High performance wireless broadband: an opportunity for rural and enterprise 5G

A report prepared for: UKWISPA and INCA

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Our report

Plum was commissioned jointly by UKWISPA[1] and INCA[2] to conduct an independent and updated assessment of the potential benefits of fixed wireless access (FWA) technologies, for provision of broadband services in the UK market.

Our work was informed with dialogue across a range of stakeholders, including BT Group, a large UK-based mobile operator, selected FWA equipment vendors, selected UK based wireless internet service providers (WISPs), and INCA and UKWISPA members.

We have also drawn upon our own experience of the telecommunications industry, both internationally and within the UK, covering both supply and demand sides, with focus on network dimensioning, cost analysis, and radio spectrum management.

To protect the commercial interests of all study participants, data has been presented in anonymised and redacted form, where appropriate.

In any time bounded study, certain limitations can arise. Whilst we carried out some site visits, we have not conducted detailed radio planning tests on particular commercial installations, nor have we assessed equipment volumes at a 'bill of materials' level. Our analyses are informed via discussions with study participants, and have been carried out at a level of detail that would typically be invoked and seen in connection with strategic planning and policy development.

We are confident that such a level provides a firm basis for comparison of cost structure across the alternative technologies considered, and is comparable to that carried out in other similar assessments.

[1] UK Wireless Internet Service Providers Association.

[2] Independent Networks Cooperative Association.

Executive summary

Purpose and approach

Plum was commissioned jointly by UKWISPA[3] and INCA[4] to conduct an independent and updated assessment of the potential benefits of fixed wireless access (FWA) technologies, for provision of broadband services in the UK market.

Our focus has been directed towards review of the performance levels available with modern commercially available FWA solutions. Within the study, we have reviewed developing UK Government policy and Ofcom positioning – with a view to considering options and implications for ongoing roll-out of broadband services.

In assessing FWA, we have given careful consideration to an appropriate counterfactual. Whilst we have considered other options, our analysis is focused principally on a comparison of FWA with fibre-to-the-cabinet – FTTC technology.

Key areas of analysis have included assessment of cost structure for FWA and FTTC solutions, radio spectrum requirements and management issues, and network implementation roll-out rates.

Throughout, our assessments are based on cases derived from stakeholder inputs, Government and Ofcom data and previous studies – as appropriate, and our own independently developed models and analyses – particular to this study.

Key findings

- The economic importance of enabling high quality broadband service access for the UK as a whole is well-known and has been recognised previously through various studies, such as that recently carried out by the University of Oxford, supported by Ofcom[5].
- With support from industry and the Government's Digital Economy Act of 2017 – leading to the broadband universal service obligation (USO) order of March 2018, plus other programmes such as BDUK[6] and LFFN[7], deployment of 'decent' broadband connectivity[8] is now underway in the UK.
- However, Government is recently on record[9] as stating that roll-out of full fibre is likely to reach only c. 50% of premises by 2025. That is, with current deployment rates and strategy, c. 50% will not be reached by 2025.
- Depending on service specifications, estimates of UK based unserved premises range from 0.9m (c. 3%) up to 16m (c. 55%), with many of these in rural areas.

[3] UK Wireless Internet Service Providers Association.

[4] Independent Networks Cooperative Association.

[5] See: https://www.ofcom.org.uk/research-and-data/telecoms-research/broadband-research/economic-impact-broadband

[6] See: https://www.gov.uk/guidance/broadband-delivery-uk

[7] See: https://www.gov.uk/government/publications/local-full-fibre-networks-challenge-fund

[8] Defined by Government within the USO order as including 10 Mbps downlink or higher, with ongoing review.

[9] See: https://www.gov.uk/government/speeches/chancellor-speech-cbi-annual-dinner-2018

- The credibility of the broadband USO is now being called into question, with concerns as to whether a 10 Mbps 'basic' service specification will meet the UK's evolving needs, and whether current rates of build-out will be sufficient. Much of the USO policy and thinking has been built on earlier studies, which are now rather dated.
- High performance broadband services, at 'superfast[10]' or higher levels, may be delivered with various alternative technologies, including both fixed line fibre, and fixed wireless options, and both of these are being pursued in the UK market today, with crucial activity from the UK's growing altnet industry, as well as established players. Whilst alternatives such as 'fixed mobile' and satellite broadband are available, these are unlikely to meet high performance needs. Government has stated that technology neutrality must be upheld, to promote competition and prevent undue market distortion.
- Depending on market scale and scenarios considered, we find that modern FWA solutions, exploiting new multiple antenna technologies – not yet commercialised by the mobile industry – can offer high performance service, with better cost per line, and infrastructure roll-out rates over fixed fibre alternatives in rural areas, or in cases where high levels of new fibre and trenching build-out would be required. This, however, is contingent on policy support and access to the 'right' type of spectrum.
- Separately, costs and deployment rates associated with fixed line fibre-to-the-cabinet FTTC installations to support broadband services can be unattractive, especially in rural areas. Whilst modern digital fixed line technologies such as G.fast and vectoring can be considered, these will incur additional cost and can be limited to 'last mile' line distances of several hundred metres only. Cost structure over distance and service capacity dimensions matter critically in delivering broadband service.
- In any case, the pursuit of solutions able to offer adequate and timely service levels with attractive costs will be important, and with 5G technologies and business models still under development, it will be important to recognise the 5G ecosystem as a whole, with various types of solutions supporting various market needs – both fixed and mobile, plus emerging private 5G enterprise.
- Current regulations limit FWA operators largely to the 5 GHz radio bands, with limited power levels, uncontrolled interference, and requirement for dynamic frequency selection (DFS) standards which must be available and enabled. Such constraints have bearing on the cost structure associated with rolling out broadband services using FWA solutions. If FWA operation were to be regulated in radio bands below 5 GHz, the improved radio performance possible would support higher cost efficiency levels.
- With the forthcoming award of spectrum in the 3.6-3.8 GHz band and the potential for future access to spectrum in the 3.8-4.2 GHz region, currently being considered by Ofcom, opportunity exists for innovative and flexible use of spectrum. With 5G mobile demand likely largely in urban areas, it is unlikely that these bands would be used in rural areas to support mobile services, whereas demand for access to this spectrum exists from FWA operators, driven by consumer demand for 'decent' broadband.
- Further, access to 3.6-3.8 GHz spectrum will be essential, as FWA equipment is readily available in this band at attractive pricing levels – due to international markets and economies of scale in the supply chain. Technical standards and commercial equipment have not as yet been

