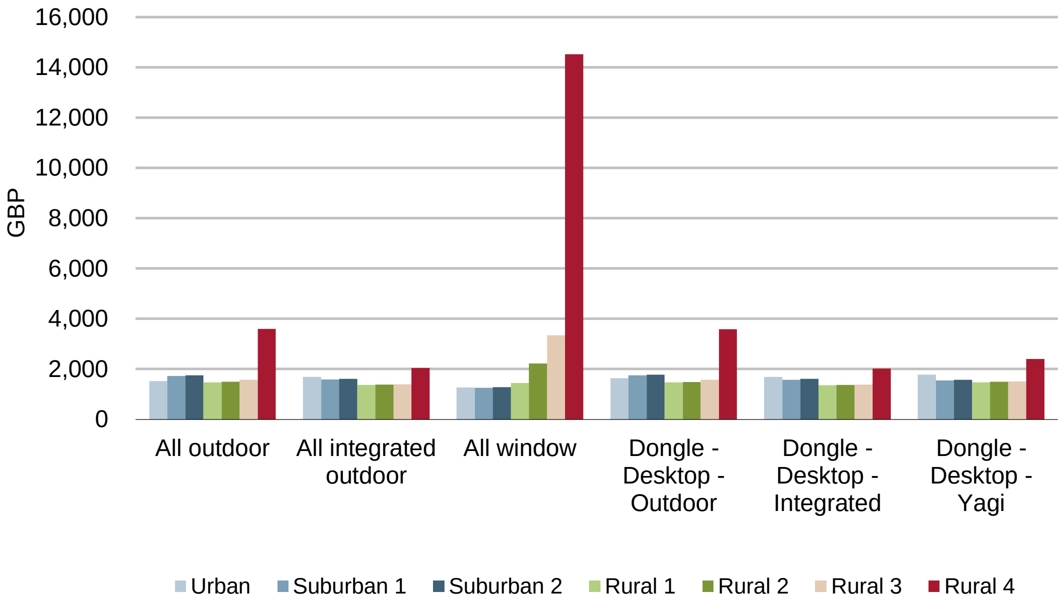

Figure 5.11: Impact of different types of CPE for terrestrial wireless on deployment cost per home connected (Scenario C, WiMAX 3.5GHz 8:1) [Source: Analysys Mason for BSG]

The results above show that different CPE may be appropriate for use in different geotypes. In more rural geotypes, the overall cost of deploying integrated outdoor CPE (in which the active electronics are mounted in a watertight enclosure immediately behind the antenna) is lower than the overall cost of deploying the standard outdoor antenna connected to a desktop unit, despite the higher cost of integrated outdoor CPE. This is because the integrated outdoor CPE achieves higher performance by eliminating the losses that occur in the RF cables linking the antenna to the desktop unit, meaning that cells are larger and users may have access to higher data rates. The use of integrated outdoor CPE significantly mitigates the impact of coverage in the final geotype when the TDD downlink to uplink ratio is 8:1. The modelling suggests that window-mounted CPE may offer a good compromise between performance and overall cost in some geotypes (we assume that a window-mounted CPE is suitable for self-installation), but due to its lower gain window-mounted CPE may be less suitable for use in the most rural geotypes.

We have also considered the impact of using a mixed deployment of CPE, for example deploying dongles and desktop units close to the base station (to minimise costs) and deploying outdoor antennas further out to maximise the cell radius. Our model indicates that the lowest-cost option is a combination of dongles, desktop CPE and integrated outdoor CPE. Figure 5.12 gives an indication of the maximum radii to which different CPE can be deployed. It should be noted that we assume only one type of CPE is deployed at a given location, and that the lowest-cost CPE is deployed as far out as possible.

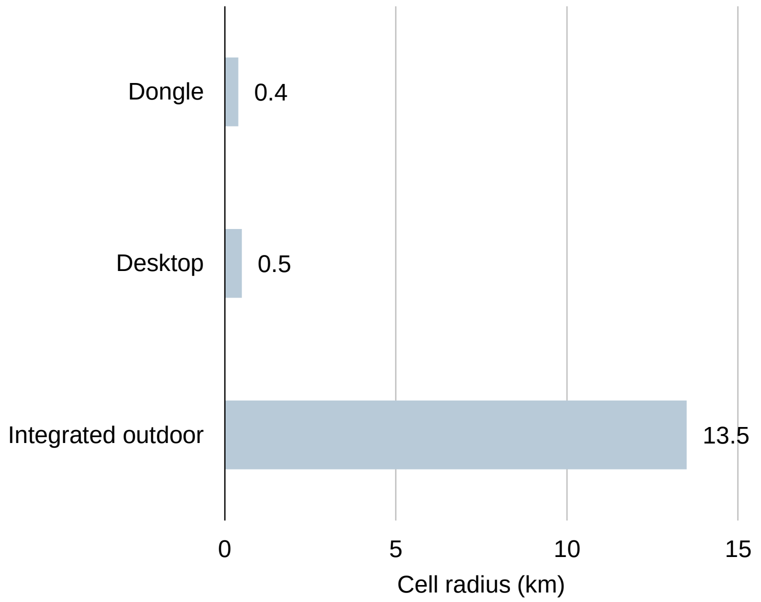

Figure 5.12: The extent to which different CPE can be deployed within the cell (Rural geotypes, Scenario B, WiMAX 3.5GHz 8:1) [Source: Analysys Mason for BSG]

In the above example, the operator would deploy dongles in premises up to 400m from the base station, desktop CPE in premises between 400m and 500m from the base station, and integrated outdoor CPE in the rest of the cell.

The indoor CPE can be deployed at lower cost, but reduces the effective throughput performance of the cell. However, the results above show that the use of this CPE strategy can deliver a further small decrease in cost.

We have also considered the impact of using a Yagi or log periodic antenna (similar to a terrestrial TV aerial) rather than a patch antenna. Yagi and log periodic antennas tend to have higher gains than patch antennas. However, as we assume that only one Yagi or log periodic antenna can be deployed (due to size and planning constraints), our modelling indicates that the overall performance is not as good as an outdoor patch antenna with MIMO.

Breakdown of upfront deployment cost

Breakdowns of the upfront deployment cost under Scenarios A, B and C for our lowest-cost terrestrial wireless technology are shown in Figures 5.13 to 5.15 below.

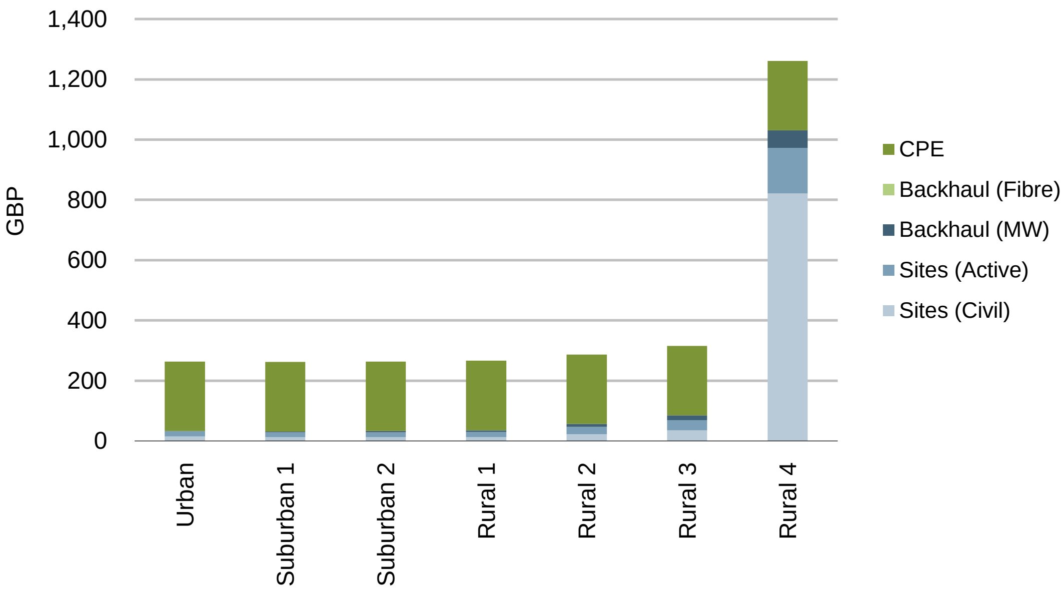

Figure 5.13: Breakdown of deployment cost per home connected by geotype for terrestrial wireless (Scenario A, WiMAX 3.5GHz 8:1, dongle/desktop/integrated outdoor CPE) [Source: Analysys Mason for BSG]

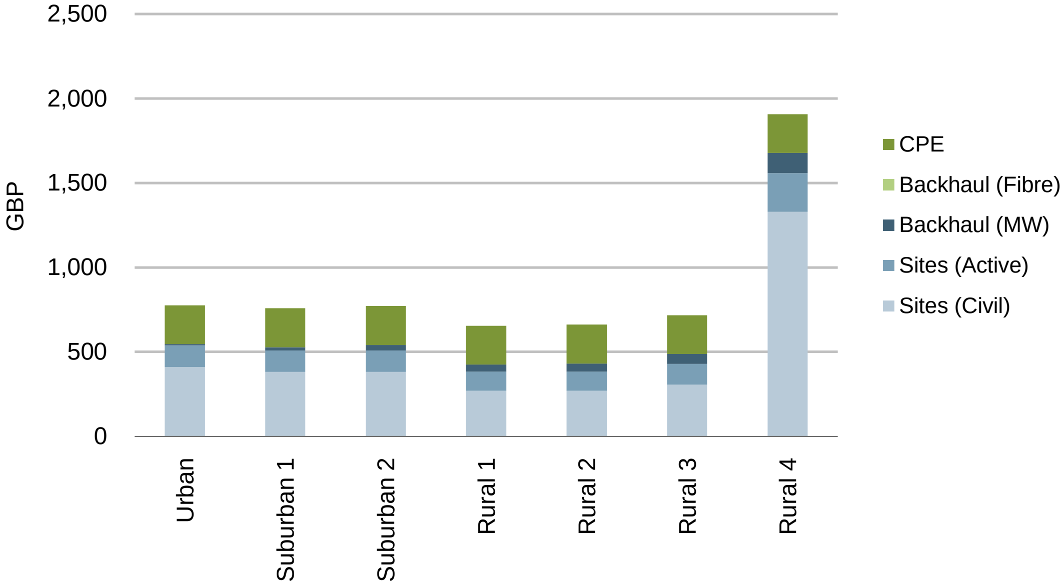

Figure 5.14: Breakdown of deployment cost per home connected by geotype for terrestrial wireless (Scenario B, WiMAX 3.5GHz 8:1, dongle/desktop/integrated outdoor CPE) [Source: Analysys Mason for BSG]

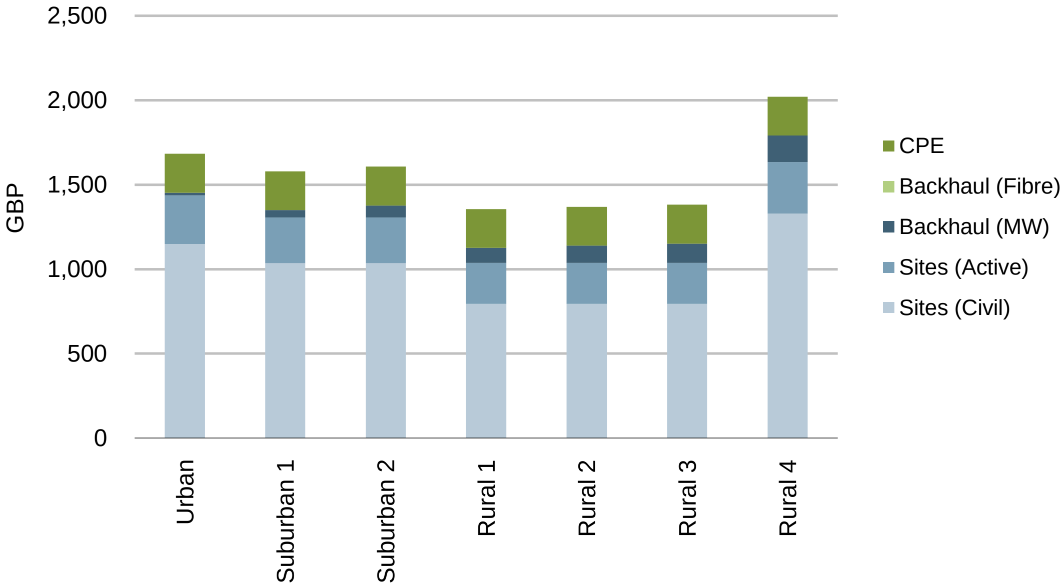

Figure 5.15: Breakdown of deployment cost per home connected by geotype for terrestrial wireless (Scenario C, WiMAX 3.5GHz 8:1, dongle/desktop/integrated outdoor CPE) [Source: Analysys Mason for BSG]

Under Scenario A, the cost per home connected is relatively uniform across most geotypes, as the relatively low traffic loading means that overall costs are dominated by the cost of CPE with an integrated outdoor antenna. Under Scenarios B and C, the cost is more dominated by the network cost, which in all but the final geotype, is driven by the average throughput specific to each geotype.

It can be seen that as demand increases, network costs account for a greater proportion of the cost per home connected.

5.2 Satellite networks

The upfront deployment cost per home connected for satellite under the three demand scenarios is shown in Figure 5.16 below. As satellite operators consider deployment business cases on a national basis, we have averaged the cost across all geotypes.

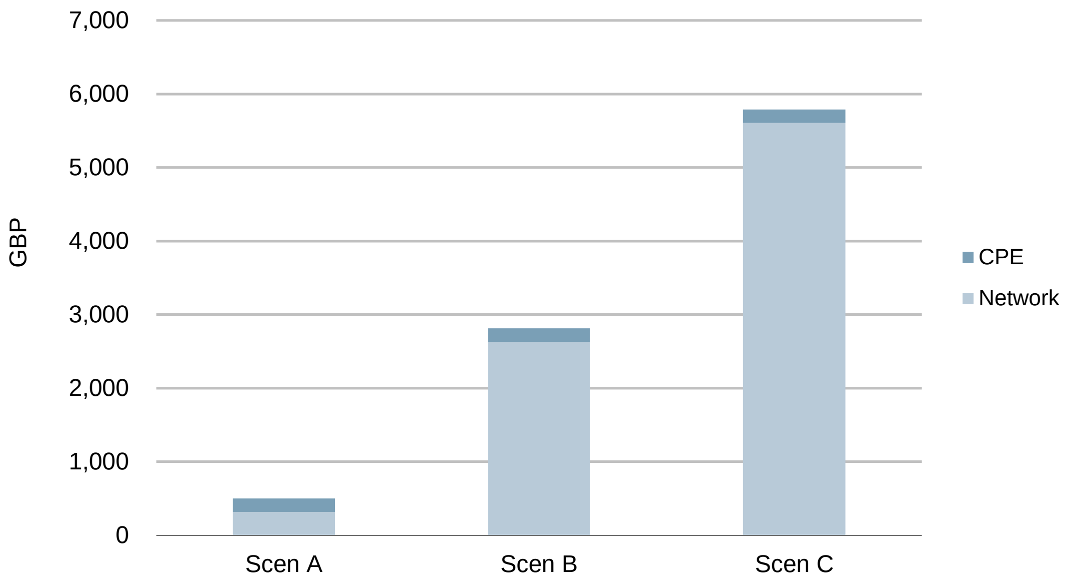

Figure 5.16: Deployment cost per home connected for satellite [Source: Analysys Mason for BSG]

The cost per home connected for satellite is GBP500 in Scenario A, GBP2800 in Scenario B and GBP5800 in Scenario C. In Scenarios B and C the costs are dominated by the network costs, of which the principal component is the cost of building and launching the satellites.

5.3 Total deployment costs in the 'final third'

In order to consider realistic deployment scenarios for both terrestrial wireless and satellite networks, we have modelled the total deployment costs for different combinations of the rural geotypes, which add up to roughly the 'final third' of UK homes (i.e. those areas where fixed NGA appears unlikely to be provided without some form of public intervention).

We have assumed that those homes served by wireless have a choice of four operators and those homes served by satellite have a choice of two operators and we have further assumed that the competing operators achieve equal market shares. It therefore follows that our hypothetical terrestrial wireless operator serves 25% of broadband homes but our hypothetical satellite operator serves 50% of broadband homes. To ensure a like-for-like comparison, the results in this section are scaled up to show the cost for each type of operator to serve all broadband homes in the final third.

5.3.1 Infrastructure requirements

Figure 5.17 shows the total number of sites required to serve all broadband homes in different combinations of geotypes within the final third using our lowest-cost terrestrial wireless technology. Results are shown for each demand scenario.

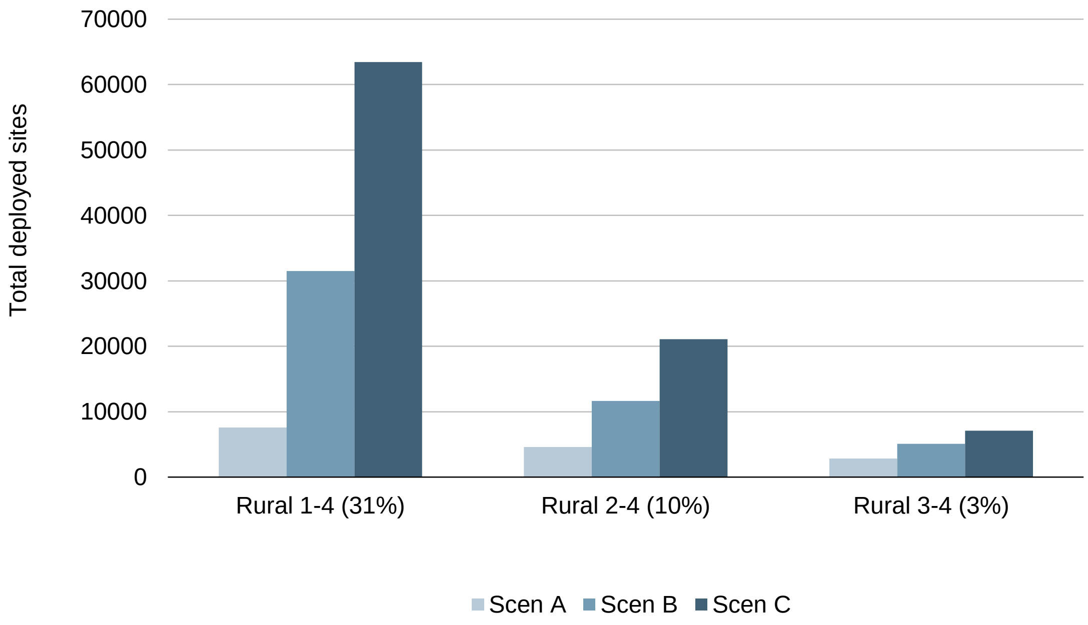

Figure 5.17: Final-third terrestrial wireless site requirements (WiMAX 3.5GHz 8:1, dongle/desktop/integrated outdoor CPE) [Source: Analysys Mason for BSG]

For a terrestrial wireless operator to support the demand from all rural geotypes (which roughly equates to the final third of the UK) using our lowest-cost technology, between 7000 and 64 000 sites would be required depending on the demand scenario. In order to support the final 10% of homes the operator would need to deploy 4000 to 21 000 sites, and to support the final 3% would need 3000 to 7000 sites (again depending on the demand scenario).

Figure 5.18 shows the total number of spotbeams required to serve all broadband homes in different combinations of geotypes within the final third using satellite. Again the results are shown for each demand scenario.

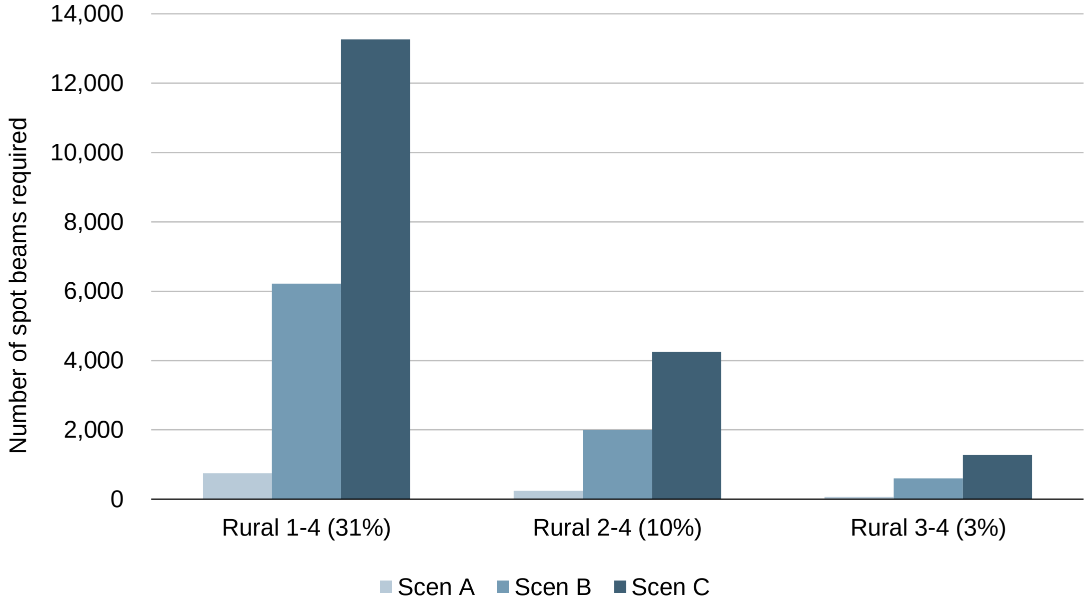

Figure 5.18: *Final-third satellite requirements (note percentages in brackets show fraction of UK population in stated geotypes) [Source: Analysys Mason for BSG]*

Each spotbeam in our hypothetical satellite system is capable of supporting the demand from around 10 900 households in Scenario A, 1350 households in Scenario B and 650 households in Scenario C. For a satellite operator to support the demand from all rural geotypes would require the deployment of 700 to 13 000 spotbeams depending on the demand scenario. To support the final 10% of homes would require 200 to 4000 spotbeams, and to support the final 3% of homes would require 70 to 1300 spotbeams (again depending on demand scenario).

Our baseline assumption is that the spread of each spotbeam is 0.2º. We estimate that with this spread all of the UK land area can be covered by 26 spotbeams[18]. This would imply a requirement for 27 to 500 satellites to cover all the rural geotypes, 8 to 154 satellites to cover the final 10% of homes, and 3 to 50 satellites to cover the final 3% of homes. Each satellite needs to be in a different orbital location so that the same spectrum can be re-used. This means that in practice only a small number of satellites can be deployed over the UK. In reality however, if satellite technology were chosen to support a large level of demand in the rural geotypes, then higher-capacity satellites incorporating a larger number of smaller spotbeams would almost certainly be developed. Such higher-capacity satellites could be expected to have a lower cost per spotbeam than we have modelled.

18 We assume that each satellite supports 100 spotbeams in total: the remaining 74 spotbeams that do not 'fit' inside the UK can be deployed elsewhere in Europe.

5.3.2 Total deployment cost

Figure 5.19 shows the total deployment cost to serve all broadband homes in different combinations of geotypes in the final third using our lowest-cost terrestrial wireless technology.

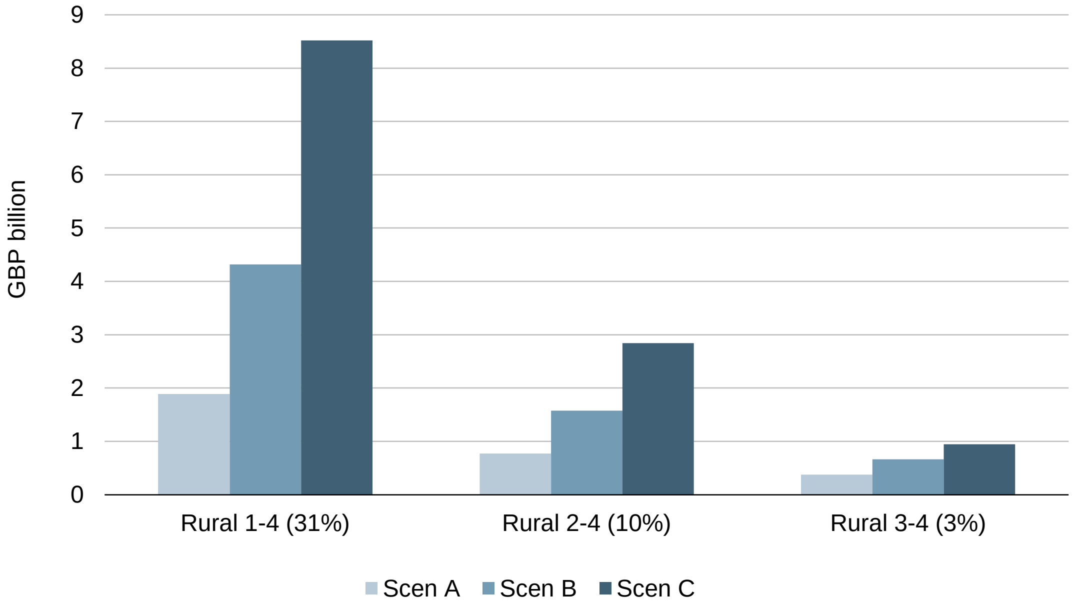

Figure 5.19: Total upfront terrestrial wireless deployment costs for the final third (WiMAX 3.5GHz 8:1, dongle/desktop/integrated outdoor CPE) [Source: Analysys Mason for BSG]

The deployment costs follow a similar profile to the required number of sites. For a terrestrial wireless operator to support the demand all rural geotypes would cost between GBP1.9 billion and GBP8.5 billion depending on the demand scenario. Supporting the final 10% of homes would cost GBP0.8 billion to GBP2.8 billion, while supporting the final 3% of homes would cost GBP0.4 billion to GBP0.9 billion (again depending on demand scenario).

Finally, Figure 5.20 shows the total deployment cost to serve all broadband homes in different combinations of geotypes within the final third using satellite.

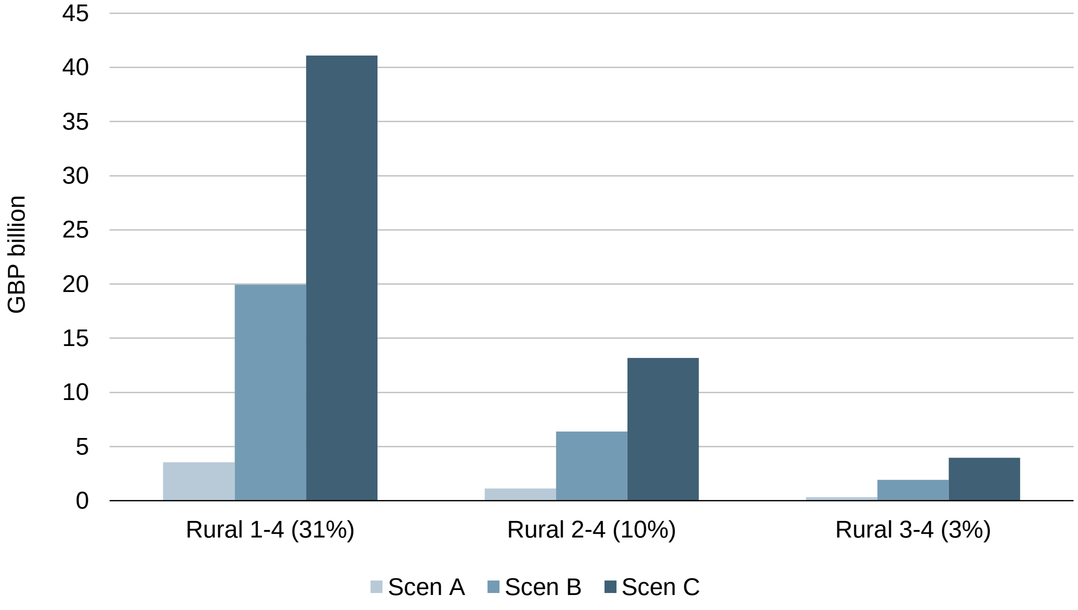

Figure 5.20: Final-third satellite deployment costs [Source: Analysys Mason for BSG]

For a satellite operator to support the demand from all rural geotypes would cost between GBP3.6 billion and GBP41.1 billion depending on the demand scenario. Supporting the final 10% of homes would cost GBP1.1 billion to GBP13.2 billion, while supporting the final 3% of homes would cost GBP0.3 billion to GBP4.0 billion (again depending on demand scenario).

5.4 Impact of other factors

5.4.1 Impact of upload traffic

Terrestrial wireless

We have considered the impact on our hypothetical terrestrial wireless network of increasing the proportion of upload traffic while maintaining a fixed downlink to uplink ratio. The results for our lowest-cost terrestrial wireless technology are shown in Figure 5.21. We assume that the increased proportion of upload traffic affects both the overall volume of traffic and peak upload demands.

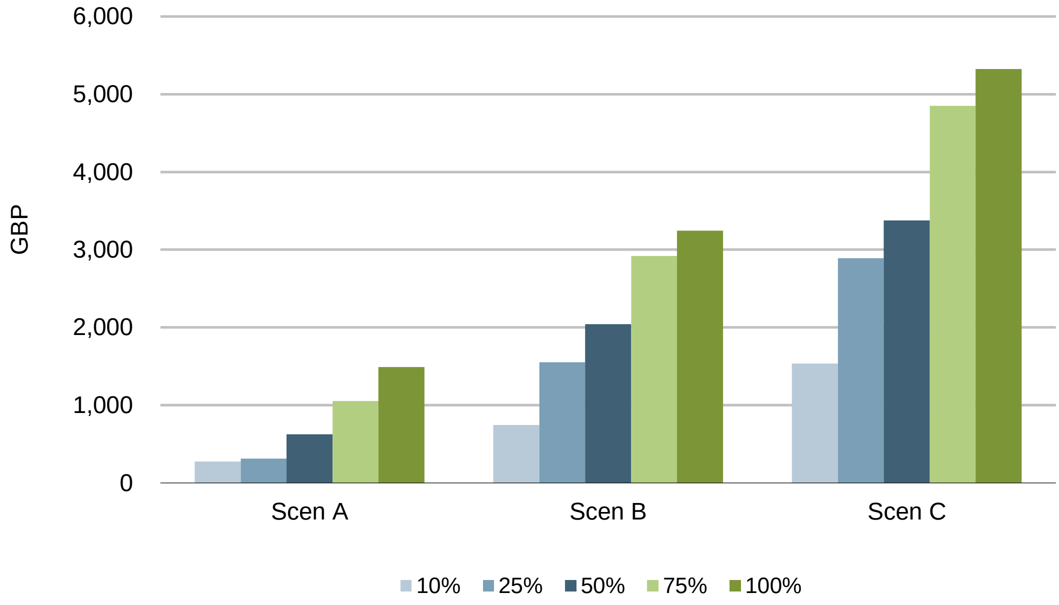

Figure 5.21: Impact of percentage of upload traffic on deployment cost per home connected for terrestrial wireless (WiMAX 3.5GHz 8:1, dongle/desktop/integrated outdoor CPE) [Source: Analysys Mason for BSG]

Our modelling shows that for a TDD network with a fixed downlink to uplink ratio of 8:1, a rise in the proportion of upload traffic leads to a rise in upfront deployment costs. Once the proportion of uplink traffic exceeds 11%, the network becomes uplink throughput limited and so more base stations are required. In reality, a TDD operator has the flexibility to alter the proportions of bandwidth attributed to uplink and downlink, and so can optimise the balance according to the traffic. This capability will reduce the cost increases seen in Figure 5.21 above. In theory FDD networks provide the same amount of capacity in both the downlink and the uplink directions so the total cost of deployment only increases if the proportion of upload traffic is more than 50% (a very unlikely scenario for residential Internet use).

Satellite

The impact of increasing the proportion of uplink traffic on a satellite network is shown in Figure 5.22 below.

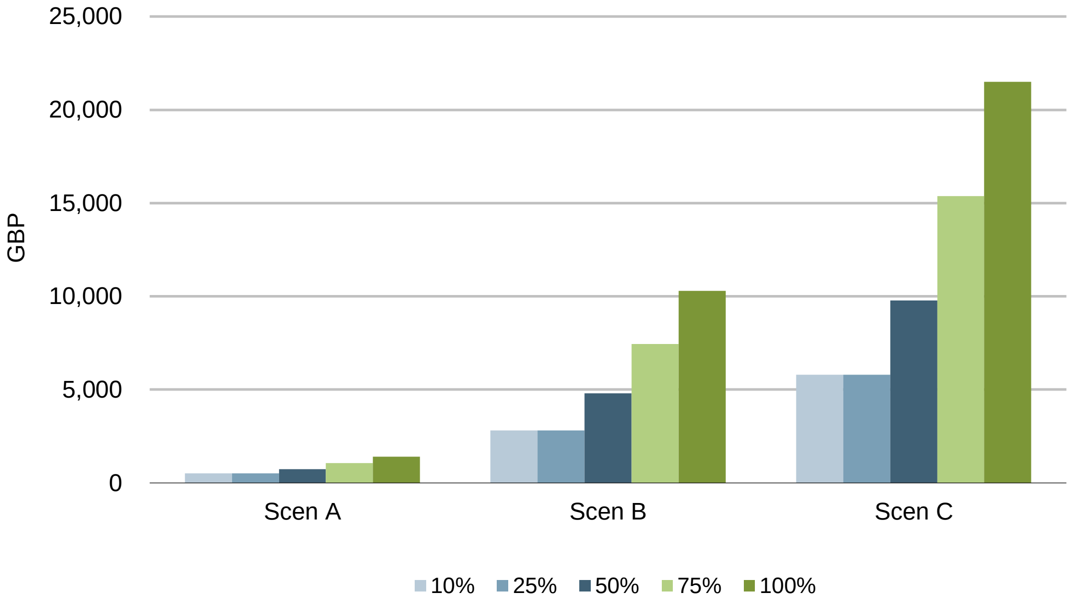

Figure 5.22: Impact of percentage of upload traffic on deployment cost per home connected for satellite networks [Source: Analysys Mason for BSG]

The impact of increased upload traffic on satellite networks is slightly different to terrestrial wireless networks. Our modelling is based on the assumption that the return link capacity equates to 30% of the forward link, and therefore no additional infrastructure costs are incurred to accommodate 25% upload traffic. However, additional costs would be incurred if upload traffic were 50% or higher.

High levels of upload traffic (as shown in the figures above) could be realised if high-bandwidth symmetrical applications (such as HD video calling or online gaming) were to achieve significant take-up. In the case of HD video calling, significant take-up would only have a notable impact on our assumptions for uplink traffic as we believe it is reasonable to assume that users are unlikely to make video calls and watch TV simultaneously.

5.4.2 Cost per home covered

We have also calculated the cost per home *covered* for terrestrial wireless and satellite networks. The average cost of *covering* a home is markedly lower than the cost of *connecting* a home in some geotypes as the coverage costs are spread across all homes covered (whereas in reality not all homes will subscribe to broadband services, and we assume that our hypothetical operator only has a proportion of those that do). Furthermore, a number of significant costs are excluded: the cost of covering a home does not include CPE, and does not consider any traffic volume demands on the network. In Scenario B the cost of coverage for a terrestrial wireless network (WiMAX 3.5GHz 8:1, dongle/desktop/integrated outdoor CPE) ranges from GBP2 to GBP297 per home depending on the geotype.

Assuming the use of a single satellite serving the UK alone with up-front costs of GBP300 million, the average cost per home covered would be around GBP10 across all geotypes. The cost could be substantially lower if the satellite provided pan-European coverage (e.g. we estimate that the cost per home covered for KA-SAT is less than GBP1), but it could also be doubled if a spare satellite is provided in orbit for redundancy purposes.

5.4.3 Mobile coverage

Although our hypothetical terrestrial wireless network has been designed to provide fixed wireless performance, we have also considered the extent to which it would also provide *mobile* coverage. We found that when the network is dimensioned for maximum fixed terrestrial wireless performance then there is no mobile coverage available at the cell edge, even outdoors, due to the relatively large cell sizes and the comparatively small power and gain of a mobile handset. Outdoor mobile coverage would be available over some inner portion of the cell, which may be of some value to users. We note that the mobile broadband service may only be available to mobile handset users in the case of an FDD deployment (existing mobile handset models do not support the use of TDD).

5.4.4 Assessment of deployment costs

Although our modelling suggests that WiMAX at 3.5GHz with a downlink to uplink ratio of 8:1 is the lowest-cost technology option, we believe that there is no single clear-cut best choice in terms of terrestrial wireless technologies. Both TDD technologies and the dual-frequency FDD technologies appear to be able to deliver broadband services at a similar cost. We believe that with different design assumptions, or more aggressive reductions in equipment costs, any of the terrestrial wireless technologies could be used to deliver wireless broadband services. Satellite appears to be uniformly more expensive than terrestrial wireless in terms of cost per home connected, but will still have an important role to play in serving the areas where we assume that terrestrial wireless will not be deployed and premises located in ‘notspots’ within the terrestrial wireless coverage area.

5.5 Spectrum costs

We have not included the cost of spectrum in any of our calculations since it is difficult to determine an appropriate set of costs with accuracy and confidence. At present there are two distinct pricing regimes for terrestrial wireless spectrum in the UK depending on whether or not the spectrum was originally allocated by auction:

- For spectrum that has been auctioned there are no additional fees to pay during the initial period of the licence, which is typically 20 years.
- For spectrum that has not been auctioned an annual fee is payable based on an administrative incentive pricing (AIP) calculation determined by Ofcom, based on the opportunity cost of spectrum.

The 2100MHz and 3.5GHz bands have already been auctioned. The 2100MHz licensees paid a total of GBP22.5 billion in 2000 for licences lasting until 2021, while the 3.5GHz licensees paid GBP7 million in 2003 (with a further GBP7 million payable in 2008 and 2013 for two available five-year extensions). These are however, sunk costs and it is not clear how they should be allocated (if at all) to future services. The 800MHz and 2.6GHz bands will be released for commercial use by means of an auction, but this is not expected to take place before 2011 and it is difficult to predict what the outcome will be in advance.

The 900MHz and 1800MHz bands are subject to the AIP regime but in July 2010 the Government proposed to direct Ofcom to determine revised AIP fees for these bands and thus the future level of charges is unclear at the time of writing.

As a potential indicator, an auction was concluded in Germany in May 2010 in which FDD spectrum was allocated in the 800MHz, 1800MHz, 2100MHz and 2.6GHz bands and unpaired spectrum was allocated in the 2100MHz and 2.6GHz bands.

In Figure 5.23, we have calculated what the cost of the spectrum we have used in our model would be if the price of spectrum per head of population (the price per MHz pop) in the UK was the same as in the German auction.

Band	*Price per MHz pop in 2010 German auction*	*Equivalent GBP price per MHz pop (GBP1:EUR1.20)*	*Amount of spectrum assumed in model*	*Indicative cost for UK spectrum*	*Indicative cost per UK home connected*
800MHz FDD	EUR0.731	GBP0.609	20MHz	GBP791 million	GBP159
1800MHz FDD	EUR0.026	GBP0.021	40MHz	GBP55 million	GBP11
2100MHz FDD	EUR0.108	GBP0.090	40MHz	GBP233 million	GBP47
2.6MHz FDD	EUR0.023	GBP0.019	40MHz	GBP49 million	GBP10
2.6MHz TDD	EUR0.021	GBP0.018	40MHz	GBP46 million	GBP9

Figure 5.23: Indicative price for UK spectrum based on German auction results, 2010 [Source: Analysys Mason for BSG]

The total costs vary from GBP46 million for 40MHz of 2.6GHz TDD spectrum to GBP791 million for 20MHz of 800MHz FDD spectrum. The indicative cost per home connected is around GBP10 in the case of 1800MHz and 2.6GHz spectrum (which would have a negligible impact on total deployment costs), around GBP50 in the case of 2100MHz FDD spectrum (which would have some impact, though not enough to alter our results) and around GBP150 in the case of 800MHz spectrum (which would make the use of 800MHz spectrum look even less attractive than it does in our base case results).

Terrestrial wireless operators will also have to pay for the spectrum used to provide microwave backhaul. This is not considered in the above analysis since the costs are not material in comparison (in February 2008 Ofcom sold 15-year national licences for 3162MHz and regional licences for 672MHz of microwave spectrum for a total of GBP1.4 million).

Satellite operators do not currently pay for their spectrum in the same way that terrestrial wireless operators do (although there is a small annual administrative charge for the spectrum used by a satellite gateway). We do not expect this situation to change in the foreseeable future and therefore we do not believe that spectrum costs are relevant to the deployment costs for satellite.

5.6 Operating costs

Our study is focused mainly on the costs of deploying communications networks, but we have also given some consideration to the ongoing operating costs. Our analysis focuses on the cost of network operation since other costs (such as customer acquisition, customer support, billing and general management overheads) are heavily dependent on the business model adopted by our hypothetical terrestrial wireless or satellite operator.

For consistency, Figure 5.24 shows our estimate of the annual network operating cost per home connected for the terrestrial wireless technology with the lowest deployment costs in our model (WiMAX network at 3.5GHz) although we note that the dual-frequency FDD LTE option requires slightly fewer sites and thus has slightly lower operating costs.

We estimate the annual operating cost per home connected to be around GBP6 in Scenario A, GBP57 in Scenario B and GBP140 in Scenario C.

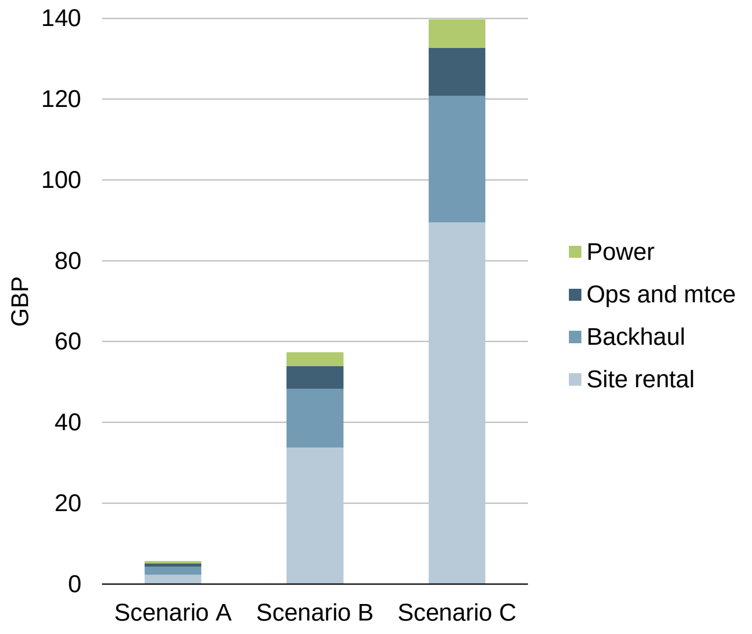

Figure 5.24: Annual network operating cost per home connected for terrestrial wireless (WiMAX 3.5GHz 8:1, dongle/desktop/ integrated outdoor CPE) [Source: Analysys Mason for BSG]

Our estimated annual operating cost per home connected for satellite is considerably lower at around GBP3 in Scenario A, GBP18 in Scenario B and GBP38 in Scenario C (see Figure 5.25). The annual operating cost for satellite is 46% of the equivalent cost for terrestrial wireless in Scenario A, 31% in Scenario B and 27% in Scenario C.

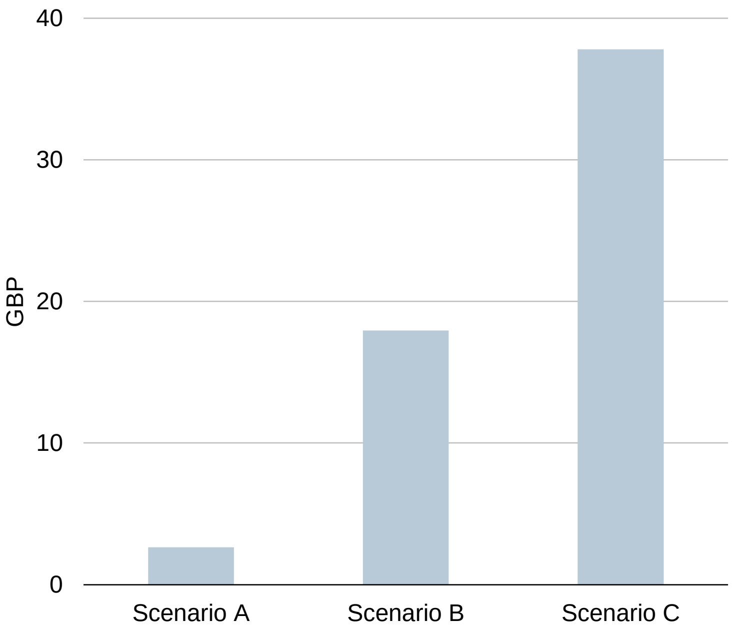

Figure 5.25: Annual network operating cost per home connected for satellite [Source: Analysys Mason for BSG]

Over a ten-year period the operating costs for satellite (without taking any account of the time value of money) would be around GBP30 per home lower than terrestrial wireless in Scenario A, GBP400 lower in Scenario B and GBP1000 lower in Scenario C. This partially offsets the additional deployment costs of satellite.