[10] Defined by Ofcom as broadband with downlink rates at 30 Mbps or more.

developed in the 3.8-4.2 GHz band, and supply is not expected to be available until c. 2023, if at all.

- Whilst the 3 GHz bands are being considered for deployment of 5G mobile services, new innovative methods for spectrum management, such as dynamic shared access and geographic licensing, can be contemplated. Such methods are already being developed in other countries (e.g. CBRS – Citizens' Broadband Radio Service in the US). These could support mixed fixed and mobile usage and new 5G business models – such as 'service neutral' enterprise networks. Whilst these benefits have been acknowledged by Ofcom, no action has, as yet, been taken.
- Development of regulation, recognising the emerging 5G ecosystem as a whole, facilitating operation of both mobile and fixed radio links in the 3.6-3.8 and 3.8-4.2 GHz bands, will support essential and widespread high quality service access for a varied mix of users across the UK. 5G should not be considered as a mobile technology only, but should be leveraged to meet varied market demands including mobile service, static broadband access, and emerging private enterprise requirements.
- Operation of FWA systems will not 'harm' mobile system deployments, or place undue demands on that industry, in the same way that distinct mobile network operators are able to co-exist today both nationally and within regional areas without problems.
- Flexible and innovative management of the national 3.6-4.2 GHz radio resource is unlikely to affect its financial value which is largely demand driven, but would reduce market entry barriers – supporting enhanced service availability and market competition levels.

Key recommendations

- 5G technology should be recognised as a solution able to serve varied UK market needs, including those across mobile, fixed broadband, and private enterprise.
- 5G FWA solutions should be considered and supported by Government – as a means to offer both cost and time efficient roll-out of high quality fixed link broadband services, in cases where fixed line fibre solutions cannot.
- Innovative methods for radio spectrum management covering the 3.6-4.2 GHz bands, such as dynamic shared access and geographic licensing, should be examined carefully by Government and Ofcom, and acted upon, as a means for enabling flexible access to spectrum, supporting these varied market needs.
- 'Blanket' national policy on both radio spectrum and technology strategy will neither properly address regional market demands nor facilitate efficient solutions. Government should uphold the principle of technology neutrality, with supporting policy, rather than single-mindedly pursuing a strategy based only on full fibre. The benefits of various technologies should be leveraged, according to particular market conditions and regional needs.
- With appropriate Government support, FWA solutions can play an important part in enabling UK success and leadership in widespread access to digital infrastructure, high quality broadband services, and the digital economy.

1 Introduction

1.1 Purpose

Our purpose in this study has been to provide an updated view on the potential benefits that could be offered with increased deployment of fixed wireless access (FWA) solutions, for provision of broadband services in the UK. We also assess the related need for allocation of radio spectrum to support FWA deployments in appropriate bands.

1.2 Scope

Our assessment has principally included review of the UK broadband USO[11], emerging new wireless and 5G business models, and relative cost structures – with primary assessment across both FWA and fixed line fibre to the cabinet and premises (FTTC/P) solutions, based on typical deployment scenarios.

We have addressed a number of key areas as below.

- Review of existing and developing UK Government policy pertaining to universal broadband service (the proposed broadband USO).
- Refresh on performance levels and associated access network investment cost levels for relevant technology types including fixed wireless access (FWA) and fibre to the cabinet or premises (FTTC/P), taking into account radio spectrum issues.
- Assessment of current and evolving methods applicable to radio spectrum management, taking into account novel available technologies, market precedents, and current and evolving policy in both the UK and other countries.
- Consideration of the situation where mobile network operators (MNOs) are unlikely to use radio spectrum in some areas, even where national licences may be held, rendering spectrum wasted or inaccessible to some.
- Reflection on the growing importance of private enterprise based networks, which may offer novel and efficient business models.
- Consideration of impacts, options and benefits, applicable to the UK market, with balanced and independent perspective, taking into account the needs of various market participants.

We have not addressed competition aspects in any detail, but would expect that with policy to support innovative, modern solutions, enabling lower costs and price points to consumers, competition would be enhanced positively.

[11] See section 2.

2 Background

2.1 Existing FWA operations

Performance levels with fixed wireless access solutions have developed significantly over recent years, with commercialisation of so-called massive (multiple user) multiple input multiple output (MU-MIMO) being a key driving factor. In fact, MU-MIMO technology – which enables high capacity solutions has been commercialised with FWA systems ahead of such in mobile radio systems – where it is technically more difficult to implement. We refer to these modern FWA systems broadly as high performance wireless broadband solutions.

Fixed wireless access services are currently available and operated in the UK, with most service providers operating equipment in the 5 GHz bands (Bands B and C – see below), under current permissions granted by Ofcom.

Table 2.1: 5 GHz bands as defined in the UK

Band	Low (MHz)	High (MHz)	Usage	Maximum power level EIRP	Licence requirements
B (Channels 100 - 140) (255 MHz)	5470	5725	Indoor and outdoor permitted	1000 mW (30 dBm)	Licence exempt; compliance with IR 2006[12] required
C (Channels 149 - 161) (125 MHz)	5725	5850	Outdoor (FWA) permitted	4000 mW (36 dBm)	Licence required; compliance with IR 2007[13] required

Over one hundred wireless service providers currently offer commercial services of varying scale across the UK; these are often referred to as alternative network (altnet) operators or wireless internet service providers (WISPs).