6 Conclusions

In this section we present the conclusions that we draw from the results presented in the previous section and discuss the policy implications of the study.

6.1 Economics of terrestrial wireless and satellite broadband networks

As noted in the introduction, while the costs of the fibre networks considered in our previous study remain broadly unchanged for a wide variation in the level of traffic per subscriber, the costs of terrestrial wireless and satellite broadband networks are highly dependent on the peak traffic loading. At the levels of demand being considered in this study, throughput factors (such as the amount of spectrum available and the MIMO schemes that can be used) have a much larger impact on the cost of terrestrial wireless networks than the coverage factors (such as the improved propagation at lower frequencies). Satellite technology is inherently capable of providing wide geographical coverage at relatively low cost per home so the overall cost per home connected for a satellite system is almost invariably determined by throughput factors.

It should also be borne in mind that in order to deliver the highest possible data rates throughout each cell, our hypothetical terrestrial wireless network has been designed to provide fixed wireless service using high-gain outdoor antennas. This is quite a different service proposition to existing mobile broadband services which are designed to work with laptop dongles indoors (albeit with lower data rates and more limited geographical coverage). While it would, in theory, be possible to increase the level of mobile coverage provided by our hypothetical terrestrial wireless network, this would further increase the number of base stations required and thus increase the cost.

6.2 Bandwidth required per home

There are large differences in the busy-hour bandwidth required per home in our three scenarios: Scenario A requires 85kbit/s, Scenario B requires 700kbit/s while Scenario C requires 1.5Mbit/s. These differences reflect the current uncertainty over future demand that exist within the broadband community. Scenario A represents an extrapolation of today's mobile broadband consumption patterns (adjusted to take account of the fact that many existing mobile broadband users also have access to fixed broadband services). Scenarios B and C are extrapolations of today's fixed broadband consumption patterns, with different levels of take-up of high-bandwidth content.

We understand that the average busy-hour bandwidth consumption of UK mobile broadband customers is currently around 10kbit/s while the equivalent figure for fixed broadband customers is around 60kbit/s and that annual growth rates are currently between 20% and 50%.

If the average *mobile* bandwidth consumption of 10kbit/s grows at 20% per annum then the requirement in 2016 will be around 30kbit/s per user; however if annual growth is 50% the requirement in 2016 will be around 115kbits per user. We believe that 30kbit/s is almost certainly an underestimate of the bandwidth that will be demanded for what is essentially a substitute for fixed broadband in 2016. Most mobile broadband devices in service today are designed for individual use rather than shared household use and, as noted above, many of today's users also have access to fixed broadband. Once these factors are taken into account, we believe that our usage-derived estimate of 85kbit/s peak bandwidth for Scenario A is a reasonable extrapolation of current mobile broadband consumption patterns.

If the average *fixed* bandwidth consumption of 60kbit/s grows at 20% per annum then the requirement in 2016 will be around 180kbit/s per home, but if annual growth is 50% the requirement in 2016 will be around 680kbits per home. Our assumption of 700kbit/s per home for Scenario B is therefore at the top end of the range obtained by extrapolating current trends. Nevertheless we believe it to be highly plausible given the current speed of transition from standard-definition (SD) to HD viewing (Ofcom reports that the number of households with access to HD channels increased from 1.9 million in 1Q 2009 to 5.1 million in 2Q 2010)[19] and the forthcoming launch of services such as those under development in Project Canvas, which are likely to increase levels of on-demand video consumption.

Our Scenario C implies fairly extreme growth between 2010 and 2016, but we think it is worth considering, both as an upper bound for the situation in 2016 and as an indication of a more central scenario for two or three years later.

We should like to draw attention to the fact that the maximum bandwidth demand per home in all of our scenarios is driven by the number of simultaneous video streams that a household may consume. We assume that there are on average 2.3 people per household and while we recognise that some households are larger than this, we believe that an increasing proportion of viewing in large households may be on handheld and portable devices with limited screen resolution. We believe it is relatively unlikely that by 2016 many people will engage in any other activities that require a significant extra amount of bandwidth *while watching streamed video content*. Consequently, we believe that an assumption of 2.3 video streams per household is a reasonable rule of thumb for assessing the maximum bandwidth required per home. Scenario A assumes that all streamed services are in SD which gives a maximum bandwidth of 4.6Mbit/s per household. Scenarios B and C assume that viewing is in HD, which gives a maximum bandwidth of 19.0Mbit/s per household. We conclude from this that, despite the uncertainty over the *average* bandwidth required per household, there is no pressing need to implement technologies that can deliver significantly in excess of 20Mbit/s *peak* bandwidth per home before 2016.

Another consequence of assuming that video streaming will be the main driver of demand is that the bandwidth requirement is highly asymmetric. The trend in ADSL since its launch has undoubtedly been towards more asymmetric services: whereas the original 512kbit/s ADSL services typically offered headline upstream speeds of 128kbit/s (a downstream to upstream ratio of 4:1), the latest 20Mbit/s services typically offer headline upload speeds of 1Mbit/s (a downstream to upstream ratio of 20:1). Among existing residential applications, only HD video calling and some forms of online gaming require high upstream bandwidth. If these applications

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19 Ofcom Communications Market Report, August 2010

become very popular in the future then it is conceivable that residential demand may be more symmetric in the future than we are assuming. We believe however, that it is highly unlikely that fully symmetric services will ever be required by more than a small minority of residential users.

6.3 Cost of deploying terrestrial wireless in different frequency bands

Figure 6.1 summarises the deployment cost per home connected for the various terrestrial wireless technologies considered in this study across each of the three demand scenarios. The results in the figure are based on a dongle/desktop/integrated outdoor CPE scheme and those for TDD technologies assume a downlink to uplink ratio of 8:1.

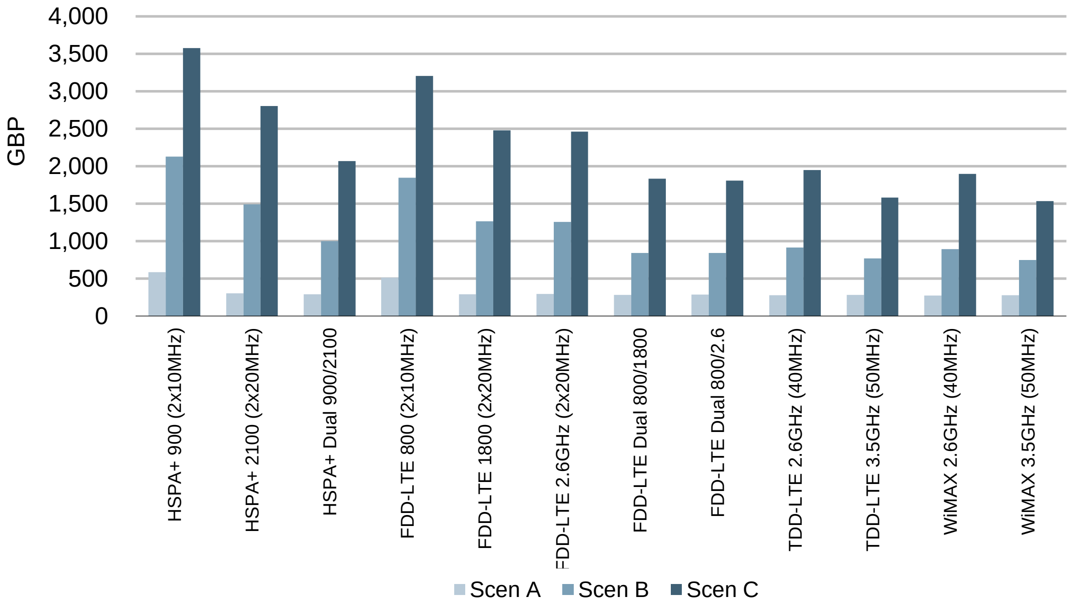

Figure 6.1: Summary of terrestrial wireless deployment costs per home connected [Source: Analysys Mason for BSG]

In Scenarios B and C the network dimensioning is almost entirely capacity-driven in all geotypes, i.e. the size of the cells is determined by the amount of traffic that each cell needs to carry, rather than the maximum coverage that can be achieved with the chosen technology. In our model the 800/900MHz technologies have much lower capacity per cell. This is mostly because we assume that our hypothetical operator only has access to 2×10MHz of spectrum at 800/900MHz (compared with 2×20MHz at the higher frequencies) but also, to a lesser extent, because we assume that physical constraints will limit the use of MIMO to two antennas per CPE device in this band (compared with four at the higher frequencies). Consequently, the 800/900MHz deployment costs look high compared to the costs for the higher frequency bands.

The conventional wisdom in the wireless industry is that low-frequency spectrum is much more valuable than high-frequency spectrum. While this is undoubtedly true when networks are predominantly coverage driven (since the extra range of low-frequency spectrum allows a given area to be covered with fewer base stations), our study suggests that for capacity-driven networks the relative abundance of high-frequency spectrum means that the latter may be a better choice. This is especially true if our assumption that more sophisticated forms of MIMO can be deployed at the higher frequencies is correct. If the demand for wireless data in 2016 does, in fact, approach the levels implied in our Scenario B then we believe the amount of spectrum available for broadband services will prove to be more important than the band in which it is available, and we might therefore expect to see a reduction in the premium attached to low-frequency spectrum. It should be noted that this study has been based on deployment of a fixed wireless network using outdoor antennas, and that the results for value of spectrum for a network focused on mobile indoor coverage may be different.

Figure 6.1 also suggests that the cost per home connected may in general be lower for TDD technologies than for FDD technologies. This results from our assumption of a highly asymmetric traffic profile. TDD technologies allow the amount of spectrum allocated to downlink and uplink traffic to be varied whereas FDD technologies do not. Historically, TDD spectrum has tended not to be valued as highly as FDD spectrum but if there is high demand for terrestrial wireless data traffic in 2016 and the profile is as asymmetric as our analysis indicates, this discount may be eroded in the future.

6.4 Cost of deploying satellite

Figure 6.2 shows that the deployment cost per home connected is significantly higher for satellite than for the terrestrial wireless although, as discussed below, this is partially offset by lower operating costs.

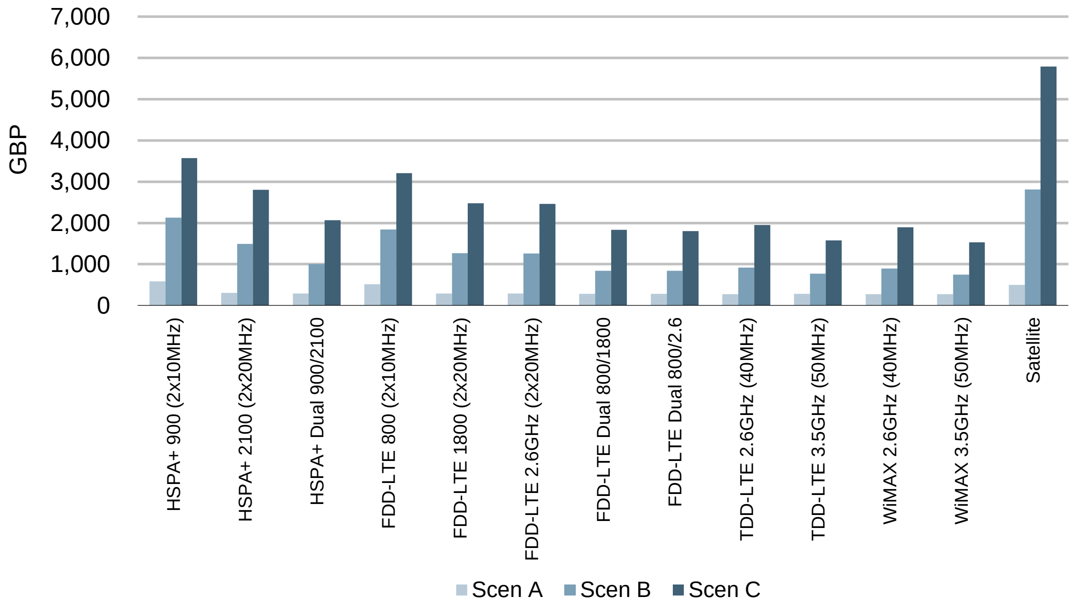

Figure 6.2: *Comparison between terrestrial wireless and satellite deployment costs per home connected [Source: Analysys Mason for BSG]*

Most of the deployment costs for satellite are associated with the construction, launch and insurance of the satellites themselves.

It should however, be noted that even in a largely terrestrial wireless network some premises will still need to be served by other means for two reasons:

- First, it is probably not economically viable to build a network that covers 100% of the UK land area (our model assumes 100% coverage of the urban geotypes, 99% population coverage of the suburban geotypes and 98% population coverage in the rural geotypes).
- Second, even within the planned coverage area of the terrestrial wireless network some premises will be in dead zones where the wireless signal is not available (sometimes referred to as 'notspots'). These notspots can result from natural features (e.g. dips in the terrain) or man-made obstructions (e.g. tall buildings which prevent the signal from reaching premises in their shadow) and are found throughout the UK. Mobile wireless networks are typically planned to offer 90% probability of coverage (i.e. no more than 10% of premises are in notspots). The probability of coverage for a fixed wireless network of the type we are considering is likely to be higher due to the ability to site CPE in the optimum location and use outdoor antennas where necessary. We believe it would be reasonable to assume that a single network would provide service to a maximum of 95% of premises within its coverage area, although this proportion is likely to rise a little if there are two or more competing infrastructures using different base station sites.

Within the context of this study, we assume that satellite will be used to serve the premises which cannot be served by terrestrial wireless. Taking both coverage and notspots into account, our model assumes that satellite will be used to serve 6% of premises nationally and 7% of premises in rural areas.

6.5 Comparison of terrestrial wireless and satellite deployment costs with fibre

Figure 6.3 and Figure 6.4 compare the deployment cost per home connected for satellite and the lowest-cost TDD and FDD terrestrial wireless technologies identified in this study (all based on 80% take-up among homes covered) with the equivalent fibre costs from our previous study.

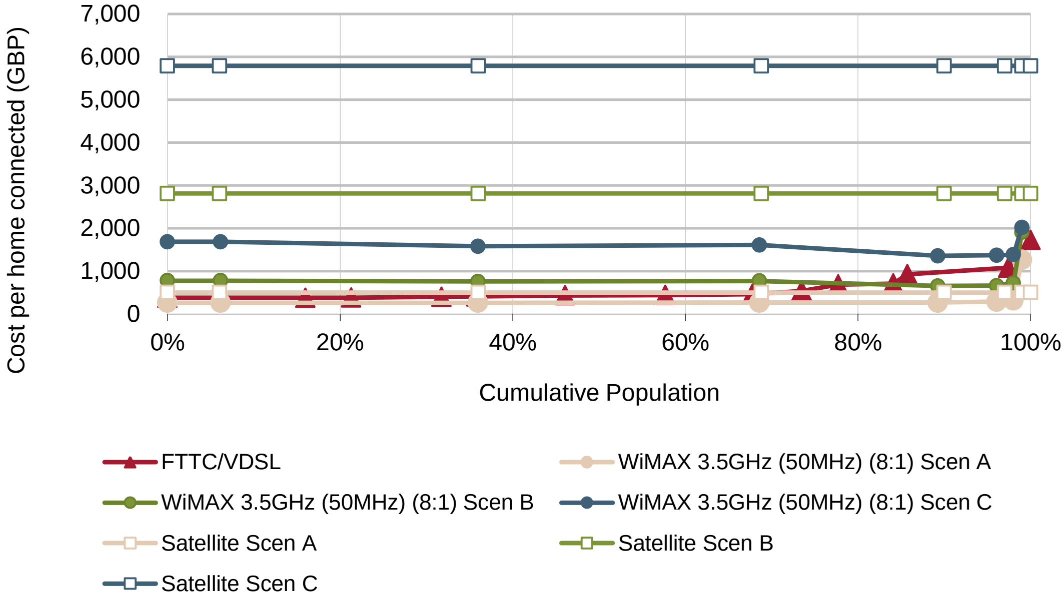

Figure 6.3: Comparison between TDD terrestrial wireless and satellite deployment costs per home connected and the equivalent fibre costs [Source: Analysys Mason for BSG]

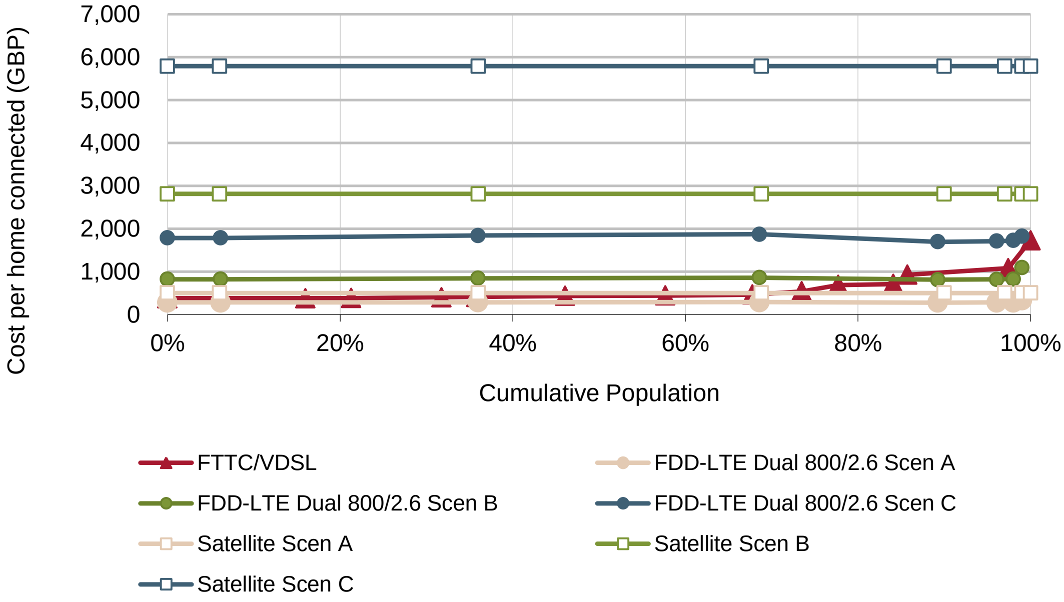

Figure 6.4: Comparison between FDD terrestrial wireless and satellite deployment costs per home connected and the equivalent fibre costs [Source: Analysys Mason for BSG]

Figure 6.5 and Figure 6.6 present the same comparisons, but focusing on the final third and deployment costs of up to GBP3000 per home connected.

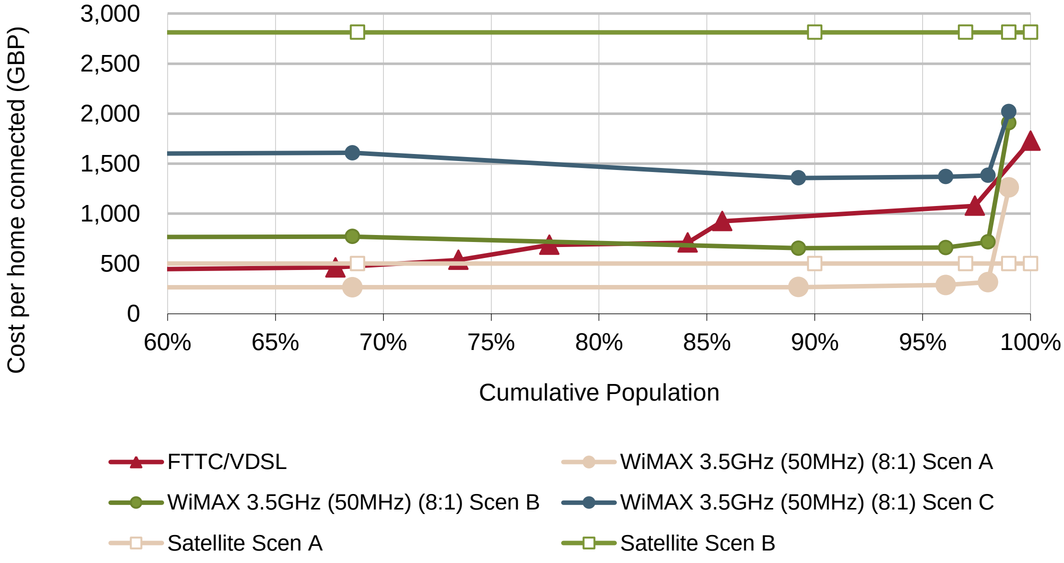

Figure 6.5: Comparison between TDD terrestrial wireless and satellite deployment costs per home connected and the equivalent fibre costs [Source: Analysys Mason for BSG]

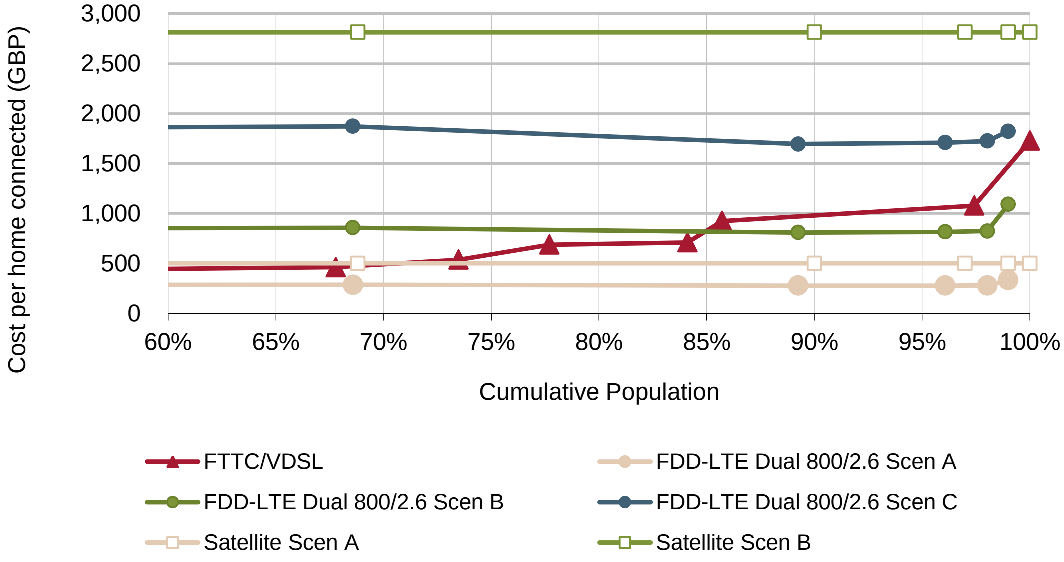

Figure 6.6: Comparison between FDD terrestrial wireless and satellite deployment costs per home connected and the equivalent fibre costs [Source: Analysys Mason for BSG]

Whereas the fibre costs rise quite steeply for the final third of UK homes, the terrestrial wireless costs remain broadly similar across all but the most rural geotype (Rural 4) and the satellite costs are identical. TDD terrestrial wireless technologies are less expensive than FDD technologies in most geotypes but FDD technologies are less expensive in the most rural geotype. Our modelling shows that in Scenario A terrestrial wireless is cheaper to deploy than FTTC/VDSL, but this result must be interpreted carefully since in this scenario the terrestrial wireless network is dimensioned to support peak download rates of 4.6Mbit/s per home, which is significantly lower than that offered by FTTC/VDSL.