UKWISPA – an industry body representing UK WISPs currently has over 60 members registered[14], and INCA – a body representing both established players and alnets deploying both fibre optic and wireless technologies currently holds over 80 members.

[12] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0027/84645/IR_2006.pdf

[13] See: https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/fixed-wireless-access

[14] See: https://ukwispa.org/ukwispa-members-list/

Operation of FWA equipment in bands lower than those at 5 GHz is generally limited by Ofcom, and rights of use are dependent on particular licences (such as with the UK Broadband Limited holdings)[15].

However, licensing for operation of equipment in the 3.5 GHz bands is being developed; key bands at this lower frequency include those as below.

Table 2.2: 3.5 GHz bands as being developed for use within the UK

Band (MHz)	Comments	Price paid in auction for spectrum rights	Bandwidth acquired within band
3400 – 3600	Ofcom's initial 5G spectrum auction (covering both 2.3 and 3.4 GHz bands) was completed in April 2018, with all four mobile network operators (MNOs) (O2, Vodafone, EE, Three) being awarded rights of use in the 3.4 – 3.6 GHz band[16,17]	O2: £318m Vodafone: £378m EE: £303m Three: £151m Total: £1,150m	O2: 40 MHz Vodafone: 50 MHz EE: 40 MHz Three: 20 MHz Total: 150 MHz
3600 – 3800	Planned for future release	Not yet confirmed	Not yet confirmed
3800 - 4200	Planned for future release	Not yet confirmed	Not yet confirmed

With its 2014 statement on variation of UK Broadband's 3.4 GHz licence[18], Ofcom noted that:

> *"The UK Broadband 3.4 GHz licence authorises the use of 40 MHz of radio spectrum in two separate 20 MHz blocks at 3480 to 3500 MHz and at 3580 to 3600 MHz. Our decision to grant an indefinite extension to the licence follows proposals set out in a consultation document published in June 2014.*
>
> *Our consultation considered the benefits to consumers that would arise if the licence were extended and UK Broadband proceeded with its investment in a new broadband network. We weighed this up against the potential costs – including the potential spectrum inefficiencies that may arise as a result of the non-contiguous nature of UK Broadband's 3.4 GHz holdings. In setting out our proposals, we said that the benefits to consumers of granting the extension outweighed any potential costs.*
>
> *Among the potential benefits we expect to arise from UK Broadband's investment are the delivery of faster broadband speeds in under-served areas; lower prices for broadband;*

[15] Note: UK Broadband, recently acquired by Three, holds licensing to operate fixed wireless access and mobile services including two blocks (2 x 20 MHz) within the 3.5 GHz band.

[16] Specific allocations in the 3.4 – 3.6 GHz UK auction completed in April 2018 are as: Vodafone (3410-3460, 50 MHz), Three (3460-3480, 20 MHz), Telefonica O2 (3500-3540, 40 MHz), and EE (3540-3580, 40 MHz). UK Broadband also holds two blocks of spectrum (3480-3500, 20 MHz; 3580-3600, 20 MHz) in the band.

[17] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/112931/2.3-GHz-and-3.4-GHz-band-plans-based-on-final-auction-results.pdf

[18] See: https://www.ofcom.org.uk/consultations-and-statements/category-2/uk-broadband-licence

provision to under-served customers (students, the less well-off etc.); additional end-to-end competition in the market for fixed broadband; and the quicker development of new equipment capable of using the 3.4 GHz band. Additionally, we consider UK Broadband's use of new technology in the 3.4 GHz band and the ability of its customers to subscribe to fast broadband without the need for a land-line as innovative approaches.

Ofcom believes a decision to grant the request will promote competition and encourage investment and innovation, in line with our statutory duties to further the interests of citizens and consumers.

We have therefore decided to grant an indefinite extension to the spectrum licence held by UK Broadband in the 3.4 GHz band".

More recently, in its October 2017 statement[19] and its 2018 update[20] on improving consumer access to mobile services at 3.6 GHz to 3.8 GHz, Ofcom set out plans to make the band available for mobile services.

In its December 2017 consultation on fixed wireless spectrum strategy[21], Ofcom stated its policy towards the 3.8 – 4.2 GHz band, where it saw potential in developing spectrum sharing solutions and retaining operation of fixed links.

Clearly, radio spectrum is a vital resource for the UK economy and must be managed effectively; Ofcom's Statement on spectrum management strategy[22] sets out a number of key principles:

- demand for spectrum is tending to increase;
- solutions enabling efficient use of spectrum should be sought;
- greater use of spectrum sharing should be developed; and
- spectrum use should be re-purposed, as appropriate, with consideration on 'high value' usage.

This was recently further acknowledged by Ofcom's Spectrum Group Director – Philip Marnick, with comments at the Dynamic Spectrum Alliance Conference, held in London in May 2018:

"Managing spectrum efficiently is crucial to improving how we enjoy technology today and enabling the services of tomorrow. It demands a collaborative approach. This includes exploring options for greater sharing of spectrum amongst different users and looking at new ways to ensure all industries can access the airwaves they need to unlock the full potential of future technology".

"5G is a range of things, … But, is it a mobile technology or is it a technology that people can use to develop different solutions at different points? Is it really something that is driven by mobile operators?"