Scenario B, with its peak download rate of 18.9Mbit/s per household can more reasonably be compared with FTTC/VDSL and here our modelling suggests that terrestrial wireless may be generally less expensive for the final 15% of homes (although TDD technologies appear more expensive than FTTC/VDSL for in the most rural geotype). It also suggests that terrestrial wireless is more expensive than FTTC/VDSL across almost all geotypes in Scenario C. For any given scenario, the cost per home connected for satellite is always higher than the equivalent cost for terrestrial wireless but, as discussed in the previous section, our model assumes that satellite is still used in areas not covered by terrestrial wireless and notspots within the coverage area of terrestrial wireless.

Figure 6.7 shows how the difference in cost between the lowest-cost TDD technology and FTTC/VDSL varies across the UK in Scenarios A, B and C. Figure 6.8 shows the same comparison for a dual-frequency FDD-LTE deployment at 800MHz and 2.6GHz (again with dongle/desktop/integrated outdoor CPE) while Figure 6.9 shows the comparison for satellite.

All three sets of diagrams take the costs by geotype from this study and map them on to the geotypes used in the previous fibre costing study (which were mostly based on a sub-division of BT local exchange areas[20]). The white areas on each map represent parts of the country where terrestrial wireless or satellite access is more expensive than FTTC/VDSL while the coloured areas represent parts of the country where terrestrial wireless or satellite access is less expensive, with different colours showing the degree is discount (e.g. yellow indicates that terrestrial wireless or satellite is 0-20% less expensive than fibre etc.).

[20] For this reason the comparisons exclude Kingston-upon-Hull where BT is not the local operator.

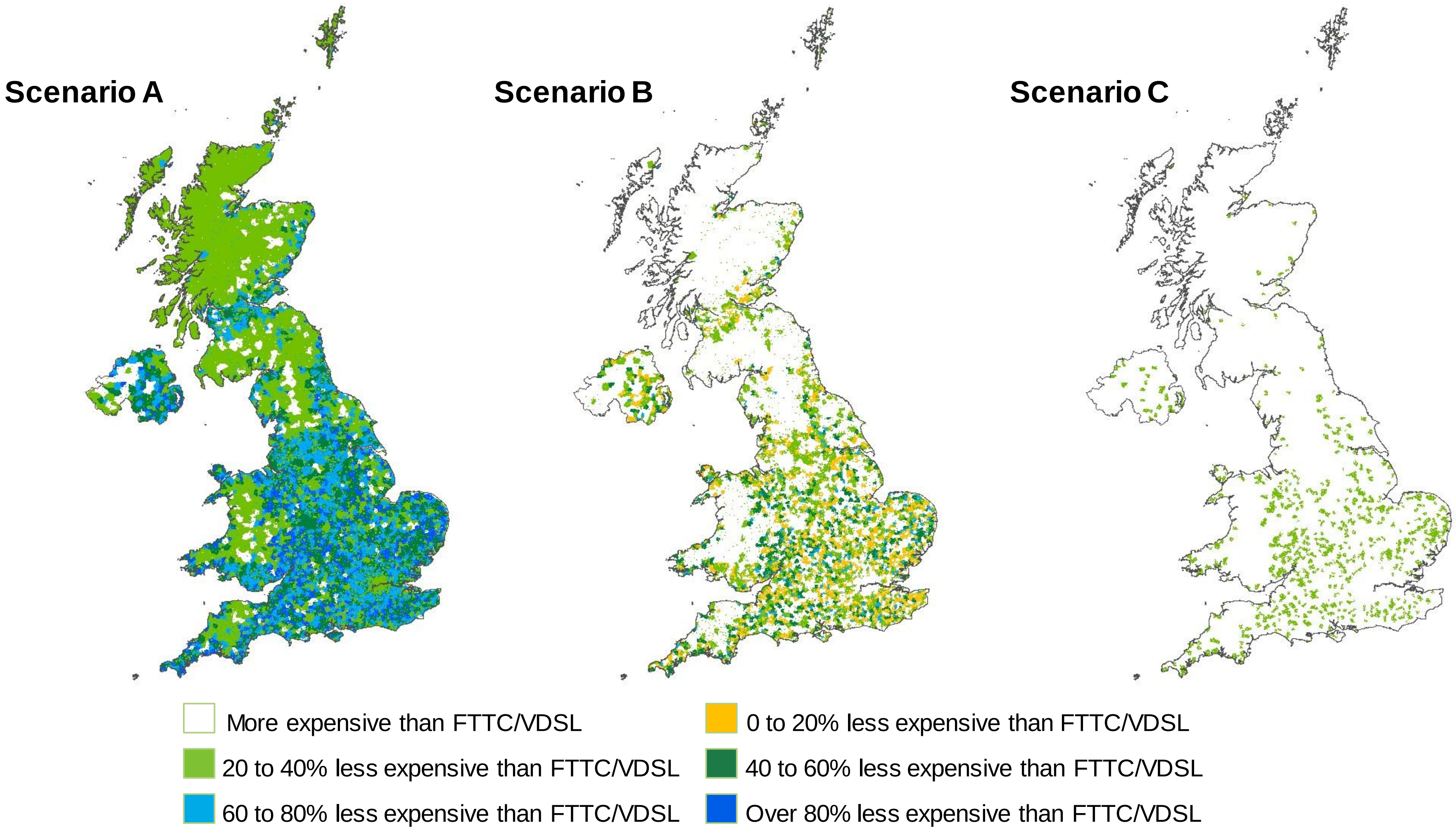

Figure 6.7: Areas where deployment costs for WiMAX 3.5GHz (8:1) are lower than for FTTC/VDSL [Source: Analysys Mason for BSG]

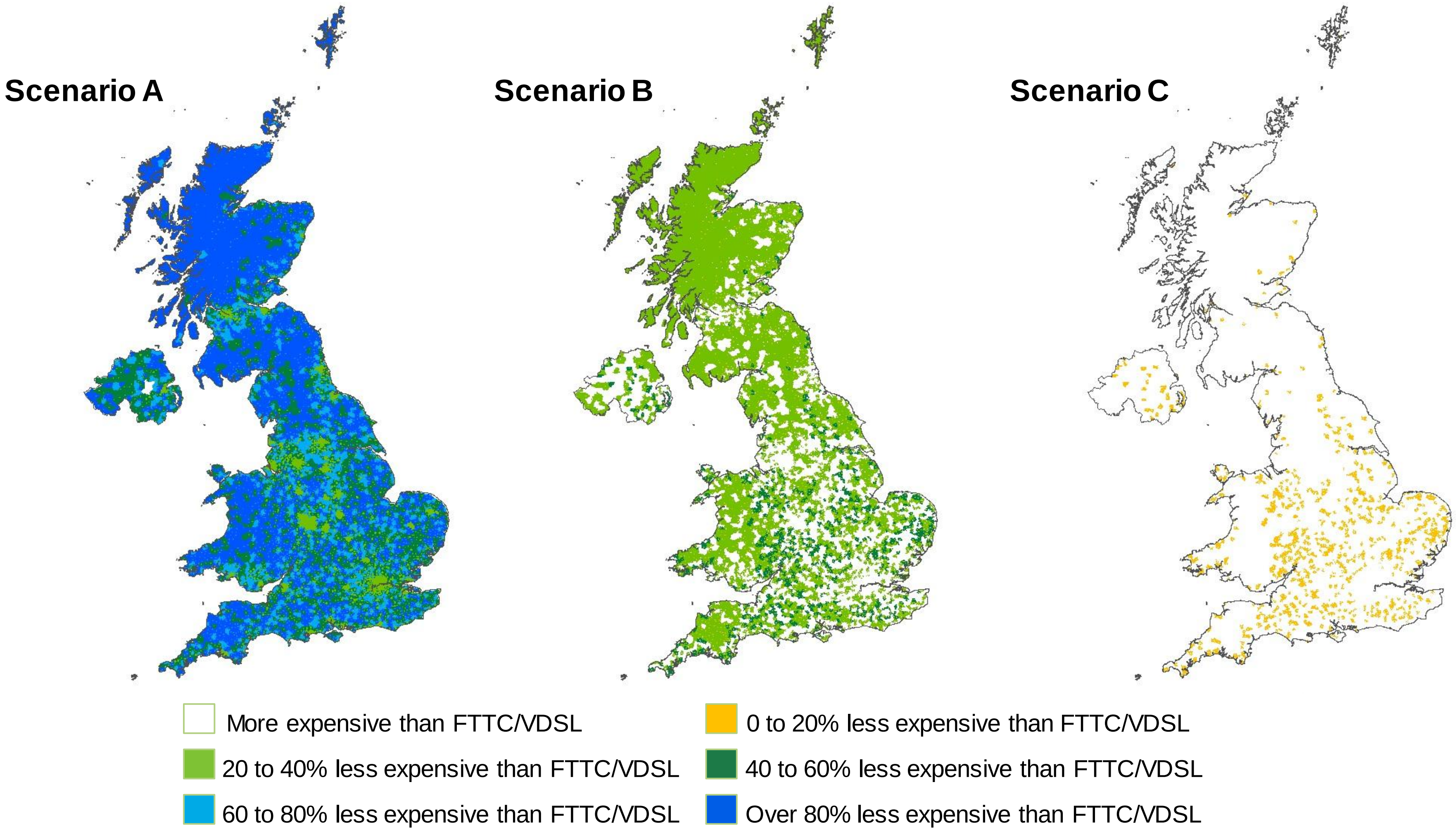

Figure 6.8: Areas where deployment costs for FDD-LTE Dual 800MHz/2.6GHz are lower than for FTTC/VDSL [Source: Analysys Mason for BSG]

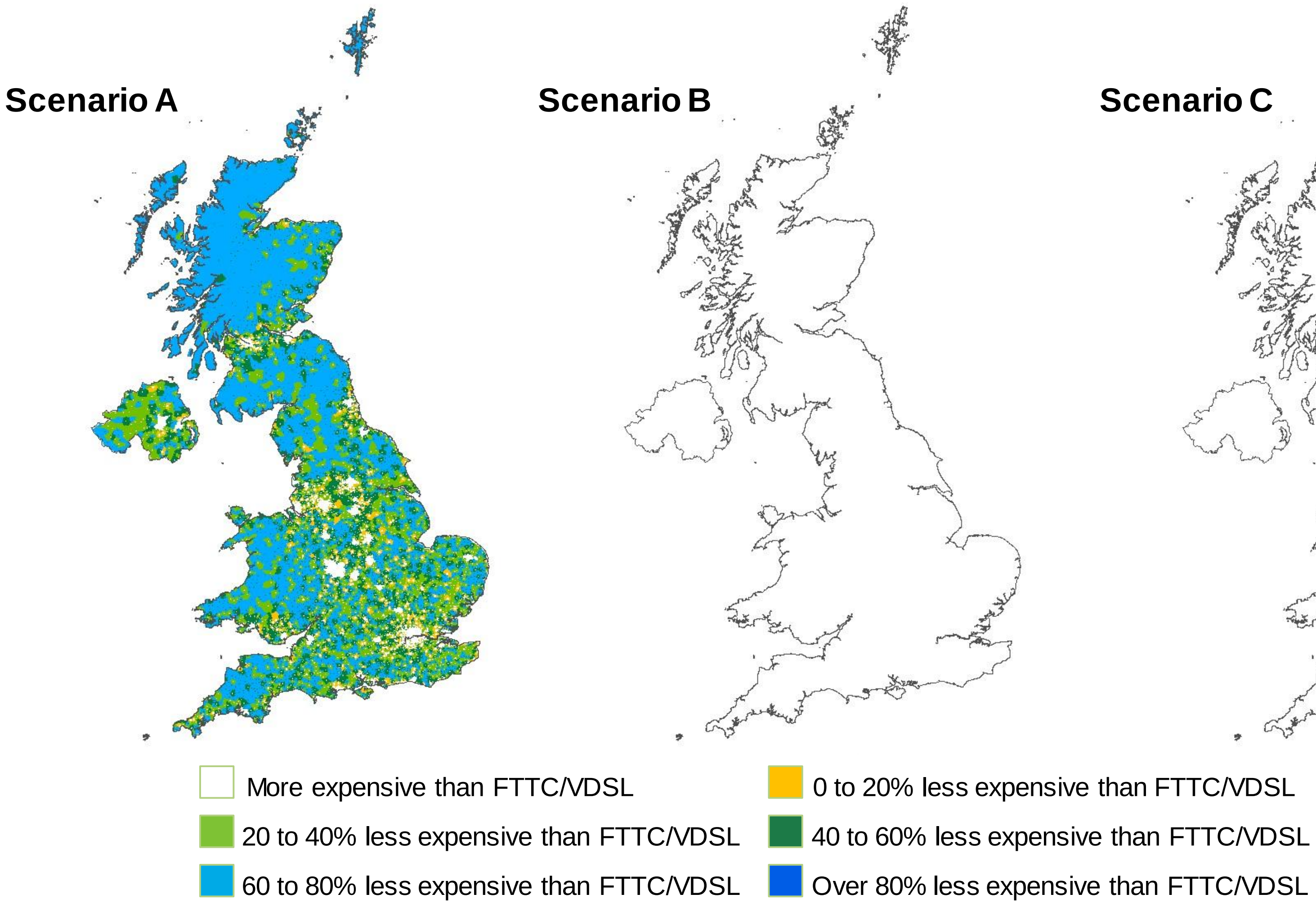

Figure 6.9: *Areas where deployment costs for satellite are lower than for FTTC/VDSL [Source: Analysys Mason for BSG]*

The population distribution of the UK is such that although in Scenario B FTTC/VDSL is less expensive than terrestrial wireless for all but the final 15% of homes, terrestrial wireless (in both its TDD and FDD forms) is less expensive than FTTC/VDSL over much of the land area of the UK.

It is important to note that although in Scenario B the cost of deploying terrestrial wireless technology in many rural areas looks attractive compared to FTTC/VDSL, the latter may provide a greater degree of future-proofing. Our hypothetical terrestrial wireless networks have been dimensioned to support exactly the amount of traffic expected in each scenario in 2016. If the bandwidth required by each household continues to grow then new base stations would need to be added continuously to keep up with demand. A network based on FTTC/VDSL, by contrast, is likely to offer a certain amount of headroom to support future traffic growth depending on the lengths of the VDSL sub-loops[21]. If the sub-loops are capable of supporting higher speeds than the 20Mbit/s peak bandwidth required in Scenarios B and C it may be that once FTTC/VDSL has been deployed in a particular area, further investment will not be required for a considerable number of years, while in the case of terrestrial wireless if the bandwidth required by each household continues to grow then new base stations will need to be added continuously to keep up with demand. If this is the case, it may be more cost-effective in the long term to deploy FTTC/VDSL in some areas where our 2016 snapshot implies that terrestrial wireless is a lower-cost option.

6.6 Implications for multiple infrastructures

In our previous fibre costing work, we concluded there are likely to be large areas of the UK where there is a single provider of fibre-based NGA but we believe that the economics of terrestrial wireless deployment (particularly in Scenarios B and C) may be such that two or more infrastructure-based players can continue to co-exist.

There are large economies of scale in *coverage-driven* wireless networks, where the lowest-cost option is clearly to have a single network of base stations shared by all operators. It is this logic which has driven T-Mobile and Three to implement network sharing in the UK and O2 and Vodafone to set up a pan-European network sharing programme called Cornerstone.

However, the results from our modelling suggest that by 2016 terrestrial wireless networks may be almost entirely *capacity-driven*. The economies of scale in capacity-driven networks are much more limited than they are in coverage-driven networks since the total number of base stations needed is independent of the number of operators, so long as each operator has sufficient spectrum to operate the maximum channel bandwidth defined in the relevant standards.

21 Consideration of the distribution of lengths for the D-side sub-loops used for VDSL is outside the scope of this study. A previous study for Ofcom by Sagentia for Ofcom (*Assessment of the theoretical limits of copper in the last mile*, available at http://stakeholders.ofcom.org.uk/binaries/research/technology-research/asses.pdf) suggests that nationally around 95% of D-side sub-loops are less than around 1150m long and we believe that by 2016 it will be possible to operate VDSL at more than 20Mbit/s over this distance. However, the national result may not be applicable to the rural geotypes since the proportion of long sub-loops in the rural geotypes may be higher than the national average.

Since Orange is now merging with T-Mobile, it appears as if there may only be two distinct FDD wireless infrastructures in the UK by 2016: one used by Orange, T-Mobile and Three and a second used by O2 and Vodafone. If terrestrial wireless networks are largely capacity-driven in 2016 as our results suggest they will be, then the savings that could be achieved by subsequently moving from two infrastructures to one appear to be quite small and, from a consumer perspective, they are probably outweighed by the increased efficiency that results from competition between the two operators.

With fewer terrestrial wireless infrastructures in the future, the level of churn between infrastructures will also be reduced. We understand that in the past high level of churn by mobile broadband subscribers has been one of the factors that has discouraged operators from rolling out wireless broadband coverage faster in rural areas. If churn between infrastructures is reduced we believe that the terrestrial wireless operators may have a greater incentive to extend their rural broadband coverage.

With regard to competition between Ka-band satellite operators, so long as Hylas-1 and KA-SAT are both launched successfully, the UK is likely to see Avanti Communications competing with Eutelsat from 2011 onwards.

6.7 Opportunities for reducing deployment costs

We see two major opportunities for reducing the deployment costs from the levels in our base case:

- release of additional spectrum for terrestrial wireless and satellite communications
- caching of popular video content on digital video recorders (DVRs) to reduce the busy-hour demand (so-called ‘sideloading’).

Access to additional spectrum

The deployment cost in a capacity-constrained terrestrial wireless network is highly dependent on the amount of spectrum available to the network. As such, for a given demand scenario, an increase in the amount of spectrum allocated to a network in a given frequency band can be expected to reduce the deployment cost per home connected, even when additional spectrum fees are taken into account. Although the UK’s five mobile licensees already have substantial paired spectrum holdings at 900MHz, 1800MHz and 2100MHz (see Figure 6.10) they are constrained in their ability to use them to support new high-speed terrestrial wireless broadband services by the need to support existing services.

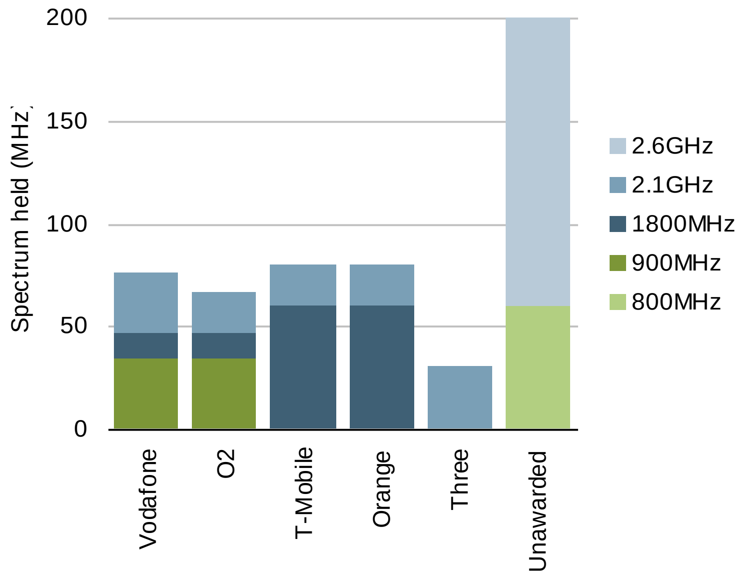

Figure 6.10: Distribution of paired spectrum [Source: Independent Spectrum Broker's Report, 2009]

The planned allocation of the new 800MHz and 2.6GHz frequencies will alleviate the shortage of terrestrial wireless spectrum to some extent but if further spectrum were to be made available then costs could be reduced below the level that we have estimated in our base case. Similarly with satellite, if the satellite itself is not power-limited then for a given demand scenario increasing the size of the spectrum block allocated to satellite will reduce costs.

Figure 6.11 illustrates the effect of increasing the amount of spectrum allocated for broadband services by showing the reduction in the cost per home that would result from a doubling of the spectrum allocated to each technology. As before, the results in the figure are based on a dongle/desktop/integrated outdoor CPE scheme and those for TDD technologies assume an 8:1 downlink to uplink ratio.

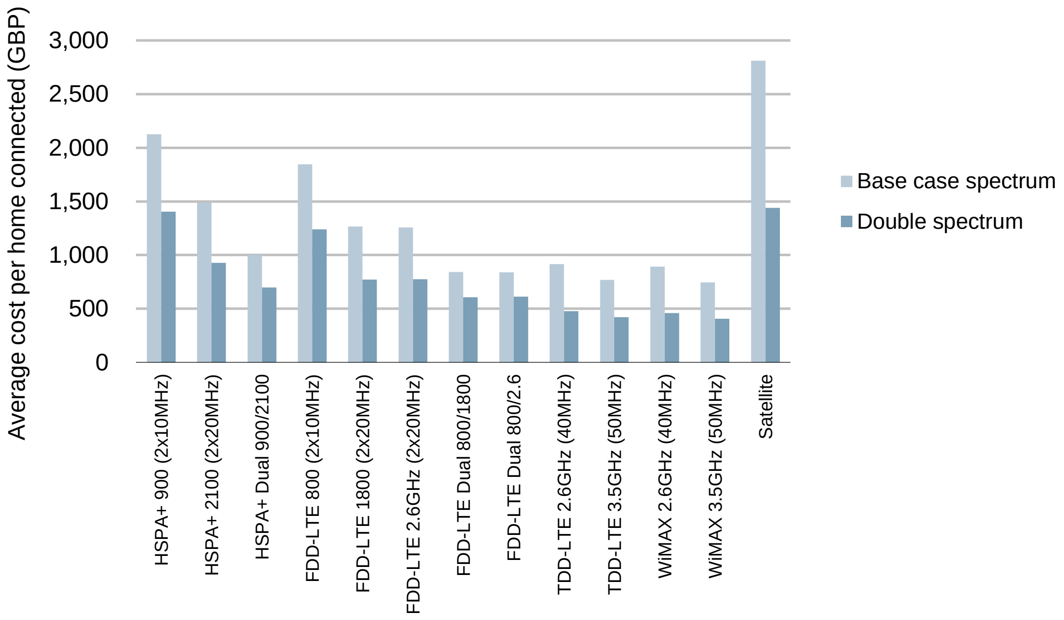

Figure 6.11: Impact of doubling spectrum availability [Source: Analysys Mason for BSG]

The reduction in cost for terrestrial wireless ranges between 27% and 39% for the FDD technologies and between 45% and 48% for the TDD technologies. The reduction in cost for satellite is 49%. UK Broadband already has access to more than twice as much spectrum at 3.5GHz as we assume in the base case. It is also conceivable that a single operator could end up with 2×40MHz of FDD spectrum at 2.6GHz, or 2×20MHz of FDD spectrum at 800MHz at the conclusion of the forthcoming auction. It would however, be difficult to provide 80MHz of TDD spectrum at 2.6GHz or any more spectrum in the 900MHz, 1800MHz and 2100MHz bands so these results should be regarded as indicative. It may also be difficult to double the size of the spectrum blocks that we have assumed will be available for satellite.