These views are in alignment with Ofcom's published Annual Plan 2018/19[23] which endorses objectives as:

- promote competition and ensure that markets work effectively for consumers;

[19] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0019/107371/Consumer-access-3.6-3.8-GHz.pdf

[20] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0018/110718/3.6GHz-3.8GHz-update-timing-spectrum-availability.pdf

[21] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0027/108594/Fixed-Wireless-Spectrum-Strategy.pdf

[22] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0021/71436/statement.pdf

[23] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/112427/Final-Annual-Plan-2018-19.pdf

- secure standards and improve quality; and
- protect consumers from harm.

5G technologies and services remain under research and development (R&D), with expectations of commercial launches around the year 2020, and it is generally now recognised by industry that 5G must develop as an 'ecosystem' (rather than with merely more incremental radio coverage and capacity) both to maintain industry and investor requirements and to support consumer needs.

It will be essential to ensure that management of radio spectrum supports a balanced set of stakeholder requirements, and this may require development of interconnection and usage across various technology solutions.

2.2 Broadband universal service obligation policy

UK Government policy to develop a broadband universal service obligation (USO) was originally mooted under the Cameron administration in 2015[24], with plans at the time to introduce a 10 Mbps basic service requirement by 2020.

It was noted in the Connected Nations December 2017 report[25] from Ofcom that around 1.1 million premises (4%) in the UK were unable to access broadband internet services with reasonable quality (defined as having a sustainable download speed of 10 Mbps), with the problem particularly acute in rural areas – where customer premises are often some distance from nearest exchange buildings, which provide trunking access to national telecommunications infrastructure. The report showed that around 17% of premises located in rural areas, and a total of 230,000 small businesses (7%), were unable to access broadband services of acceptable quality, as defined. Higher numbers were cited in connection with 'superfast' broadband services – as defined by the DCMS[26,27,28] – with download data rates of up to 24 Mbps[29].

An update to the Connected Nations report was produced in April 2018[30], noting that the number of UK premises unable to access 10 Mbps broadband services had fallen (as of January 2018 data) to around 925,000 (3%) (from the 1.1 million reported previously, based on May 2017 data) (i.e. a progress run rate of around 260,000 premises per year).

Progress towards a UK broadband USO was made with the Government's Digital Economy Act 2017, which introduced powers to enable the introduction, and review, of a USO with a download data rate of at least 10 Mbps.

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[24] See: https://www.gov.uk/government/news/government-plans-to-make-sure-no-one-is-left-behind-on-broadband-access

[25] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0024/108843/summary-report-connected-nations-2017.pdf

[26] See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/418567/UK_Next_Generation_Network_Infrastructure_Deployment_Plan_March_15.pdf

[27] See: https://www.gov.uk/guidance/broadband-delivery-uk

[28] See: http://researchbriefings.files.parliament.uk/documents/SN06643/SN06643.pdf

[29] Note: 'superfast' broadband services are defined by Ofcom, in line with the European Commission's definition, as those with download data rates up to 30 Mbps.

[30] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0017/113543/Connected-Nations-update-Spring-2018.pdf

In March 2018, Government decided, by way of a legislative order[31], to introduce a broadband USO. Under the USO legislation, homes and businesses will be able to request a connection up to a cost threshold of £3,400. For the most expensive to reach properties where the costs of providing a USO connection exceed this amount, consumers will need to consider other options[32].

Implementation of the USO has now been passed to Ofcom, and this is expected to take up to two years (i.e. to c. year 2020), involving consultation on draft regulations for designation of providers, service conditions, implementation options, and funding issues.

Notably, no UK Government public funding will be made available for implementation of the USO order. Ofcom will be responsible for working with industry to ensure execution, with establishment of an industry fund. Further, it is expected that the 10 Mbps threshold will be kept under review, to ensure that market needs are met in the appropriate time frame.

Ofcom responded to a DCMS request[33] for technical advice and recommendations on the design and implementation of the USO in its statement published in December 2016[34], with supporting study[35].

In providing its response to Government, Ofcom noted that considerable uncertainty exists around how market needs will evolve.

It was also stated that cost analyses provided were preliminary estimates only, and it was noted in the supporting study that:

> *"the accuracy of the conclusions could be improved by conducting a more detailed cost modelling exercise based on actual premises data and a better understanding of certain key parameters".*

An updated set of cost estimates was published in July 2017[36], including an additional scenario with data rate set at 20 Mbps. With the update, Ofcom further noted that:

> *"the objective of this modelling work has not been to give a precise figure for each of the scenarios examined. Instead, these figures represent preliminary estimates of the order of magnitude of each scenario's cost, and what drives those costs, to inform policy development".*

Additionally, it is worth noting the Scottish R100 (Reaching 100%) programme, which aims to enable superfast 30 Mbps connectivity to 100% of Scottish premises by 2021 ('the final 5%'), supported by an initial tranche of public money at £600m (equivalent to around £2,640 per premise, on average[37]) – announced with the December 2017 Scottish Budget. This augments the existing Digital Scotland programme – with an investment at £428m. Under European Commission state aid guidelines, public sector intervention in broadband infrastructure investment is limited to those areas where there is no current or planned (within the next 3 years) commercial deployments, to avoid distorting what might

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[31] See: http://www.legislation.gov.uk/uksi/2018/445/pdfs/uksi_20180445_en.pdf

[32] For example, with customers paying any excess fees over the £3,400 threshold, or seeking satellite based options.

[33] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0027/53676/dcms_letter.pdf

[34] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0028/95581/final-report.pdf

[35] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0027/95580/annex6.pdf

[36] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0015/105342/Technical-advice-on-a-broadband-USO-Updated-cost-estimates.pdf

[37] Based on the number of next generation access (NGA) 'white' premises as identified in the Scottish Government's recent public consultation report, see: http://www.gov.scot/Resource/0053/00535392.pdf

otherwise be or become a competitive market. With the Digital Connectivity debate in the Scottish Parliament in May 2018, it was mooted that the R100 programme may include a voucher scheme, supporting end users with broadband connection costs – similar to that introduced by the UK Government with its £67m Gigabit Broadband Voucher Scheme[38], announced in March 2018[39].

Clearly, implementation of the UK USO must be informed with development of sufficiently accurate and robust cost analyses.

Consequently, in the following section, we provide further analysis on cost structure and performance associated with various technology solutions as candidates for USO and wider implementation.

[38] See: https://gigabitvoucher.culture.gov.uk/

[39] The UK Government voucher scheme offers up to £3000 for small businesses and £500 for residential users – against the cost of a 'full fibre' (fibre to the premises – FTTP) connection.

3 Cost and implementation assessment

In this section, we address cost structure and implementation issues associated with next generation access (NGA) technologies enabling broadband service provision.

Analysis is provided across both fixed wireless access (FWA) and fixed line fibre-to-the-cabinet (FTTC) technologies, drawing upon specific dialogue carried out by Plum with FWA vendors and UK based service providers.

We also carried out specific discussions with selected national service providers, including BT Group and a large UK-based mobile operator.

In addition, we draw upon Plum's UK and international experience in wireless and fixed line telecommunications architecture and cost modelling, developed across numerous private strategy and public policy engagements.

For fibre access connections, we assess the FTTC case; we do not address fibre to the premises (FTTP) connections directly which we would expect, in the main, to incur more investment cost over FTTC. Thus, our cost analyses for the fibre case are generally conservative with respect to FTTP connections.

3.1 Point-to-multipoint FWA case

We met with a number of fixed wireless access equipment vendors, industry participants, and commercially established UK based wireless internet service providers (WISPs) during May 2018. A full list of study participants is provided in Appendix B. Our discussions were focused on commercial operations, infrastructure architecture dimensioning, broadband service capabilities, and financial performance levels.

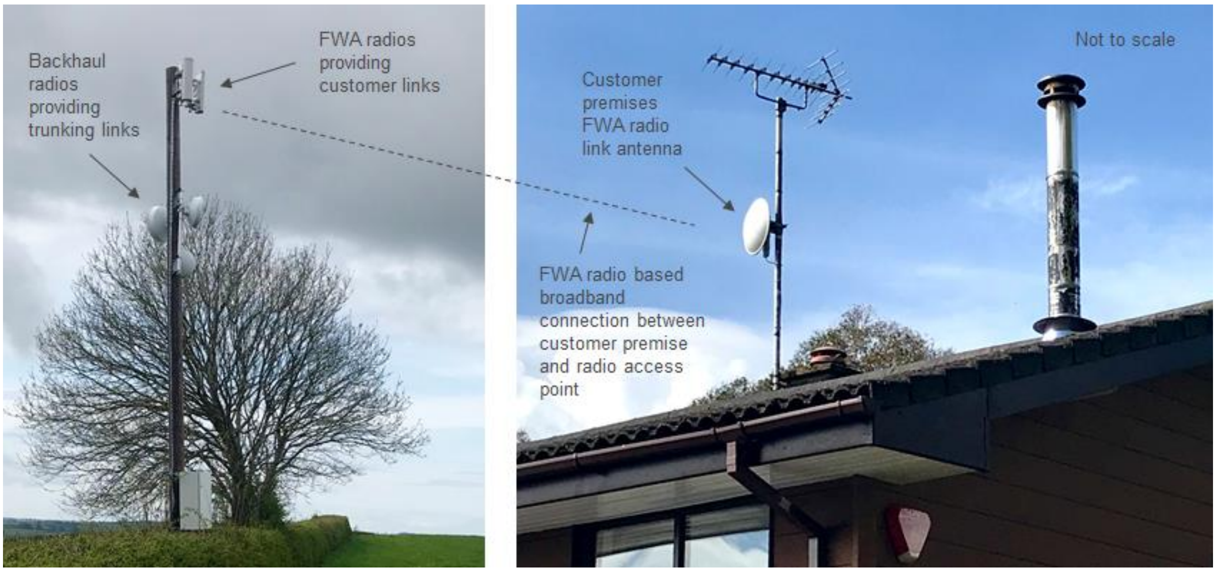
One of the larger WISPs advised us in writing that:

> *"NGA [next generation access] specifications require a minimum of 30 Mbps download speed. Given the length of contract term and the increases in demand for internet access, we feel that 30 Mbps is nowhere near fast enough to meet the expectations of the average user, whether rural, suburban or urban. Therefore, we are investing in providing coverage initially at 100 Mbps and over the next five years, we expect to increase this to 500 Mbps, with many having access at 2 Gbps.*
>
> *Fixed Wireless technology has recently leapfrogged most 'fibre' services in terms of speeds and costs. [Our company] is already delivering speeds in excess of 160Mbps to selected properties … and we will be piloting services in excess of 1 Gbps in the coming months".*

As well as coverage, capacity, and cost, latency (delay of data, from networks to user devices) is an important parameter in broadband systems design and resultant quality of service to end-users. Whilst we have not assessed latency issues in any detail, we were advised by one wireless equipment vendor that data packet latency with its FWA products is calculated at c. 5 milliseconds in both downlink and uplink paths. This level of performance is in line with that attainable with fixed line networks, and requirements for time sensitive applications such as voice, video, and gaming.

Below, we lay out a case example for a typical established UK based fixed wireless service provider, with point-to-multipoint (non-meshed) operations in the 5 GHz C band (5725 – 5850 MHz), in a rural village-like environment. To illustrate scale and configuration, images of a commercial installation of this type are shown below.