Assuming that each of the spectrum allocations could be doubled, Figure 6.12 and Figure 6.13 compare the deployment cost per home connected for the lowest-cost terrestrial wireless technologies (TDD and FDD respectively) and satellite technology considered in this study with the FTTC/VDSL fibre costs from our previous study.

Figure 6.12 shows that with double the amount of spectrum at 3.5GHz (where there is definitely more spectrum available) the cost of TDD terrestrial wireless technology is less than or equal to the cost of FTTC/VDSL across all but the most rural geotype in Scenario B (with the base-case spectrum allocation the cost was only lower for the final 15% of homes, excluding the most rural geotype).

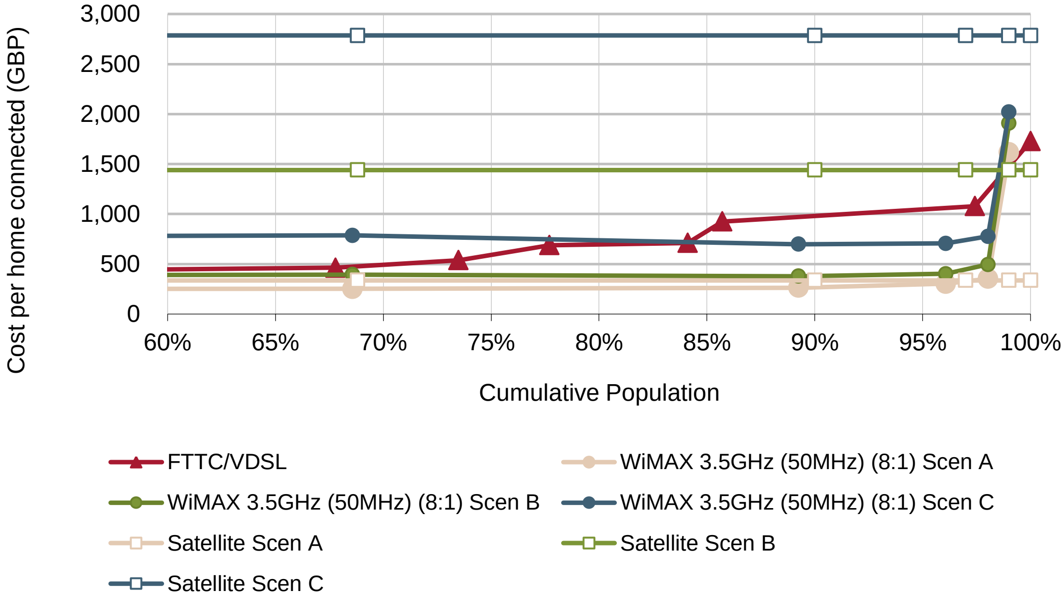

Figure 6.12: *Comparison between TDD terrestrial wireless and satellite deployment costs per home connected (with increased spectrum allocation) and the equivalent fibre costs [Source: Analysys Mason for BSG]*

Figure 6.13 shows that with double the amount of spectrum at 800MHz and 2.6GHz (where it may be available, depending on the outcome of the forthcoming auction) the cost of FDD terrestrial wireless technology is less than the cost of FTTC/VDSL for the final 24% of homes in Scenario B (compared to the final 15% of homes with the base-case spectrum allocation). It is also interesting to note that with double the amount of satellite spectrum, the cost of satellite is lower than the cost of FTTC/VDSL for the final geotype in Scenario B (previously it was around 60% more expensive).

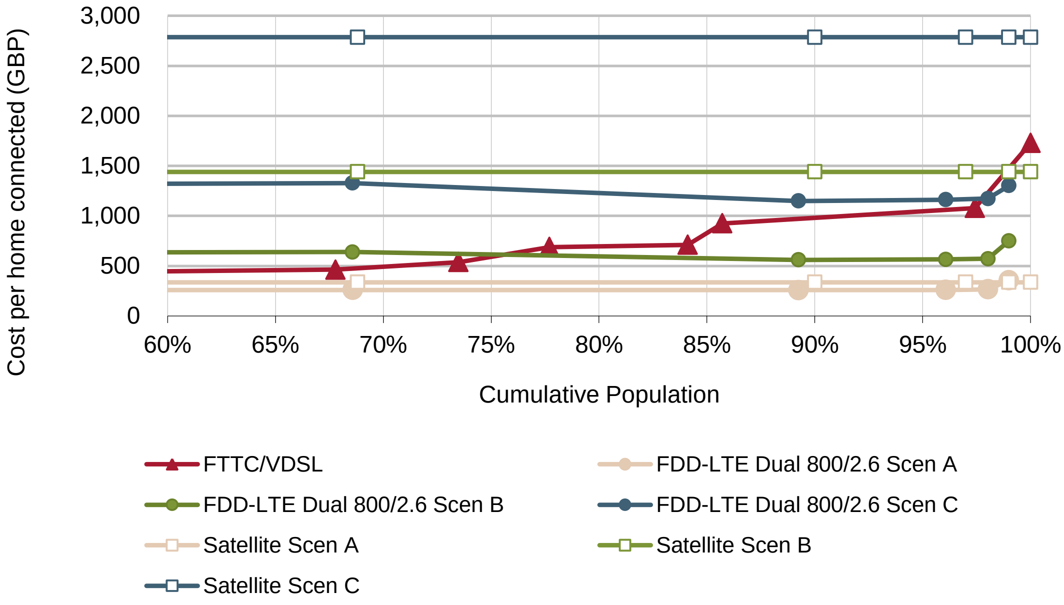

Figure 6.13: *Comparison between FDD terrestrial wireless and satellite deployment costs per home connected (with increased spectrum allocation) and the equivalent fibre costs [Source: Analysys Mason for BSG]*

Figure 6.14 shows how the difference in cost between the lowest-cost TDD technology and FTTC/VDSL varies across the UK in Scenario B with the 50MHz of spectrum in the left-hand map and 100MHz of spectrum in the right-hand map. It can be seen that when the amount of spectrum allocated to the terrestrial wireless service is doubled, some of the white areas (where the deployment costs for terrestrial wireless are higher than for FTTC/VDSL) are eliminated and the cost savings in many parts of the country are increased.

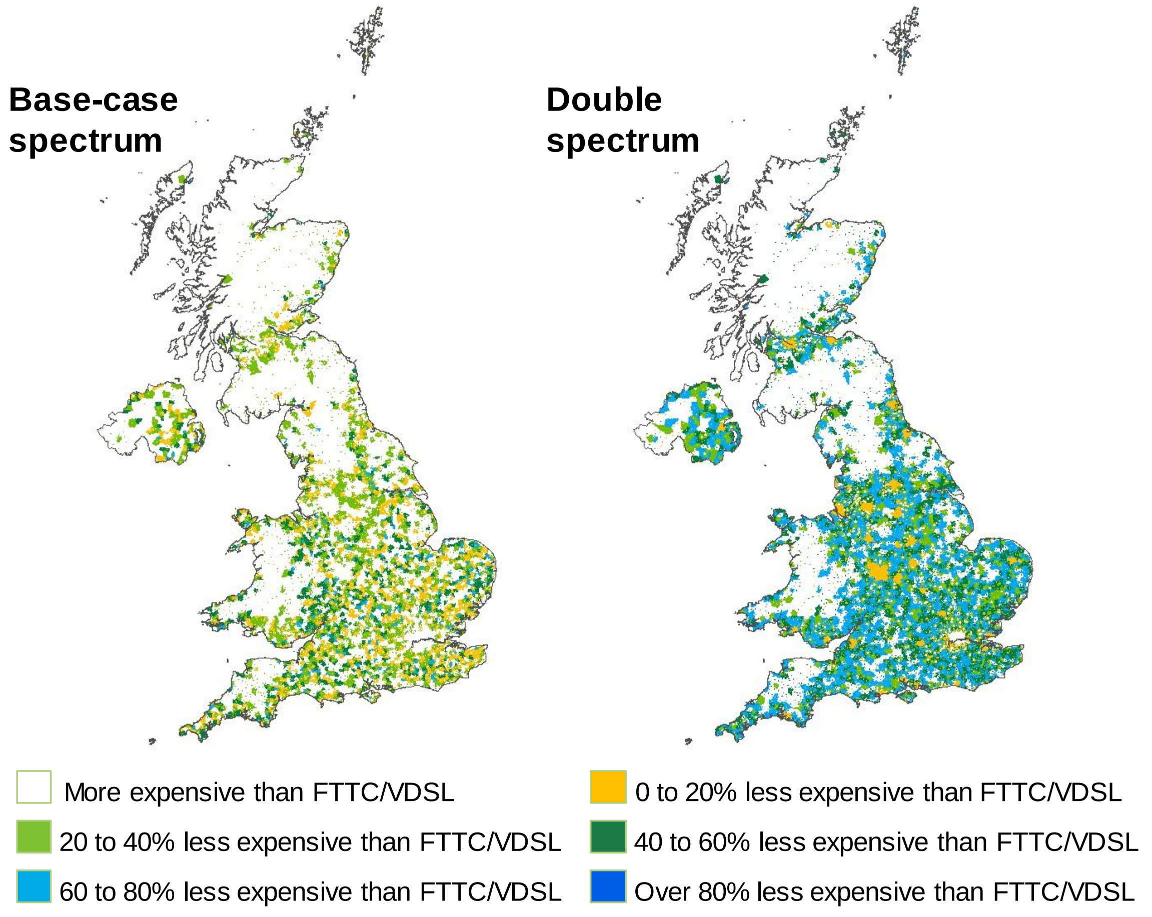

Figure 6.14: Areas where deployment costs for the lowest-cost TDD technology are lower than for FTTC/VDSL in Scenario B under base-case spectrum allocation and double spectrum allocation [Source: Analysys Mason for BSG]

Flattening peak traffic demand

Since the deployment costs for both terrestrial wireless and satellite networks are dependent on the busy-hour traffic per customer, and since in our demand scenarios the biggest driver of busy-hour traffic is streaming of on-demand video, it follows that any steps that can be taken to reduce the amount of traffic that has to be streamed in the busy hour will significantly reduce the deployment costs.

Terrestrial wireless operators are already starting to offload some of their peak traffic on to WiFi networks and femtocells, but this strategy can only be used in areas where high-bandwidth fixed broadband services are available. Another option, which can be implemented nationwide, is to push popular video content to customers at off-peak times and cache it locally on DVRs so that it is available for viewing on demand, a technique known as 'sideloading'. BSkyB has already implemented a form of this technology in the UK for its Sky Anytime service which stores a range of popular programmes from the last seven days on the hard drives of its satellite customers' Sky HD and Sky+ set top boxes. At the time of writing a 1.5TB hard disk drive can be purchased for under GBP50 (excluding VAT) and it has been estimated that the cost per GB for hard-drive storage has halved roughly every 14 months for the last 25 years[22]. If this trend continues it should be possible to buy a 40TB hard drive for GBP40 in mid-2016, which would provide sufficient storage for nearly 10 000 hours of HD content.

Satellite technology is particularly well-suited to support sideloading since a single satellite can broadcast a large number of video channels simultaneously over the whole of the UK. Customers could, in principle, receive many standard and HD TV channels from a Ku-band satellite adjacent to the Ka-band broadband satellite using a single antenna equipped with two feeds, or the programmes to be sideloaded could be rebroadcast on the Ka-band satellite.

Sideloading could also be applied to terrestrial wireless networks (to deliver a smaller number of channels) using standards such as Digital Video Broadcasting – Handheld (DVB-H) and Multimedia Broadcast Multicast Service (MBMS) which have already been ratified, though they are not currently being used commercially in the UK.

We have modelled the impact of sideloading on the results. It should be noted that we assume that sideloading only affects spontaneous on-demand TV requests, and that other traffic on the network (including spontaneous video-to-PC traffic, and linear TV traffic) is unaffected. The daily traffic profile demands for Scenario B without and with side-loading are shown in Figures 6.11 and 6.12.

22 Source: http://www.mkomo.com/cost-per-gigabyte

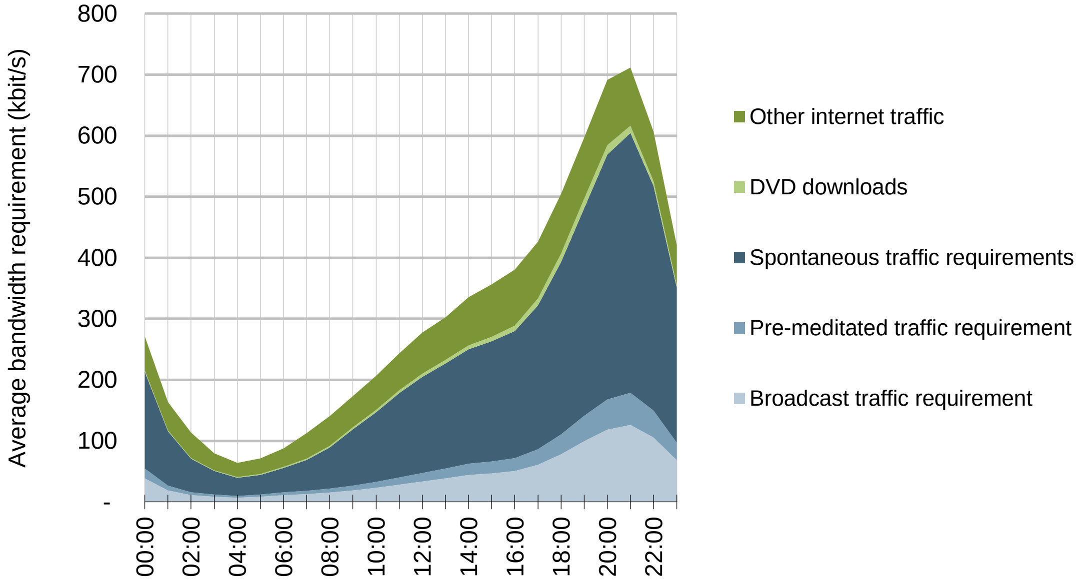

Figure 6.15: Average bandwidth requirement per home (Scenario B, no side loading) [Source: Analysys Mason for BSG]

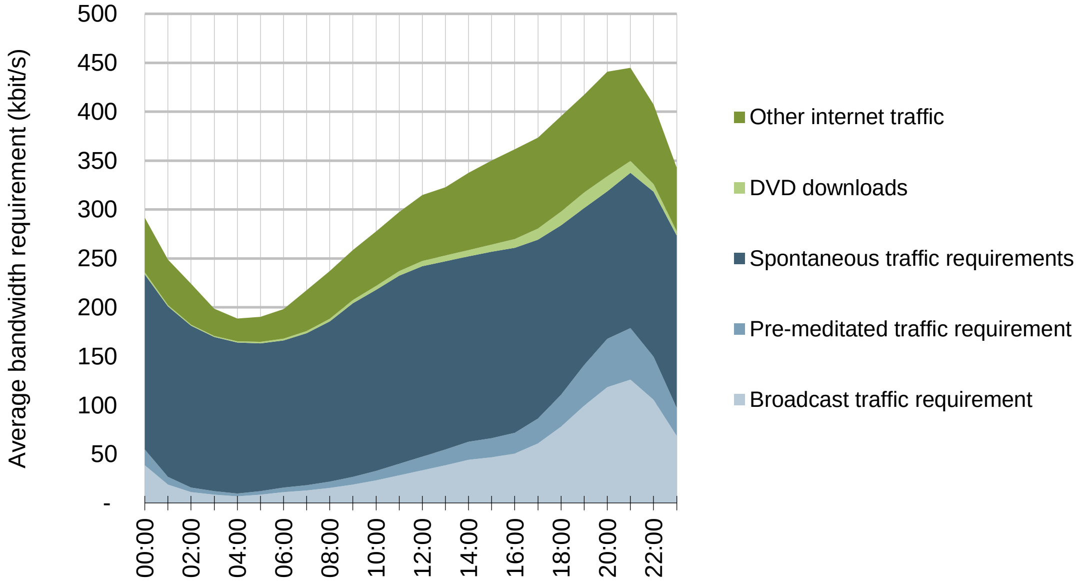

Figure 6.16: Average bandwidth requirement per home (Scenario B, with side loading) [Source: Analysys Mason for BSG

The impact of sideloading the 80% of the most popular on-demand content is shown in Figure 6.17 below.

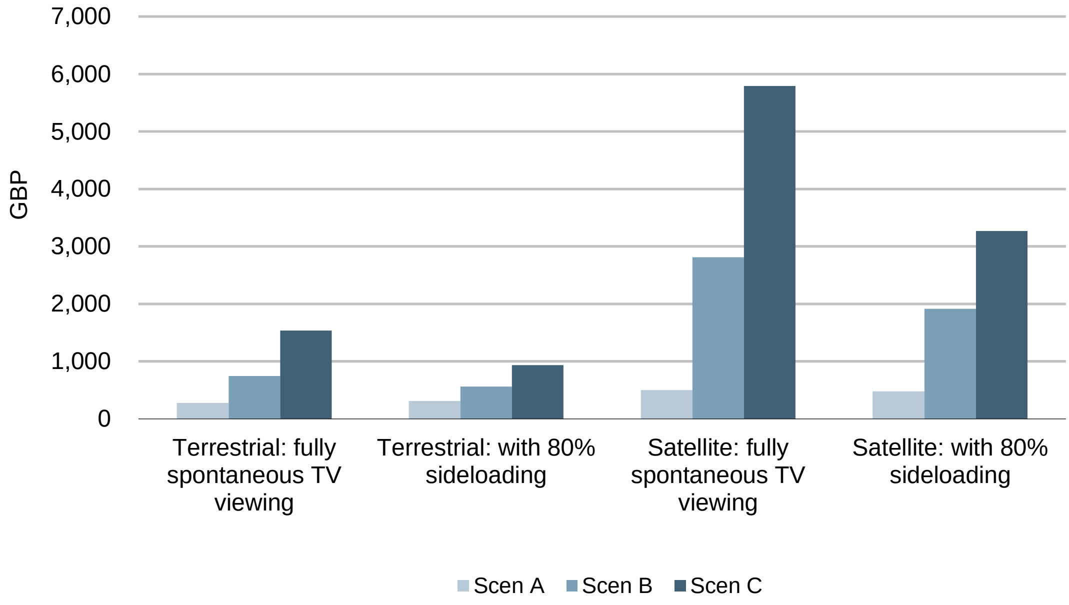

Figure 6.17: Impact of sideloading on-demand content [Source: Analysys Mason for BSG]

Sideloading reduces the cost per home connected in Scenarios B and C by between 25% and 39% for terrestrial wireless (results shown here for the lowest-cost TDD technology (WiMAX 3.5GHz with 8:1 downlink to uplink ratio). For Scenario A, the cost per home actually increases by 12%, as the small reduction in base-station requirements is off-set by the additional cost of a hard-disk drive at the customer premises. For satellite, the cost per home connected is reduced by between 4% and 44%, depending on the demand scenario.

It should be noted that sideloading of content would require some practical issues be addressed. If the content is to be stored from a live 'on-air' broadcast (e.g. Freesat, Sky), then:

- the orbital location of broadband satellite needs to be within a few degrees of that used by broadcast satellite if both services are to use the same antenna
- the user terminal will need multiple front-ends in order to receive content from multiple channels at the same time, which would increase CPE costs over and above those considered in the study (it is assumed that the satellites would not be so far apart as to require a multi-dish solution).

6.8 Operating costs

The estimated annual operating costs per line for the various fibre technologies that we considered in our previous fibre costing study are reproduced in Figure 6.18, alongside Openreach's actual costs for 2007 which were the starting points for our estimates. These costs include various items that we have not considered in the current study, such as interconnection costs, customer service, billing costs and general management costs.

	Annual cost per line (GBP)			
Cost category	*2007 Openreach actual*	*FTTC/VDSL estimate*	*FTTH/GPON estimate*	*FTTH/PTP estimate*
Provision/maintenance	12.84	11.56	2.57	2.57
Network support	10.44	11.48	5.22	5.22
General support	12.63	12.63	10.10	10.10
General management	14.77	14.77	13.29	13.29
Finance and billing	0.84	0.84	0.84	0.84
Accommodation	6.47	6.47	6.47	6.47
Bad debts	0.05	0.05	0.05	0.05
Others	1.57	1.57	1.57	1.57
Total	59.61	59.37	40.11	40.11
'Network costs'	29.75	29.51	14.26	14.26

Figure 6.18: Estimated annual operating costs per line for FTTC/VDSL and FTTH compared to Openreach's actual costs for 2007[Source: Openreach, Analysys Mason for BSG]

Figure 6.19 summarises the annual operating costs from the current study.

	Annual operating cost per home connected (GBP)		
	Scenario A	*Scenario B*	*Scenario C*
Terrestrial wireless	6	57	140
Satellite	3	18	38

Figure 6.19: Estimated annual network operating costs per home connected for terrestrial wireless and satellite [Source: Openreach, Analysys Mason for BSG]

We believe that the annual network operating cost per home connected in the current study can broadly be compared to the sum of provision/maintenance, network support and accommodation in Figure 6.18 (labelled as 'network costs in the bottom row of the table). For terrestrial wireless, the annual network operating cost per home connected is lower than the equivalent fibre costs in Scenario A, but higher by around GBP27 per annum in Scenario B, which means that over a ten-year period (and ignoring the time value of money) the lower deployment cost for terrestrial wireless may be entirely offset by higher operating costs. The annual operating cost per home connected is considerably higher than the equivalent fibre costs in Scenario C.