Figure 3.1: 5.8 GHz FWA installation showing radio access point and customer antenna

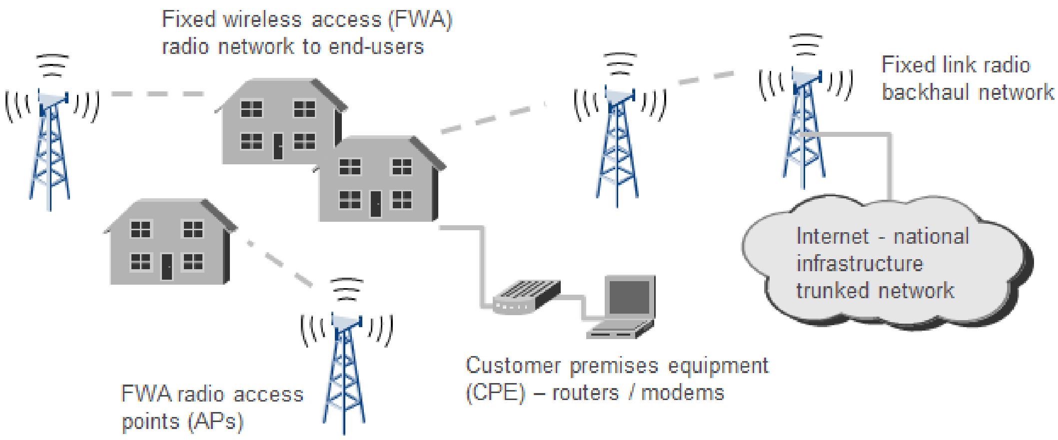


Summary architecture for the case is shown below (see Figure 3.2). Data are based on our discussions with stakeholders, plus our own modelling assessments – combining engineering and financial analysis.

We have based our analyses on ‘realistic’ commercial scenarios – that is, we assume FWA equipment with ‘middle’ (rather than ‘high end’) performance and cost (see Appendix A).

Later in this section, we consider a case with FWA operations in the 3.5 GHz (3600 – 4200 MHz) band.

Figure 3.2: Architecture overview for point-to-multipoint FWA case



Assessment of commercial performance and cost structure is critically dependent on engineering design, system dimensioning, and deployment configuration. In the FWA case assessment, we assume that backhaul can be provisioned via radio links (e.g. with cost-effective in-band solutions, or via microwave point-to-point links).

We have assessed technical system information provided to us from both vendors and wireless service providers with our own independent technical analysis; details of this are provided in Appendix A, which includes a radio engineering model – modified in line with recent Ofcom studies[40], and our dialogue with stakeholders. Case data are shown below.

Table 3.1: FWA case example – 5.8 GHz radio system, rural village, 'base' case[41]

Case example parameter	Values used
Total connected premises in village	Variable in model (demand aggregation)
Density of premises	Variable in model (demand aggregation)
Village size (radius)	4 km from centre to edge max
Village size (total area)	50 sq. km
Radio sector beam angle	90 degrees
Radio sector beam range (at 36 dBm EIRP transmitter power)	4 km (see Appendix A)
Radio sector beam area coverage	12.5 km
Radio sector data rate throughput	90-200 Mbps (see Appendix A)
Mean number of sectors per AP site	4
Committed data rate per connected premises	2.4 Mbps (variable, with required service rate)
Radio system contention factor designed	c. 10:1 (variable in model)
Effective data rate per connected premises	24 Mbps (i.e. UK Government 'superfast' broadband)
CPE + installation cost per connection	£250
Cost per sector radio	£5,000[42] (blended access point site cost)
Cost per backhaul link	Nominal investment assumed with radio backhaul

[40] See: http://www.cl.cam.ac.uk/research/dtg/www/publications/public/vsa23/VTC05_Empirical.pdf

[41] Sources: vendor estimates, public data, Plum analyses; see also Appendix A.

[42] This figure is higher than that provided to us by some WISPs. We have used 'conservative' numbers in our analysis.

Investment cost per connected premises	**£383 (excludes any radio spectrum costs)** **(Variable on capacity requirements – see below; shown for 24 Mbps 'superfast' link per customer line)**

Unit investment costs for FWA AP (access point) equipment can be lower than those with mobile radio access network nodes – as fixed links with directive antennas can support lower transmitter power levels and less stringent receiver sensitivity requirements.

The case shown above assumes FWA operations with a 5 GHz system. This particular case shows that a capacity (rather than coverage) limited design results, meaning that sufficient radio equipment must be installed to provide adequate data rates to connected premises (over and above that required to provide required radio beam coverage).

However, capacity is only realisable to premises with sufficiently robust radio linkages. If additional radio link margin was required in the radio system design to accommodate significant building or terrain shadowing, significantly higher numbers of AP sites would be required.

Whilst the case shows that feasible performance is possible with 5 GHz radios, acceptable results will always be dependent on direct or near line of sight (LOS) radio connections. This can limit roll-out flexibility and cost benefits. Significant benefits will be possible with operations in lower bands. With licensed operations in the 3.5 GHz bands, these will include:

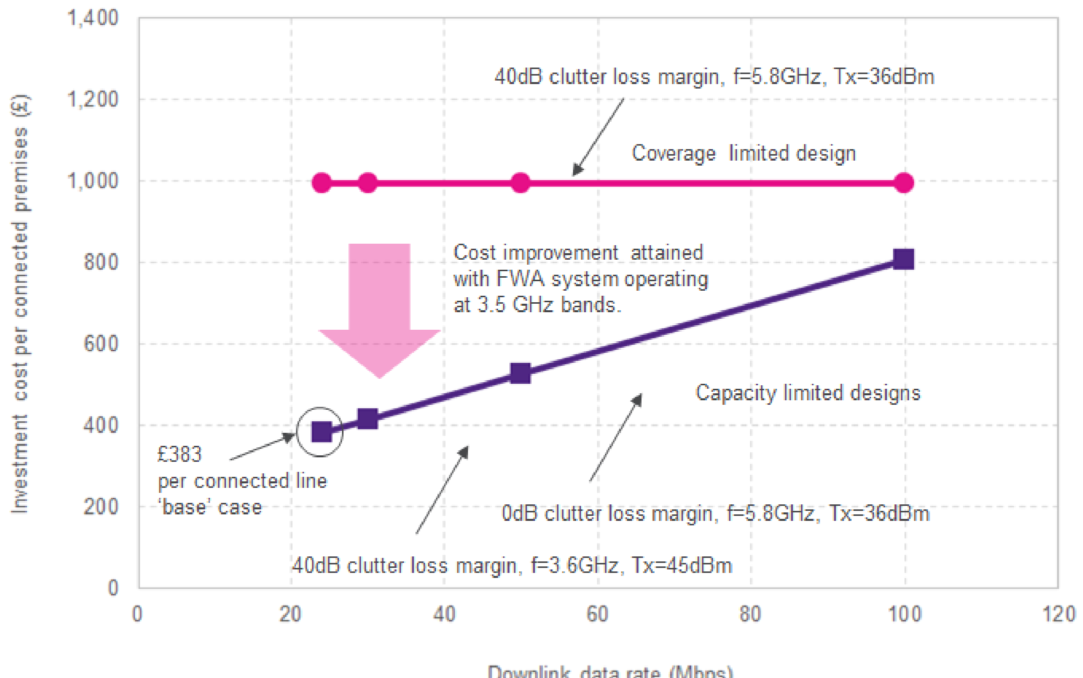
- reduced radio link path attenuation, due to improved physical radio propagation including tree foliage effects;
- regulated use of higher transmit power levels, allowing greater clutter penetration (required in cases where 'shadowing' may occur); and
- improved service quality levels, due to dedicated band usage, reduced interference, and effective 'carrier grade' spectrum management.

We investigate the impact of these benefits below. The figure shows the variability of investment cost per connected premises for the village case as above, taking into account typical clutter losses[43] in the FWA outdoor environment.

With operation in the 3.5 GHz band, coverage can be improved per AP, which largely removes cost sensitivity to coverage in the design. Cost variation then becomes largely a function of required data rate per connection.

[43] Typical clutter loss levels have been studied in a separate study carried out for Ofcom by Plum; see: https://www.ofcom.org.uk/__data/assets/pdf_file/0016/84022/building_materials_and_propagation.pdf

Figure 3.3: FWA case example – comparing 5.8GHz and 3.6 GHz radio systems, rural village



Source: Plum Consulting analysis, 2018.

The figure shows that cost structure is heavily influenced by data rate required per connected line, and requirement for clutter mitigation. Clutter mitigation can either be achieved by adding additional cost with 5.8 GHz band systems, or without the need for additional cost with 3.6 GHz band solutions.

Comparison within the case across both 5.8 GHz and 3.6 GHz radio link designs clearly shows the economic benefits possible with operation at the lower band.

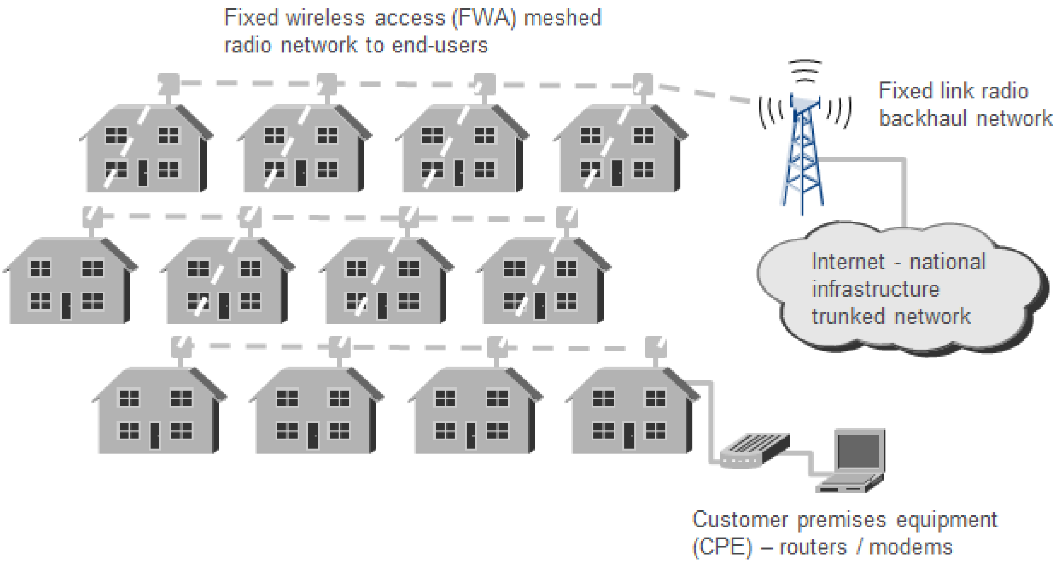
With higher transmitter power and improved physical link radio propagation characteristics, clutter shadowing losses are effectively significantly reduced and system design costs become largely dependent on capacity levels that must be supplied to meet market demands.

3.2 Meshed FWA case

An alternative to the point-to-multipoint FWA solution is offered with so-called meshed solutions. These are being developed, typically, using much higher frequency bands (e.g. 60 GHz, typically licence exempt in the UK).

Radio carrier frequency blocks in the 30-300 GHz spectrum region are often referred to as millimetre wave (mmW) bands – with reference to the radio wavelengths involved. Radio propagation at these frequencies is very different from that at lower bands and offers the potential for short line-of-sight links (e.g. several hundreds of metres between radio points). Typical summary architecture is shown below (see Figure 3.4).

Figure 3.4: Architecture overview for meshed FWA case



From our discussions with selected vendors, we expect that mmW band products will begin to become generally available around the year 2019 and beyond.