For satellite, the annual operating cost per home connected is lower than the equivalent fibre costs in Scenario A, between the cost for FTTH and FTTC/VDSL in Scenario B (but not sufficiently less than the FTTC/VDSL cost to offset the increased cost of deployment) and somewhat higher than both the FTTH and FTTC/VDSL costs in Scenario C.

In the earlier fibre study we also considered the network power consumption per customer. Figure 6.20 compares the results from the fibre study with the power consumption for terrestrial wireless (we believe that the network power consumption per customer for satellite is negligible since mains power is only required to operate a small number of satellite gateways).

Network type	*Average network power per customer (W)*
Openreach 2007	1.95
FTTC/VDSL	3.82
FTTH/GPON	0.60
FTTH/PTP	4.19
Terrestrial wireless Scenario A	0.70
Terrestrial wireless Scenario B	4.87
Terrestrial wireless Scenario C	10.31

Figure 6.20: Comparison of network power per customer for fibre and terrestrial wireless networks [Source: Analysys Mason for BSG]

It can be see that the power consumption per customer in Scenario A is similar to the FTTH/GPON case, Scenario B is similar to the FTTC/VDSL case and Scenario C requires around 170% more power per customer than FTTC/VDSL. We have not looked at the relative power consumption of fibre, wireless and satellite CPE in detail.

6.9 Universal service commitment

At the time of writing the technical definition of the universal service agreement (USC) was still being agreed by industry. Consequently, we have not considered the USC in detail. The current suggestion for a USC download service is “Access offering throughput of at least 2Mbit/s for 90% of the time during the busiest 3 hour period daily”[23]. We understand that this definition refers to a 90% chance of a particular user being able to receive 2Mbit/s during the busy hour[24].

We believe that the performance of the networks we have modelled is likely to be commensurate with this requirement (the level of over-provisioning we included in our Erlang C calculation is sufficient to ensure a 98% probability of an on-demand video stream starting with 5 seconds). Furthermore, we believe that the average bandwidth per home in our lowest wireless demand scenario for 2016 is higher than the average bandwidth provided by a typical fixed broadband network in 2010. We believe that as the definition of USC develops, the detailed assumption and wide range of scenarios provided in this report will provide a useful indicator of performance.

23 Source: Department for Business, Innovation & Skills, http://www.bis.gov.uk/assets/biscore/business-sectors/docs/b/10-1065-bduk-usc-theoretical-exercise-request-information.pdf

24 Clarification sought from Broadband Delivery UK

6.10 Impact on mobile coverage in rural areas

The provision of fixed terrestrial wireless services in rural areas is likely to lead to an improvement in mobile coverage in these areas, though our modelling suggest that it would probably not result in the availability of contiguous outdoor mobile broadband service. Moreover, the mobile broadband service may only be available to mobile handset users in the case of an FDD deployment (existing mobile handset models do not support the use of TDD).

6.11 Other policy considerations

As Figure 6.21 shows, the number of terrestrial wireless sites needed to support Scenarios B and C on a national basis is far higher than the 12 000 sites that we assume our hypothetical operator has today. Given that new base station sites are frequently opposed by local residents, it may be difficult for an operator to deploy this number of additional sites in practice. The problem will be exacerbated if it is not possible for the operator to re-use 100% of existing sites (e.g. because they cannot be upgraded for MIMO operation).

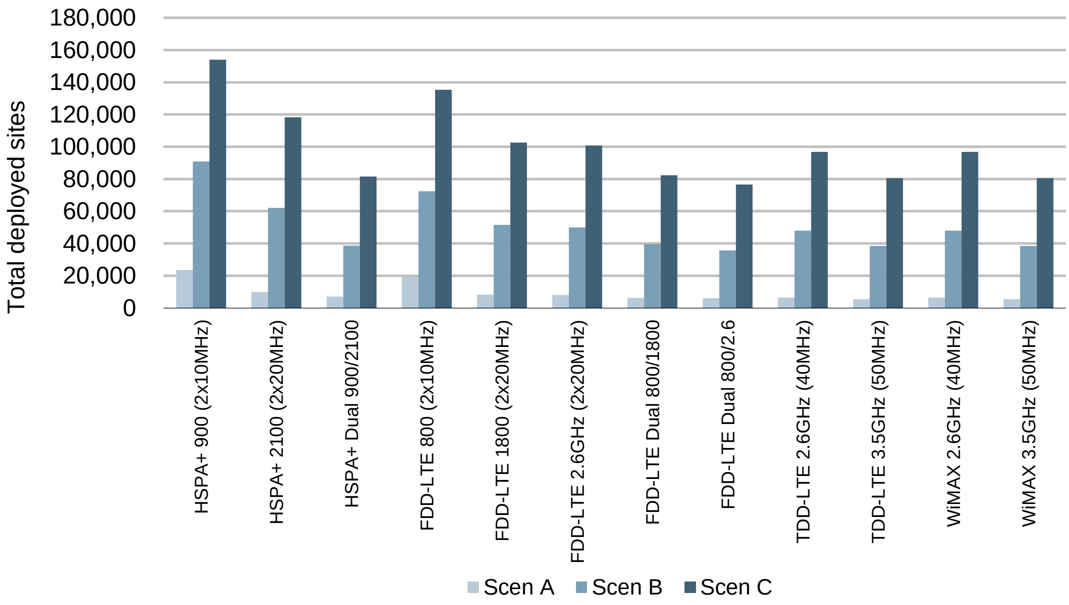

Figure 6.21: Total number of sites required per operator for terrestrial wireless broadband across the UK in 2016 [Source: Analysys Mason for BSG]

Moreover around 18% of the UK is made up of areas that have been designated as National Parks, Areas of Outstanding Natural Beauty (in England, Wales and Northern Ireland) and National Scenic Areas (in Scotland). It may be particularly difficult to find acceptable sites in these areas for the large number of new base stations that would be required for a terrestrial wireless deployment supporting the traffic envisaged in our Scenarios B and C.

At the same time there may be objections to the installation of outdoor terrestrial wireless or satellite antennas on premises in these areas, particularly if the new antennas are installed alongside existing terrestrial TV aerials and receive-only satellite TV dishes (although we understand that a receive-only satellite TV dish could be replaced by a dual-receiver dish which, although larger than the receive-only dish, would be capable of receiving satellite TV as well as supporting satellite broadband).

For the reasons outlined above National Parks, Areas of Outstanding Natural Beauty and National Scenic Areas present a particular challenge with respect to the delivery of next-generation broadband. They are, almost by definition, sparsely populated and thus unlikely to be covered by fibre roll-outs unless there is some form of public intervention.

Policy-makers are therefore likely to be faced with a difficult choice between three options for National Parks, Areas of Outstanding Natural Beauty and National Scenic Areas:

- accept the additional visual intrusion that is likely to be associated with the deployment of terrestrial wireless and/or satellite broadband in these areas
- find the funding necessary to subsidise the roll-out of less visually-intrusive fibre-based NGA in these areas
- accept that the availability and speed of broadband access in these areas will continue to lag behind other parts of the UK.

Finally, we note that the maximum permitted mean in-block transmission power for mobile and nomadic CPE operating in the 800MHz band is 23dBm[25]. This is considerably lower than the power limits for the other bands considered in this study and reduces the attractiveness of the 800MHz band relative to the other bands that can be used to provide terrestrial wireless services. The Commission Decision states that Member States may relax the limit for specific deployments, e.g. fixed station terminals in rural areas, provided that the protection of other service, networks and applications is not compromised and cross-border obligations are fulfilled. We believe it would be helpful if Ofcom could consider permitting such a relaxation in the UK.

6.12 Concluding remarks

Given our base-case assumptions on spectrum availability and based on the costs identified in our study, we believe that terrestrial wireless technology could cost effectively support a level of throughput that is similar to our predicted fixed network traffic demand in the year 2016 for the final 15% of UK homes, although this would require a large increase in the number of base stations deployed. With more spectrum devoted to the provision of broadband services than we assume in our base case, terrestrial wireless technology could deliver this level of throughput to a larger number of homes, potentially including all of the final third.

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25 Commission Decision of 6 May 2010 on harmonised technical conditions of use in the 790-862MHz frequency band for terrestrial systems capable of providing electronic communications services in the European Union (ref 2010/267/EU)

The study has also shown that satellite can play an important complementary role by delivering NGA to homes that lie outside the coverage area of terrestrial wireless and those that are located in 'notspots' within the coverage area. The cost of deploying satellite broadband could also be reduced through the allocation of additional spectrum, and it seems probable that satellite operators will further reduce the effective cost by implementing sideloading.

Although there are huge uncertainties about the level of demand in 2016, under three credible scenarios the peak demand for the average household is under 20Mbit/s. We think it unlikely that new residential applications requiring significantly in excess of 20Mbit/s will emerge before 2016. We therefore believe that the economic case for delivering higher bandwidths in the next five years is uncertain.

We believe that private-sector investment in fibre, terrestrial wireless and satellite technologies will deliver incremental increases in bandwidth over the next five years that reflect the underlying demand from consumers. Given that the lack of clarity over what the average level of demand will be in 2016, and the complex interplay of other factors which ultimately determine which technology is most cost-effective for a particular location, we believe that a cautious approach to public intervention is required.

It is however, apparent that the cost per home connected could be reduced through the release of additional terrestrial wireless and satellite spectrum and we believe this would encourage the private sector to improve the provision of broadband services in rural areas.

Annex A: Key inputs and assumptions

In this annex, we provide details of the key inputs and assumptions used in the study.

A.1 Demand

A.1.1 Overview of usage scenarios

We have modelled low-, medium- and high-usage scenarios. The three scenarios are based on the approach that we took in our work for Ofcom in 2008 in which we examined the impact on UK ISPs' fixed networks of delivering high-quality video services online. However, we have adapted the low-usage scenario so that it more closely represents an extrapolation of the way in which mobile broadband has been used to date.

A summary of each scenario is given below.

Scenario A (mobile broadband evolution)

Scenario A represents demand in a world in which the retail business model for satellite and terrestrial wireless broadband access is similar to mobile broadband today. Demand is constrained by the existence of prepaid subscriptions and relatively stringent usage caps in monthly pricing plans. The scenario is based on our lowest forecast of the growth in fixed internet traffic (including around 28% annual growth 2010 to 2016), with additional reductions to represent the impact of the mobile broadband business model. These reductions have been calibrated against existing mobile broadband traffic data (and we have taken into account the fact that existing mobile broadband users will also have a fixed broadband subscription, which most will opt to use during the busy hour: either via a desktop or laptop, or via a WiFi connection from their mobile device).

A summary of the different components of Scenario A is given below.

- most TV viewing is via traditional linear broadcasts (or via Sky+-type devices)
- on-demand content is generally consumed on the PC at a lower quality, with some people accessing the same lower-quality content on their TV
- most content is from traditional broadcasters, plus a few online specialists
- very limited shift to broadcasting linear content over IP networks
- modest shift from DVD acquisition to electronic download
- no HD content delivered via terrestrial wireless or satellite technology
- streaming content via terrestrial wireless or satellite technology limited to 2Mbit/s bandwidth
- consumption of IP data on terrestrial wireless networks (including web browsing and watching IP-video) is restricted by the influence of pricing plan usage caps
- performance of satellite and terrestrial wireless technology is sufficient to:

  - watch good-quality (i.e. low level of interruption) standard-definition streamed video content, including for example YouTube and iPlayer most of the time
  - enable acceptable, basic, current-technology video conferencing, e.g. Skype, most of the time
  - provide access to current online government services, e.g. tax self-assessment form
  - provide a good responsive web browsing experience
  - support email services.

Scenario B (fixed broadband evolution)

Scenario B represents demand in a world in which the retail business model for terrestrial wireless broadband is similar to fixed broadband today. Demand is less constrained than in Scenario A due to large (or unlimited) usage caps and predominantly pay-monthly subscriptions. Scenario B represents our view of the most likely evolution of fixed broadband traffic (including around 40% annual traffic growth from 2010 to 2016), and includes an increasing consumer preference for viewing on-demand content over IP networks (often in HD).

A summary of the different components of Scenario B is given below.

- major shift in TV viewing preferences to on-demand content, often delivered over IP networks
- a larger proportion of the content is from specialist independent channels rather than existing broadcasters
- limited shift to broadcasting linear content over IP networks
- content is easily accessible via TV sets, with a large proportion in HD
- significant move from DVD acquisition to electronic download.

Scenario C (accelerated IP-video evolution)

Scenario C also represents demand in a world in which the retail business model is similar to fixed broadband today. However, Scenario C considers the impact of an even greater change in consumer behaviour, with a large proportion of the content viewed being on-demand video delivered over IP networks. Almost all TV content is delivered in HD. Annual traffic growth is around 50% from 2010 to 2016.

- a large proportion of TV is on-demand and consumed over IP networks
- the vast majority of TV content is in HD
- more pronounced shift to broadcasting linear content over IP networks
- wide range of specialist independent channels, at the expense of existing broadcasters
- larger move from DVD acquisition to electronic download.

It should be noted that although the three scenarios represent three different evolutions of IP traffic consumption to 2016, the scenarios could also be interpreted as representing traffic consumption at different points in time. For example, if terrestrial wireless broadband services do look like Scenario B in 2016, Scenario C could represent the level of traffic consumption several years later.

This is an important concept for understanding how continued investment would be need in the network to meet the ongoing demand.

The three scenarios are based on the approach that we took in our work for Ofcom in 2008 which examined the impact on UK ISPs' fixed networks of delivering high-quality video services online. However, we have adapted the low-usage scenario so that it more closely represents an extrapolation of the way in which mobile broadband has been used to date.

A.1.2 Detailed assumptions of usage scenarios

The detailed assumptions associated with the three scenarios are shown in Figure A.1. It should be noted that the long-term figures are shown for 2018, although we have considered a snapshot of the market from 2016 for this study. We use interpolation curves to determine the relevant value in 2016.

Assumptions	*Scen A*	*Scen B*	*Scen C*
Share of video content accessed via PC (2018)	7%	14%	17%
Share of non-linear content (of total video content) (2018)	20%	40%	60%
Share of video-to-PC traffic originating from broadcaster portals / websites (2018)	12%	30%	35%
Share of HD content in total TV content (2008)	0%	1%	1%
Share of HD content in total TV content (2018)	0%	50%	90%
Share of broadcast traffic transmitted via IP networks (2018)	5%	10%	15%
Share of on-demand traffic transmitted via IP networks (2018)	100%	100%	100%
Share of on-demand traffic which is spontaneous (2018)	25%	35%	45%
Share of DVD rentals & sales which is done online (2018)	5%	10%	30%
Bandwidth requirements for HD streams (2018) (Mbit/s)	N/A	6	6
Bandwidth requirement for Broadcast streaming (2018) (Mbit/s)	2	6	6
Bandwidth requirement for DVD download (2018) (Mbit/s)	2	6	6

Figure A.1: Main demand scenario assumptions [Source: Analysys Mason for BSG]

It should be noted that in the case of Scenario A, we impose additional correction factors on the assumptions below so that this scenario represents an extrapolation of the traffic patterns on today's mobile broadband networks (i.e. where data consumption is limited by usage caps). The correction factors are calibrated against operator data and are as follows:

- consumption of IP video: 39% of a fixed network under the same scenario
- consumption of other IP data: 28% of a fixed network under the same scenario.

It should also be noted that in calibrating the correction factors against operator data, we have estimated the impact of those users who have both a fixed and mobile internet subscription. We have assumed that 59% of mobile broadband subscribers today also have a fixed broadband subscription[26], and 75% of those customers with dual subscriptions will use their fixed connection (and therefore will not be using their mobile connection) during the busy hour.

We have also made a number of other assumptions relating to the parameters for traffic demand on the network which are used across the scenarios. These are shown in Figure A.2 below:

26 Based on data provided by operators.

Assumption	*Value*
IP signalling overhead factor[27]	97%
SD bandwidth	2
HD bandwidth (2007) (Mbit/s)	18
HD bandwidth (2016) (Mbit/s)	8.3
DVD bandwidth (2016) (Mbit/s)[28]	6
iPlayer streaming bandwidth (2008) (Mbit/s)	0.50
iPlayer downloading encoding (2008) (Mbit/s)	1.00
YouTube streaming bandwidth (2008) (Mbit/s)	0.32
iPlayer streaming bandwidth (2018) (Mbit/s)	6.00
iPlayer downloading encoding (2018)	2.00
YouTube streaming bandwidth (2018)	1.50
DVDs per transaction (2008)[29]	1.50
DVDs per transaction (2018)	3.00
Average length of downloaded DVD in minutes (2008)	90
Average length of downloaded DVD in minutes (2018)	90
TV consumption per individual (minutes/day) (2008)	216
On-demand TV consumption (hours/week) (2008)	2.68
On-demand TV consumption (minutes/day) (2008)	23
Video to PC minutes per person (minutes/day) (2008)	5.55
iPlayer streaming to download ratio (2008)	0.89
iPlayer streaming to download ratio (2018)	0.83
IP share of broadcast TV traffic (2008)	0.01%
IP share of on-demand TV traffic (2008)	1.50%

Figure A.2: Additional demand parameters [Source: Analysys Mason, Analysys Mason Research, Cisco, BBC, BARB, YouGov, ComScore, Sagentia]

We have undertaken further analysis to quantify the impact of multi-room viewing in a typical household more accurately. Since on-demand video services require a separate stream for each television, it is important to consider the impact of multi-room versus communal viewing. We have been unable to find sources of data in this area, so we built up our own assumptions for how each type of content could be viewed. This is shown in Figure A.3 below.

27 The IP signalling overhead factor is applied to derive the bandwidth requirements for non-video use as the source data (from Cisco) is in terms of total PB downloaded per month across Europe. We have not applied the factor to video traffic, as signalling overhead is implicitly included in our assumed bandwidth requirements.

28 Includes a blended average of standard and high definition.

29 We have included the impact of a new business model, whereby DVD viewing moves away from physical discs to a download-based approach.

Content	*Multi-room % (2008)*	*Multi-room % (2018)*
Linear broadcast	35%	45%
Pre-meditated	60%	60%
On demand: TV	60%	60%
On-demand: PC	75%	65%
On-demand: alternative	90%	95%
DVDs	25%	25%

Figure A.3: Multi-room viewing assumptions [Source: Analysys Mason for BSG]

The amount of video viewing in each scenario is shown in Figure A.4 below.

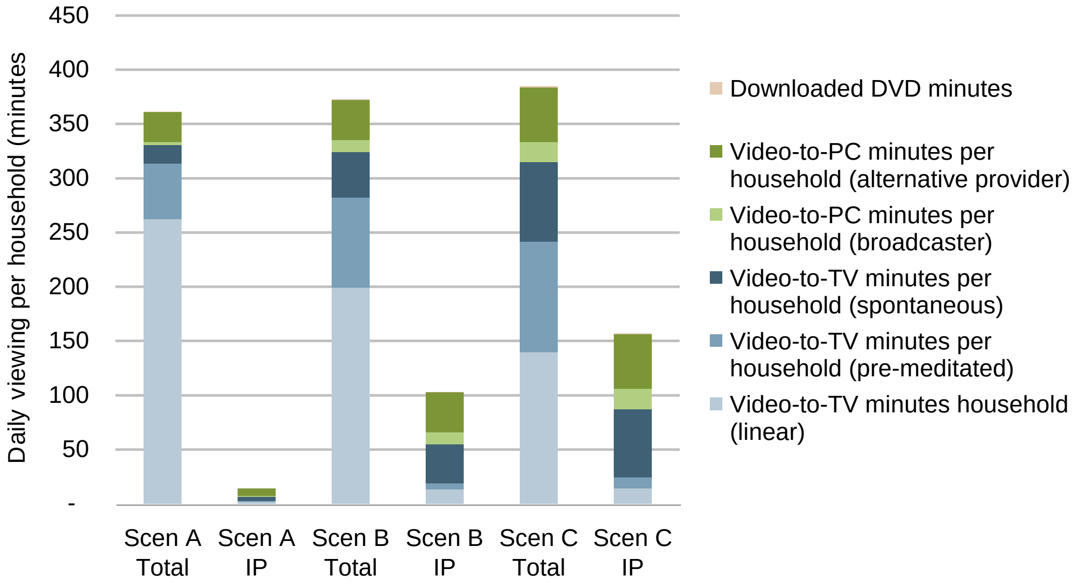

Figure A.4: Comparison of video viewing in 2016 for demand scenarios [Source: Analysys Mason for BSG]

This results in the monthly IP data requirement for each scenario shown in Figure A.5 below.

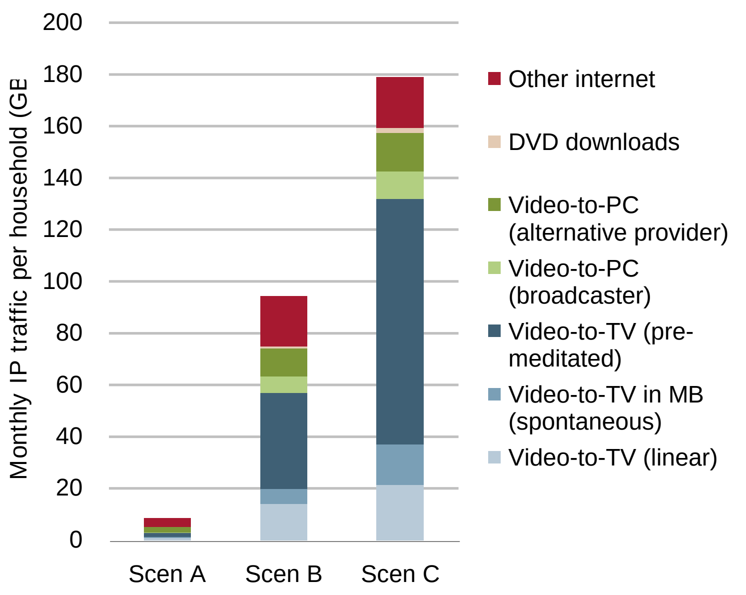

Figure A.5: Comparison of monthly IP data required in 2016 in low, medium and high-usage scenarios [Source: Analysys Mason for BSG]

HD video traffic has a significant impact on bandwidth requirements and we have varied the overall proportions of HD and SD video traffic by scenario, as shown Figure A.6.

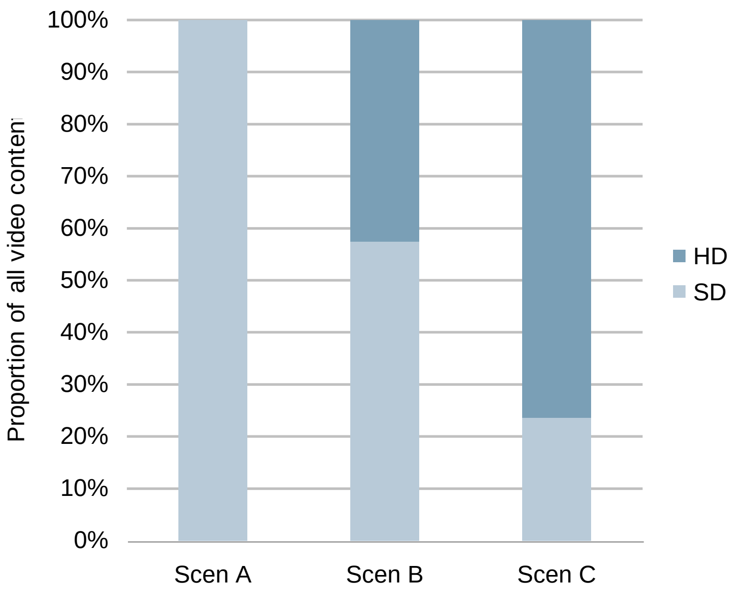

Figure A.6: Proportion of HD and SD video traffic [Source: Analysys Mason for BSG]

Scenarios B and C contain the same assumptions about non-video traffic, which amounts to approximately 20GB per household per month in 2016, as shown in Figure A.7 below. Scenario A has the same breakdown as below, but due to the applied mobile broadband correction factor, the total non-video traffic is assumed to be just 5.5GB of per household per month in 2016.

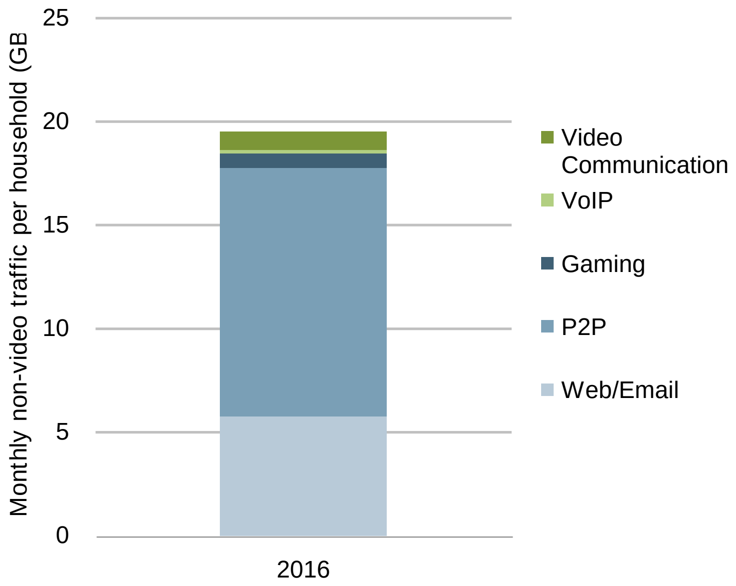

Figure A.7: Non-video traffic per household in 2016 for all scenarios [Source: Analysys Mason for BSG]

We expect that IP traffic in 2016 will be dominated by viewing video and therefore the proportion of upload traffic will be comparatively small. However, we have included a sensitivity in the modelling to test impact of increase volumes of upload traffic.

We have considered the shape of download traffic through the day to establish the busy hour demand on the network. The shape of the traffic is dictated by the total amount downloaded (which is driven by stream bandwidth and viewing minutes for video) and the distribution of use through the day.

We estimate that these assumptions will result in an average busy hour demand per household of around 85kbit/s in Scenario A, 711kbit/s in Scenario B and 1.5Mbit/s in Scenario C.

The hourly shape of average demand per household for the three scenarios is shown in Figure A.8, Figure A.9 and Figure A.10 below.

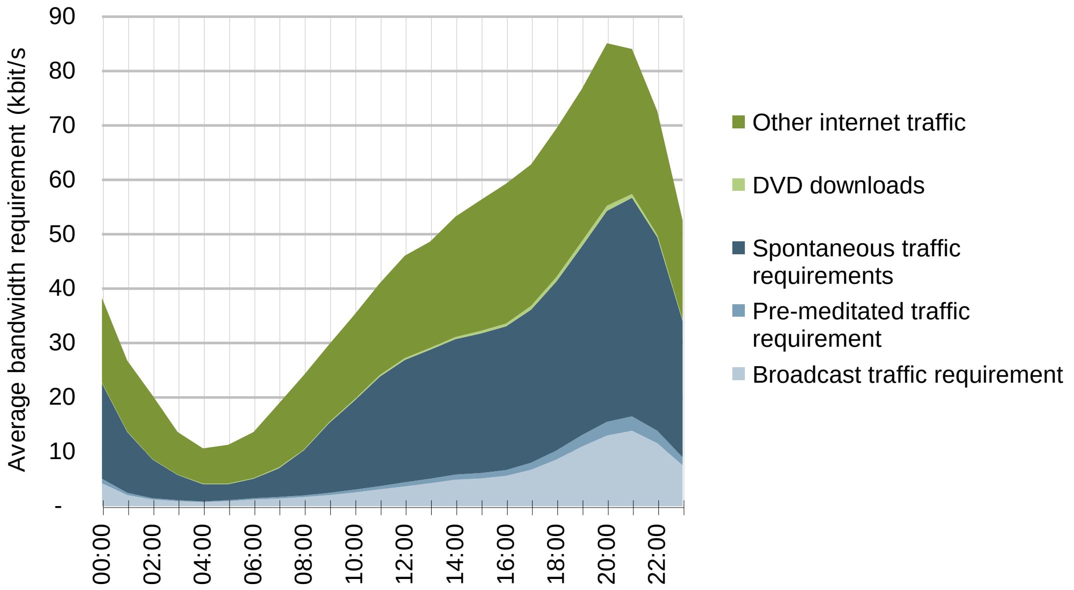

Figure A.8: Average bandwidth requirement per home, Scenario A [Source: Analysys Mason for BSG]

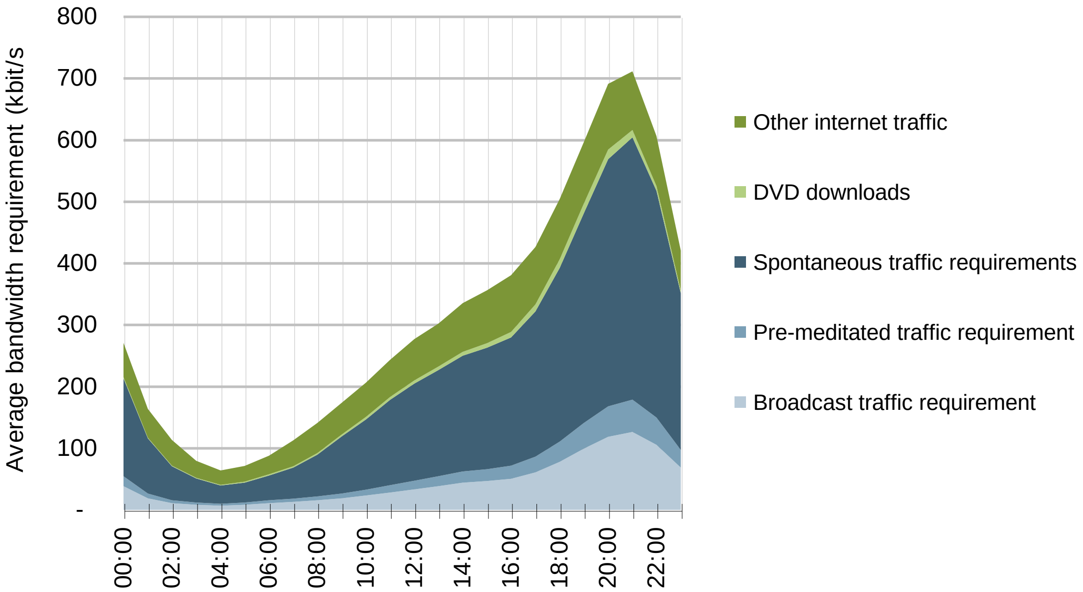

Figure A.9: Average bandwidth requirement per home, Scenario B [Source: Analysys Mason for BSG]

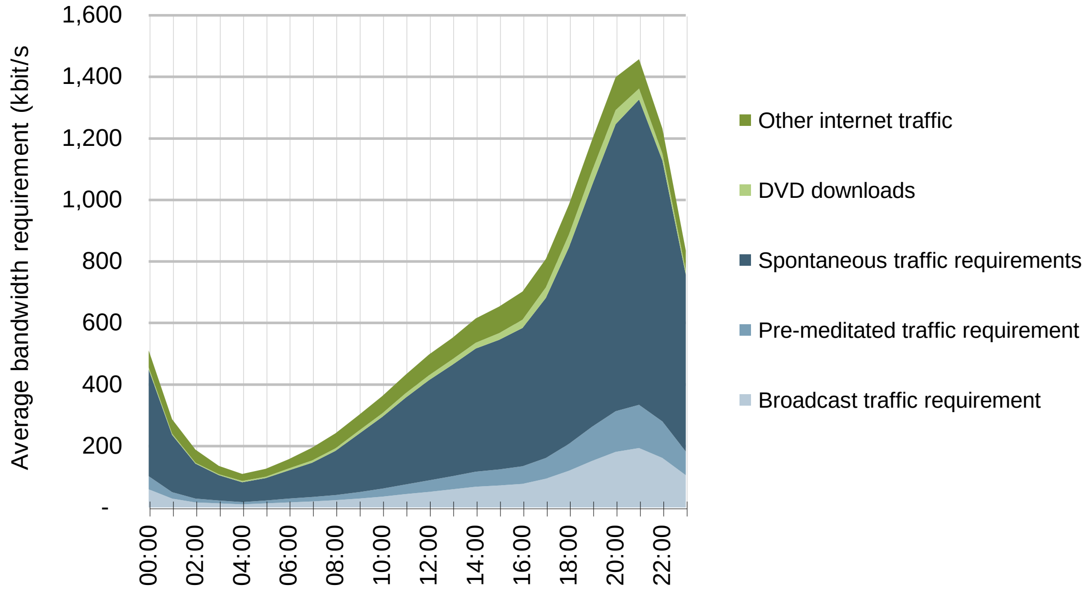

Figure A.10: Average bandwidth requirement per home, Scenario C [Source: Analysys Mason for BSG]

As discussed above we have used Erlang C to overprovision the network beyond these peaks to accommodate random demand. The key input parameters and associated over-provisioning outputs of the Erlang C calculation for the three scenarios for the downlink are shown in Figure A.11.

It should be noted that the Erlang C calculation is not valid for a service take-up of below 2%.

	Households per sector			BH streaming take-up			Over-provisioning factor		
Geotype	Scen A	Scen B	Scen C				Scen A	Scen B	Scen C
Urban	422	126	61				103%	74%	82%
Suburban 1	677	117	57				93%	75%	91%
Suburban 2	646	117	57				93%	75%	91%
Rural 1	371	139	68	2%	13%	22%	117%	66%	82%
Rural 2	135	84	68				247%	93%	82%
Rural 3	87	54	54				338%	131%	91%
Rural 4	17	11	11				450%	131%	91%

Figure A.11: Erlang C inputs and output for downlink (WiMAX at 3.5GHz, 8:1 downlink to uplink ratio) [Source: Analysys Mason for BSG]

The maximum bandwidth demand per household will be realised in a situation where all members of the household are watching a separate stream in the highest definition available. Assuming 2.3 people per household in 2016, the maximum bandwidth requirements per household is shown in Figure A.12 below.

Scenario	*Maximum bandwidth requirement (Mbit/s)*
A	4.6
B	19.0
C	19.0

Figure A.12: Maximum bandwidth requirement per household [Source: Analysys Mason for BSG]

It should be noted that the figure of 19.0Mbit/s for Scenarios B and C is based on 2.3 people each watching an HD stream of 8.3Mbit/s.

We have included an allowance for IP overheads in our input assumptions for "other" (i.e. non-video) IP traffic equal to 3%. We assume that the data rates for IP-video implicitly include an allowance for any overheads. In terms of signalling, we have included a margin in our link budgets for terrestrial wireless networks. For signalling in satellite networks, we have assumed a signalling overhead of 5%.

A.2 Technical assumptions

In this section we present the assumptions relating to the technical capabilities of terrestrial wireless networks, including technologies and spectrum bands, detailed technical and performance assumptions, and indicative link budgets.

A.2.1 Link budget assumptions for terrestrial wireless networks

In this section we provide a summary of the technical input assumptions that Analysys Mason has used to model the deployment of a terrestrial wireless broadband network for the UK. The assumptions presented below include the inputs to link budgets and the data rate performance of the various wireless broadband technologies.

CPE antenna performance

Antenna type	*Parameter*	*800/900MHz*	*1800/2100MHz*	*2.6GHz*	*3.5GHz*	*Notes*
"Patch" antenna (including outdoor and window mounted)	Antenna gain	10dBi	11.5dBi	13dBi	15dBi	Frequency dependent only (assumed to be the same set of figures for all technologies) Assumes "patch" antennas which could support MIMO Applies to outdoor mounting (outdoor antenna and integrated outdoor unit) and indoor window mounting
Outdoor roof mounted Yagi or Log Periodic antenna	Antenna gain	13.5dBi	14.5dBi	16dBi	18dBi	Frequency dependent only (assumed to be the same set of figures for all technologies)
Outdoor antenna	Cable losses	4dB	5dB	6dB	7dB	Frequency dependent only (assumed to be the same set of figures for all technologies). Based on 10m of good quality cable (e.g. LMR200/BWL195 or similar would be suitable for national deployment using MIMO)
Window antenna	Cable and misalignment losses	3.33dB	3.67dB	4.00dB	4.33dB	Assumed to be 1/3 of length of outdoor antenna cable
Yagi or Log Periodic antenna	Cable losses	1.33dB	1.67dB	2.00dB	2.33dB	Based on 10m of high-quality cable, e.g. LMR400 (assumed to be suitable as size of antenna will mean only SISO schemes will be deployed
Indoor desktop	Antenna gain	3dBi	3dBi	3dBi	3dBi	
Dongle	Antenna gain	1dB	1dB	1dB	1dB	Assumed to be the same for all frequencies and technologies

Figure A.13: Antenna performance assumptions [Source: Analysys Mason for BSG]

Other CPE performance

Parameter	*Value*	*Notes*
Power amplifier output power[30]	24dBm[31]	All parameters assumed to be the same for all CPE, and for all technologies and frequencies
Number of transmit antennas	Dictated by MIMO scheme	
Receiver noise figure	7dB	

Figure A.14: Other CPE performance assumptions [Source: Analysys Mason for BSG]

We recognise that CPE performance is also dictated by standardised user equipment (UE) categories. We have assumed that by 2016, a standardised UE category will be widely available that supports the other data rate related assumptions made in this study (e.g. up to 64QAM modulation and up to 4×4 MIMO antenna schemes).

We recognise that the type of RAKE receiver will also impact the performance of HSPA+. We note that advanced interference aware Rake receivers are being developed which significantly reduce the impact of inter- and intra-cell interference[32]. We have assumed that by 2016, UE standards will mean that advanced Rake receivers will be readily available and therefore have only included a small interference margin in our HSPA+ link budgets.

30 Power level in line with maximum available as defined in 3GPP UMTS User Equipment standard, reference: 3GPP TS 25.101 version 9.4.0 Release 9; under a multiple antenna MIMO scheme, each power amplifier is assumed to have this power output

31 We recognise that this power amplifier rating results in an EIRP that is beyond the limit for mobile terminals set in the European Commission Decision of 6 May 2010 on harmonised technical conditions of use of the 790-862MHz frequency band for terrestrial systems capable of providing electronic communications services in the European Union (ref 2010/267/EU). The decision allows Member States to relax the limits for specific deployments, e.g. fixed station terminals in rural areas, provided that the protection of other service, networks and applications is not compromised and cross-border obligations are fulfilled. This relaxation has already been granted in other Member States and our calculation assumes that it will also be granted in the UK

32 "HSPA Evolution – Boosting the performance of mobile broadband access", Ericsson Review No. 1, 2008; "UMTS Evolution from 3GPP Release 7 to Release 8 HSPA and SAE/LTE?", 3G Americas, December 2007

Base station performance

Parameter	*800/900MHz*	*1800/2100MHz*	*2.6GHz*	*3.5GHz*	*Notes*
Power amplifier output power	37	38	40	38	Frequency dependent only (assumed to be the same set of figures for all technologies)
Number of transmit antennas	4	4	4	4	Assumed to be same for all frequencies and technologies (see notes about MIMO below)
Antenna gain	16dBi	18dBi	21dBi	23dBi	Source: Ofcom spectrum liberalisation, and industry benchmarks
Transmitter/cable losses	2dB	3dB	4dB	5dB	Cable losses assume higher-quality cable than used in home
Receiver noise figure	4dB	4dB	4dB	4dB	Assumed to be same for all frequencies and technologies

Figure A.15: Base station performance assumptions [Source: Analysys Mason for BSG]

Other link budget parameters

Parameter	*Value*	*Notes*
Insertion losses	2.5dB (FDD) 1.0dB (TDD)	To represent duplexer losses for FDD and switch losses for TDD
TDD power adjustment	-1.8dB downlink -4.8dB uplink	Based on a 2:1 downlink to uplink ratio To represent the impact of downlink to uplink ratio on output power
Interference margin (to account for 1:1 frequency re-use)	HSPA+: 1dB LTE and WiMAX: 4dB (uplink) and 1dB (downlink)	HSPA+ margin included to account for cell breathing effect from other users, but also including the effect of advanced interference aware rake receivers LTE and WiMAX margin included to account for other-cell interference
Control channel overhead	0.8dB (downlink only)	Assumed to be the same for all technologies
Building penetration loss	15dB (desktop CPE), 5dB (Window mounted antenna)	Assumed to be the same for all technologies
Number of sub-channels[33]	Dependent on data rate	Used to derive sub-channelisation gain for LTE and WiMAX; assumed to be the same for both OFDM technologies and all frequencies
Processing gain	Data rate dependent	HSPA+ only.

Figure A.16: Other link budget parameters [Source: Analysys Mason for BSG]

We have calculated the shadow margin based on the standard deviation of lognormal fading (and the standard deviation of building penetration loss for indoor antenna) for different terrain types and frequencies. It is assumed that the standard deviation for suburban and rural areas can be considered the same. The shadow fade margin is shown in Figure A.17 for 1800/2100MHz.

Location of CPE antenna	*Urban*	*Suburban*	*Rural*
Outdoor	5.39dB	6.27dB	6.27dB
Indoor	6.74dB	7.46dB	7.46dB

Figure A.17: Shadow fade margin for 1800/2100MHz [Source: Analysys Mason for BSG]

33 We recognise that sub-channelisation schemes represent a trade-off between supporting multiple users and providing maximum bandwidth to each user.

We have also used a cell-edge probability calculation to derive the shadow fade margin. This calculation is based on a McLaurin series approximation, which is widely employed by operators to calculate cell performance. We have assumed a cell edge probability requirement of 75%. This gives a cell area probability of around 87% to 90% (depending on geotype and indoor/outdoor reception). However, it should be noted that the other inputs to the calculation (standard deviations for lognormal fading and building penetration loss) are based on a mobile voice network, so the resultant shadow fade margin is likely to be slightly too conservative for a fixed wireless network. In reality, the cell area probability for the fixed terrestrial wireless network may be closer to 95%.

A.2.2 Technology performance parameters for terrestrial wireless networks

In Figure A.18 we show the parameters that influence the data rate performance of the different technologies. Currently we are assuming that the data rate provided by a technology is dictated by:

- the acceptable signal-to-noise ratio at the receiver, which dictates the best available modulation and error correction scheme, which dictates the available throughput in bit/s/Hz. We assume that this relationship is the same for all technologies.
- the available spectrum. We have made assumptions on the spectrum available at each technology-frequency combination as part of our scenarios[34].

Parameter	*HSPA+*	*FDD-LTE*	*TDD-LTE*	*WIMAX*	*Notes*
Sector throughput reduction	10%	10%	10%	10%	Assumed to be the same for all technologies Applied to weighted average of available data rates across sector Takes account of variations in user demand and the ability to fully receive the benefits of MIMO, and assumes no mobility requirement
Signalling overhead	10%	10%	10%	10%	Assumed to be the same for all technologies
Dual carrier gain[35]	15%	0%	0%	0%	HSPA+ only Applied to available data rate (assuming the use of dual-carrier technology)

Figure A.18: Technology performance parameters [Source: Analysys Mason for BSG]

We have included the impact of two types of MIMO scheme: MIMO A and MIMO B.

34 It should be noted that for HSPA+, only 3.84MHz out of every 5MHz of spectrum is available to carry data.

35 Calibrated from data in ”White Paper – Dual Cell HSDPA and its Future Evolution”, Nomor Research GmbH, January 2009

- MIMO A (space time block coding) involves sending multiple parallel streams of the same data. This increases the chance that the receiver can identify a strong signal and so increases the data rate at the cell edge.

- MIMO B (spatial multiplexing) involves splitting the data between different streams. This creates a direct increase in the available throughput for a given amount of spectrum. However, the benefits of MIMO B can only be fully realised where there is a relatively high signal-to-noise ratio (i.e. close to the centre of the cell).

Both MIMO A and MIMO B schemes can be employed in the same cell, delivering benefits to both cell radius and average throughput.

We have assumed that the MIMO scheme available will vary according to frequency (due to antenna size constraints)[36]. The schemes are shown in Figure A.19.

CPE type	*800/900MHz*	*1800/2100MHz*	*2.6GHz*	*3.5GHz*
Dongle	1×4	1×4	1×4	1×4
Desktop (IDU)	2×4	4×4	4×4	4×4
External (ODU)	2×4	4×4	4×4	4×4
Integrated external	2×4	4×4	4×4	4×4
Window	2×4	4×4	4×4	4×4
Log P or Yagi	1×4	1×4	1×4	1×4

Figure A.19: MIMO schemes [Source: Analysys Mason for BSG]

For the impact of MIMO A, we have included a signal strength gain in the link budgets. The ideal MIMO A gain is given by $10\log(N_t \times N_r)$, where N_t is the number of transmit antennas and N_r is the number of receive antennas. We note that this formula represents an ideal scenario, and that in reality gains will be lower, especially for higher-order MIMO schemes (e.g. 4×4) and in rural areas. Therefore we have reduced the gains provided by 2×4 and 4×4 MIMO schemes from the ideal suggested by the formula to 4.5dB and 6dB respectively.

For the impact of MIMO B, we have assumed data rate increases for each MIMO scheme as shown in Figure A.20 below.

36 It should be noted that 1x4 MIMO schemes are in fact Multiple Input Single Output (MISO) on the downlink and Single Input Multiple Output (SIMO) on the uplink.

MIMO scheme	*Data rate multiplier*
1×4	1.5
2×4	2.0
4×4	3.6

Figure A.20: Impact of MIMO schemes [Source: Analysys Mason for BSG]

Our current assumptions provide the following average sector downlink throughputs. Please note that these rates are calculated using the weighted average methodology in Section 4.3.2. We have calibrated these data rates against the published theoretical performance of next-generation technologies. A selection of the average sector downlink throughput values used in the study is shown in Figure A.21.

Technology/band	*Total spectrum available*	*Average throughput*			*Notes*
		Scenario A	*Scenario B*	*Scenario C*	
HSPA+ 900MHz	2×10MHz	20	37	37	Assumes 4×2 MIMO and dual carrier technology
HSPA+ 2100MHz	2×20MHz	38	48	48	Assumes 4×4 MIMO and dual carrier technology
FDD-LTE 800MHz	2×10MHz	23	42	42	Assumes 4×2 MIMO
FDD-LTE 1800MHz	2×20MHz	44	55	55	Assumes 4×4 MIMO
FDD-LTE 2.6GHz	2×20MHz	44	56	56	Assumes 4×4 MIMO
TDD-LTE 2.6GHz	40MHz	56	58	58	Assumes 4×4 MIMO and 2:1 downlink to uplink ratio
TDD-LTE 3.5GHz	50MHz	70	70	70	Assumes 4×4 MIMO and 2:1 downlink to uplink ratio
WiMAX 2.6GHz	40MHz	56	58	58	Assumes 4×4 MIMO and 2:1 downlink to uplink ratio
WiMAX 3.5GHz	50MHz	70	70	70	Assumes 4×4 MIMO and 2:1 downlink to uplink ratio
SPA+ Dual 900/2100	2×30MHz	49	70	70	Assumes same technology as individual freq
FDD-LTE Dual 800/1800	2×30MHz	56	69	69	Assumes same technology as individual freq
FDD-LTE Dual 800/2.6	2×30MHz	58	74	74	Assumes same technology as individual freq

Figure A.21: Average sector downlink throughputs [Source: Analysys Mason for BSG]

It can be seen that the average throughput for Scenarios B and C is often higher than the throughput in Scenario A. This is because the required cell edge date rate is higher in Scenarios B and C than Scenario A. This change in requirement creates a trade-off between coverage and throughput: under Scenario B and C, the cell size for a given technology/frequency is often smaller than for Scenario A, but the cell throughput is increased. The cell radii used in the modelling are presented in Section 4.3.2.

This effect is not seen for all technology/frequency combinations, as it depends on whether the increase in cell edge data rate requires a change in the required signal-to-noise ratio in the link budget. The effect is largest in the sub-1GHz scenarios (Scenario B and C throughputs appear significantly higher than Scenario A) because the lower available bandwidth requires a substantial uplift in signal-to-noise ratio to deliver the required data rate.

A.2.3 Indicative link budgets for terrestrial wireless networks

In this section we have provided two indicative link budgets, based on the assumptions set out above:

- Link budget 1 shows parameters for demand **Scenario B**, with **WIMAX (3:1)** and an **outdoor** customer premises antenna in the **3.5GHz band**.
- Link budget 2 shows parameters for demand **Scenario A**, with **HSPA+** and an **indoor** customer premises antenna in the **900MHz band**.

Link budget 1: Scenario B, WiMAX at 3.5GHz (3:1), outdoor antenna

Parameter	*Downlink*	*Uplink*
Required data rate	19.00Mbit/s	1.90Mbit/s
Nearest performance step	22.02Mbit/s	7.34Mbit/s
Required SNR	1.00dB	1.00dB

Figure A.22: Data rate requirements [Source: Analysys Mason for BSG]

It should be noted that uplink is assumed to be 10% of downlink, and performance steps are dictated by modulation rate and impact of MIMO (and dual-carrier).

Parameter	*Downlink*	*Uplink*
Power amplifier output power	38.00dBm	24.00dBm
Number of transmit antennas	4	4
Number of transmit antennas	4	4
Power amplifier back off	-	-
Transmit antenna gain	23.00dBi	15.50dBi
Transmitter losses[37]	6.00dB	8.00dB
TDD power adjustment	-1.25dB	-6.02dB
Effective Isotropic radiated power	**53.75dBm**	**24.98dBm**

Figure A.23: Transmit power [Source: Analysys Mason for BSG]

37 Includes insertion losses (duplexer losses for FDD and switch losses for TDD)

Parameter	*Downlink*	*Uplink*
Channel bandwidth[38]	50.00MHz	50.00MHz
Number of subchannels[39]	4.00	16.00
Receiver noise level	-97.01dBm	-97.01dBm
Receiver noise figure	7.00dB	4.00dB
Required SNR	1.00dB	1.00dB
Spreading factor	-	-
Processing gain	-	-
Sub-channelisation gain	6.02dB	12.04dB
Receiver sensitivity	-95.03dBm	-104.05dBm
Receiver antenna gain	15dBi	23dBi
Macro diversity gain	-	-
MIMO A gain	6.00dB	6.00dB
Receiver losses	8.00dB	6.00dB
Fast fade margin	-	-
Interference margin[40]	4.00dB	1.00dB
Control channel overhead	0.80dB	-
Maximum path loss	**156.98dB**	**151.03dB**
Adjusted maximum path loss[41]	**153.03dB**	**151.03dB**

Figure A.24: Maximum path loss [Source: Analysys Mason for BSG]

	Urban		*Suburban*		*Rural*	
Parameter	*Downlink*	*Uplink*	*Downlink*	*Uplink*	*Downlink*	*Uplink*
Shadow-fade margin	5.87	5.87	6.81	6.81	6.81	6.81
Building penetration loss	-	-	-	-	-	-
Link margin	147.17	145.17	146.22	144.22	146.22	144.22

Figure A.25: Radio path losses [Source: Analysys Mason for BSG]

38 For all technologies, we have built the link budgets based on the total bandwidth available. We recognise that for OFDM technologies, both EIRP and receiver noise level can be calculated on the basis of individual sub-channels. However, we believe that calculating the link budgets based on the total bandwidth allows us to compare technologies on a consistent basis, while containing the complexity of the input calculations.

39 To calculate the available number of subchannels without an iterative calculation, we have assumed a base spectral efficiency of 2.5bits/hertz for all OFDM technologies. We limit the uplink subchannels to a maximum of 16.

40 Any required variation in the interference margin between demand scenarios (due to different cell edge data rates) can be mitigated through the use of antenna tilt. Therefore, we have assumed that interference margin does not vary between demand scenarios.

41 In order to compare technology capacities on a fair and equal basis, we limited the overlap of the link budgets to 2dB.

Link budget 2: Scenario A, HSPA+ at 900MHz, desktop antenna

Parameter	*Downlink*	*Uplink*
Required data rate	4.57Mbit/s	0.46Mbit/s
Nearest performance step	5.19Mbit/s	1.08Mbit/s
Required SNR	1.00dB	0.02dB

Figure A.26: Data rate requirements [Source: Analysys Mason for BSG]

It should be noted that uplink is assumed to be 10% of downlink, and performance steps are dictated by modulation rate and impact of MIMO (and dual-carrier).

Parameter	*Downlink*	*Uplink*
Power amplifier output power	37.00dBm	24.00dBm
Number of transmit antennas	4.00	2.00
Number of transmit antennas	2.00	4.00
Power amplifier back off	-	-
Transmit antenna gain	16.00dBi	3.00dBi
Transmitter losses	4.5dB	2.5dB
Effective Isotropic radiated power	**48.50dBm**	**24.50dBm**

Figure A.27: Transmit power [Source: Analysys Mason for BSG]

Parameter	*Downlink*	*Uplink*
Channel bandwidth	10MHz	10MHz
Number of subchannels	-	-
Receiver noise level	-104.00dBm	-104.00dBm
Receiver noise figure	7.00dB	4.00dB
Required SNR	1.00dB	0.02dB
Spreading factor[42]	5.00	-
Processing gain	6.99dB	9.24dB
Sub-channelisation gain	-	-
Receiver sensitivity	-102.99dBm	-109.23dBm
Receiver antenna gain	3.00dBi	16.00dBi
Macro diversity gain	-	-
MIMO A gain	4.50dB	4.50dB
Receiver losses	2.5dB	4.5dB
Fast fade margin	-	-
Interference margin	1.00dB	1.00dB
Control channel overhead	0.80dB	-
Maximum path loss	**154.69dB**	**148.73dB**
Adjusted maximum path loss[43]	**150.73dB**	**148.73dB**

Figure A.28: Maximum path loss [Source: Analysys Mason for BSG]

	Urban		*Suburban*		*Rural*	
Parameter	*Downlink*	*Uplink*	*Downlink*	*Uplink*	*Downlink*	*Uplink*
Shadow-fade margin	6.22	6.22	7.02	7.02	7.02	7.02
Building penetration loss	15.00	15.00	15.00	15.00	15.00	15.00
Link margin	129.51	127.51	128.71	126.71	128.71	126.71

Figure A.29: Radio path losses [Source: Analysys Mason for BSG]

A.2.4 Network coverage and geotype variant assumptions

In this section we give an overview of the assumptions for network coverage and also those that vary by geotype (see Figure A.30 below).

42 To calculate the spreading factor without an iterative calculation, we have assumed a base spectral efficiency of 2.5bits/hertz.

43 In order to compare technology capacities on a fair and equal basis, we limited the overlap of the link budgets to 2dB.

Throughout the modelling, we have assumed that the market share of the terrestrial wireless operator is 25% and that broadband penetration is 80% of households in 2016.

Parameter	Urban	Suburban 1	Suburban 2	Rural 1	Rural 2	Rural 3	Rural 4	Notes
Network coverage	100%	99%	99%	98%	98%	98%	98%	Equivalent to 99% of households overall
Backhaul: microwave	10%	30%	50%	70%	80%	90%	100%	Analysys Mason estimate
Backhaul: existing fibre	90%	70%	50%	30%	20%	10%	0%	Analysys Mason estimate
Existing sites	724	3,600	3,934	2,543	840	240	120	Assumed 12 000 existing sites, distributed according to population
Site re-use	100%	100%	100%	100%	100%	100%	100%	Percentage of existing sites that can be re-used (and so incur only upgrade costs)

Figure A.30: Geotype variant parameters for terrestrial wireless networks [Source: Analysys Mason for BSG]

For satellite broadband, we again assumed that broadband penetration is 80% by household, but that the market share would be 50%.

A.2.5 Backhaul technical assumptions

Figure A.31 shows out technical assumptions for microwave backhaul for terrestrial wireless networks.

Parameter	*Value*	*Notes*
Microwave link capacity	310Mbit/s	Based on 2×155Mbit/s STM-1 links
Average number of microwave hops	2.2	Based on a network where base stations are daisy chained in 3 levels Assumes that sites are close enough to daisy chain and no intermediate microwave-only sites will be required

Figure A.31: Backhaul technical assumptions [Source: Analysys Mason for BSG]

It should be noted that we have not considered any components relating to other nodes in the network (e.g. BTS-facing port at the BSC).

A.2.6 Satellite assumptions

Figure A.32 shows our technical assumptions for satellite broadband, based on information for KA-SAT provided by Eutelsat[44].

Parameter	*Value*	*Source*	*Notes*
Spot beam spread	0.2 degrees	Analysys Mason	
Downlink capacity of satellite	100Gbit/s	Analysys Mason	Based on high capacity broadband satellites currently under construction
Uplink capacity of satellite	30Gbit/s	Analysys Mason	Assumed to be 30% of downlink Based on current and planned high capacity broadband satellites
Spot beams per satellite	100	Analysys Mason	Based on high-capacity broadband satellites currently under construction
Height of orbit	35 000km	NASA[45]	
Area factor	2.6	Analysys Mason	Used in place of Pi to calculate the area of the hexagon

Figure A.32: Key satellite technical parameters [Source: Analysys Mason for BSG]

In order to compare satellite costs and capabilities on an equal basis to terrestrial wireless, we have modelled the impact of satellite addressing all of the UK broadband market.

We estimate that approximately 26 spotbeams with a spread of 0.2º will be required to cover the whole of the UK land area. We note that if a larger number of spotbeams is required to meet the demand for satellite broadband, then the spotbeam spread will need to be reduced below 0.2º (which requires the development of a larger reflector for the satellite) or else multiple satellites in different orbital locations will be required.

A.3 Cost inputsTerrestrial wireless cost inputs

Deployment costs

Figure A.33 and Figure A.34 show a summary of the key cost inputs for the study. We have assumed an annual real cost reduction of 5% for all hardware items from 2010 prices. The costs given below are for 2016 in real 2010 prices. Our cost assumptions are based on data from vendors.

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[44] Our calculations are based on KA-SAT data as Avanti has not yet agreed to release their own cost data for the purposes of this report.

[45] http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/970408d.html

Network element	*Unit cost*				*Source*	*Notes*
	HSPA+ (2 carrier)	*HSPA+ (4 carrier)*	*FDD-LTE (10MHz)*	*FDD-LTE (20MHz)*		
Civil costs (new site)	GBP97 990	GBP97 990	GBP97 990	GBP97 990	Ofcom MTR model	Independent of technology
Civil costs (upgrade site)	GBP17 814	GBP17 814	GBP17 814	GBP17 814	Ofcom MTR model	Independent of technology
Antenna (new site)	GBP287	GBP287	GBP287	GBP287	Industry benchmarks and Analysys Mason estimate	For 4×4 MIMO antenna (assumes 50% increase in cost over non-MIMO antenna)
Base station (new site)	GBP13793	GBP15326	GBP13793	GBP15326	Industry benchmarks	Base station capacity assumed to be 200Mbit/s for all technologies[46]
Antenna (upgrade site)	GBP287	GBP287	GBP287	GBP287	Industry benchmarks and Analysys Mason estimate	For 4×4 MIMO antenna (assumes 50% increase in cost over non-MIMO antenna)
Base station (upgrade site)	GBP 13793	GBP15326	GBP 13793	GBP15326	Ofcom MTR model, Industry benchmarks	Base station capacity assumed to be 200Mbit/s for all technologies

Figure A.33: 2016 terrestrial wireless FDD network site costs (real 2010 prices) [Source: Analysys Mason for BSG]

46 We note that it may be more cost effective to deploy base stations with a higher capacity (e.g. 1Gbit/s). At the time of writing, no data was available on the cost of such a base station.

Network element	*Unit cost*				*Source*	*Notes*
	TDD-LTE (40MHz)	*TDD-LTE (50MHz)*	*WiMAX (40MHz)*	*WiMAX (50MHz)*		
Civil costs (new site)	GBP97 990	GBP97 990	GBP97 990	GBP97 990	Ofcom MTR model	Independent of technology
Civil costs (upgrade site)	GBP17 814	GBP17 814	GBP17 814	GBP17 814	Ofcom MTR model	Independent of technology
Antenna (new site)	GBP287	GBP287	GBP287	GBP287	Industry benchmarks and Analysys Mason estimate	For 4×4 MIMO antenna (assumes 50% increase in cost over non-MIMO antenna)
Base station (new site)	GBP15 326	GBP16 092	GBP12 931	GBP13 578	Industry benchmarks	Base station capacity assumed to be 200Mbit/s for all technologies
Antenna (upgrade site)	GBP287	GBP287	GBP287	GBP287	Industry benchmarks and Analysys Mason estimate	For 4×4 MIMO antenna (assumes 50% increase in cost over non-MIMO antenna)
Base station (upgrade site)	GBP15 326	GBP16 092	GBP12 931	GBP13 578	Ofcom MTR model, Industry benchmarks	Base station capacity assumed to be 200Mbit/s for all technologies

Figure A.34: 2016 terrestrial wireless TDD network site costs (real 2010 prices) [Source: Analysys Mason for BSG]

It should be noted that for a dual-frequency deployment, we assume that twice as many antennas are needed for each sector, and there will be a 15% increase in active equipment capex.

Figure A.35 shows our backhaul and CPE cost assumptions.

Network element	*Unit cost*	*Source*	*Notes*
Microwave backhaul	GBP3675	Analysys Mason	For 2×STM-1 link (310Mbit/s capacity)
Fibre backhaul	N/A		We assume that existing fibre can be used for backhaul at no additional capex cost
Dongle CPE	GBP25	Analysys Mason estimate	
Desktop CPE	GBP50	Analysys Mason estimate	To include integrated modem/amplifier/antenna unit
Outdoor antenna CPE	GBP85	Analysys Mason estimate	To include outdoor MIMO antenna, cable and indoor modem/amplifier Note: we do not consider how this cost would vary with MIMO scheme (i.e. with different numbers of power amplifiers)
Integrated outdoor CPE	GBP113	Analysys Mason estimate	Assumed to be 33% more expensive than standard external antenna
Window mounted internal antenna CPE	GBP70	Analysys Mason estimate	To include indoor MIMO antenna, cable and indoor modem/amplifier
Outdoor Log Periodic or Yagi antenna CPE	GBP95	Analysys Mason estimate	To include outdoor antenna, cable and indoor modem/amplifier
Installation of outdoor CPE	GBP125	Analysys Mason estimate	Assumed to be similar to current Freeview charge
Installation of indoor CPE	N/A		Assumed that the customer will be able to set this up themselves

Figure A.35: 2016 terrestrial wireless network other costs (real 2010 prices) [Source: Analysys Mason for BSG]

Operating costs

We consider the following categories of operating cost for a terrestrial wireless network:

- base station site rental (very few base stations in the UK are located on property owned by the network operators)
- rental payments for fibre backhaul (assumed to be leased, unlike microwave backhaul, which is assumed to be self-provided)

- base station operations and maintenance (network management and optimisation, remote diagnostics, on-site maintenance and repair)
- base station power (considered separately from base station operations and maintenance so that the carbon footprint of satellite and terrestrial wireless technologies can be compared to fibre technologies).

Our assumptions about base station site rentals are shown in Figure A.36 and our assumptions about the other cost categories are shown in Figure A.37.

Base station type	*Additional annual rental for existing site*	*Annual rental for new site*
Urban geotype	GBP2750	GBP11 000
Suburban geotypes	GBP2250	GBP9000
Rural 1 and rural 2 geotypes	GBP2000	GBP8000
Rural 3 and rural 4 geotypes	GBP1625	GBP6500

Figure A.36: Base station site rental assumptions [Source: Analysys Mason for BSG]

Cost category	*Assumption*	*Notes*
Rental payments for fibre backhaul	GBP5000 per site per annum	Microwave backhaul is assumed to be self-provided
Operations and maintenance	GBP1000 per site per annum	
Base station power	250W + 6.67 times total RF power output Cost of power is 7.5p per kWh	Assumes baseband etc. consumes 250W and RF power amplifier efficiency improves to 15%. No allowance for air conditioning (i.e. use of convection-cooled outdoor equipment)

Figure A.37: Assumptions concerning terrestrial wireless operating expenditure [Source: Analysys Mason for BSG]

A.3.2 Satellite cost inputs

Our satellite deployment cost assumptions are shown in Figure A.38 below.

Deployment costs

Network element	*Unit cost*	*Source*	*Notes*
Total capex per satellite system	GBP300 million	Analysys Mason	Includes ground control and space segment (insurance and launch and satellite) Based on high-capacity broadband satellites currently under construction
CPE	GBP84	Analysys Mason	
CPE installation	GBP100	Analysys Mason	Assumed to be similar to current Freesat charge

Figure A.38: 2016 satellite network costs [Source: Analysys Mason for BSG]

Figure A.39 below shows an example of how the technical and cost assumptions are used to calculate satellite capabilities and deployment costs.

Element	*Unit*	*Scen A*	*Scen B*	*Scen C*
Total CPE cost	CBP	184	184	184
Satellite cost	GBP	300 million	300 million	300 million
Satellite capacity				
Downlink	Gbit/s	100	100	100
Uplink	Gbit/s	30	30	30
Spot beams		100	100	100
Spot beam spread	degrees	0.2	0.2	0.2
Height of orbit	km	35 000	35 000	35 000
Area factor		2.6	2.6	2.6
Capacity calculation				
Capacity per beam[47]				
Downlink	Mbit/s	950	950	950
Uplink	Mbit/s	285	285	285
Total BB households	HH	22.8 million	22.8 million	22.8 million
Market share	%	50%	50%	50%
Households served	HH	11.4 million	11.4 million	11.4 million
Downlink capacity:				
Peak BH demand	Mbit/s	0.09	0.71	1.46
Total demand	Mbit/s	1 million	8.1 million	16.6 million
Ideal spot beams required		1,044	8,520	17,448
Households per spot beam	HH	10 890	1335	652
Video stream take-up	%	2%	14%	23%
Over provisioning factor	%	15%	17%	22%
Over provisioned demand		1.1 million	9.5 million	20.2 million
Actual spot beams required		1201	9965	21 259
Uplink Capacity:				
Peak BH demand	Mbit/s	0.01	0.07	0.15
Total demand	Mbit/s	99 226	809 439	1.7 million
Ideal spot beams required		348	2840	5816
Households per spot beam	HH	32 669	4005	1956

47 Note this capacity includes an allowance for signalling overhead.

Element	*Unit*	*Scen A*	*Scen B*	*Scen C*
Video stream take-up	%	2%	14%	23%
Over provisioning factor	%	9%	10%	11%
Over provisioned demand	Mbit/s	108 156	890 383	1 840 239
Actual spot beams required		379	3124	6457
Coverage calculation				
Spot beam spread	radians	0.003490659	0.003490659	0.003490659
Radius of spot beam	km	61.09	61.09	61.09
Area covered by spot beam	sq km	9702	9702	9702
Total area required for coverage	sq km	250 941	250 941	250 941
Actual spot beams required		26	26	26
Spot beams for network		**1201**	**9965**	**21 259**
Cost per beam	GBP	3 000 000	3 000 000	3 000 000
Total satellite cost	GBP	3.6 billion	30 billion	64 billion
Cost per CPE	GBP	184	184	184
Total CPE cost	GBP	2.1 billion	2.1 billion	2.1 billion
Total deployment cost	GBP	**5.7 billion**	**32 billion**	**66 billion**
Cost per home connected	GBP	**500**	**2812**	**5791**

Figure A.39: Example satellite calculation [Source: Analysys Mason for BSG]

Operating costs

Based on inputs from Eutelsat and Avanti Communications, we have made a high-level assumption regarding the total annual operating costs for a satellite, to include the following cost categories:

- satellite telemetry, tracking and control (i.e. remote monitoring and management of the satellite to maintain it in its correct orbital location and ensure that it is operating correctly)
- satellite gateway operations and maintenance (network management and optimisation, remote diagnostics, on-site maintenance and repair)
- rental payments for connectivity between gateways (required for the purposes of resilience) and from the gateways to the internet.