We understand that, with such commercial availability, both mesh radio AP and CPE devices will be offered at price points around several hundreds of pounds per device, enabling dense broadband meshes to be deployed unobtrusively with attractive small form factor units, typically at handheld sizes.

Our scope here has not extended to a detailed review of mmW band meshed FWA architectures. However, we anticipate that these solutions could offer very attractive alternatives to trenched fibre in areas where dense broadband access networks are required and no existing fibre is available. Such situations could include those with older city buildings in urban areas – where cost to install new fibre and ducting could be prohibitive.

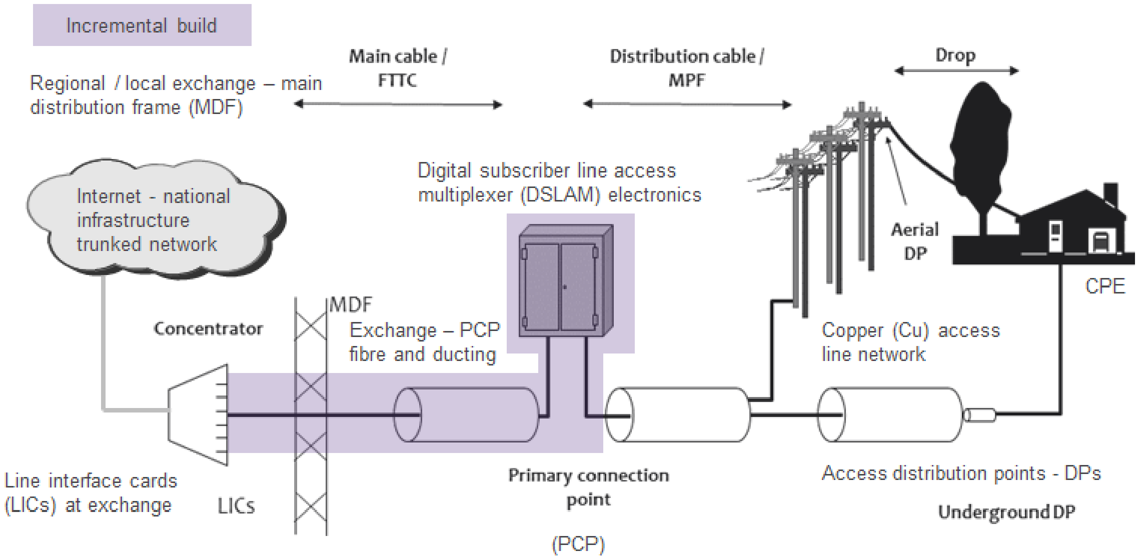
3.3 FTTC case

In this section, we assess cost structure that would be associated with development of a new fibre to the cabinet (FTTC) installation.

We assume a legacy case situation where a rural village area is connected to a regional switching exchange via copper links only. To provide an FTTC facility, new incremental build in the access network would be required – with fibre and trenching or overhead cabling from village cabinets (primary connection points - PCPs) to the exchange, and digital subscriber line access multiplexers (DSLAMs) (with digital line cards) at the cabinets.

Summary architecture as assumed is shown below (see Figure 3.5).

Figure 3.5: Architecture overview for FTTC case



We note that trenching and cabling costs can vary on a case by case basis, depending on distances, and regional characteristics. Also, DSLAM costs per line can vary, depending on cabinet chassis sizing, total volume of access line cards supportable, and whether cabinets are fully or partially populated.

Our intent here is to illustrate typical, likely, and contextualised cost structure, drawing upon relevant commercial experience with vendors and service providers in both the UK and internationally, and to provide cost comparison between FWA and FTTC solutions for various selected situations.

Key cost assumptions for the FTTC case are set out below.

Table 3.2: Cost assumptions for FTTC case

FTTC infrastructure items	Investment cost assumptions
New fibre and ducting planning, build and installation from exchange to PCP cabinet, non-urban areas, rural route	Variable: £60k-500k[44] per trunk route (exchange MDF to PCP cabinet)
New DSLAM / PCP cabinet + exchange / MDF digital line termination equipment (including DSLAM chassis, switch / modem, installation materials, ETSI rack, site survey and installation services, DSLAM line cards, line termination cards)	£70[45] per connected line

[44] Source: Plum private dialogue with UK operators, based on reported costs to install new fibre to rural areas; typical backhaul fibre / trenching routes at 2-10km assumed. See also: Ofcom data: https://www.ofcom.org.uk/consultations-and-statements/category-1/broadband-uso and Plum report on USO: http://plumconsulting.co.uk/impact-broadband-universal-service-obligation-uk/

[45] Source: Plum private dialogue with network equipment vendors. Note: in practice, DSLAM costs will vary according to both fixed and variable (line card) costs. We assume a blended average figure here, based on typical and likely configurations.

New CPE router / modem	£50[46] per connected line

It should be noted that copper line length is a critical factor with FTTC solutions. Whilst G.fast and vectored digital subscriber line technologies are being rolled out commercially in the UK, these can add additional cost and may only be suitable for 'short' loop distances; G.fast is typically only able to offer data rates above other digital line technologies with copper line distances of several hundreds of metres or less.

Cost comparisons have also been studied by the National Infrastructure Commission (NIC) in a recent report[47]. The report estimates investment cost levels per connected line for FTTP/C and FWA solutions over various geotypes, and indicates that in rural cases, investment cost levels with FWA can be attractive.

3.4 Alternative options

We note that various alternative solutions may also be available for wireless broadband provision.

- For example, 'fixed mobile' 4G and MiFi – use of mobile networks with local WiFi connection capabilities – are already being offered commercially in the UK market; and
- satellite (e.g. VSAT – very small aperture terminal) solutions are also currently available.

We have not considered these and other potential alternatives in any detail in our study, but note that capacity and service quality could be limited if these were implemented on a regional scale.

We believe that these limitations would render these options of limited use.

Satellite systems typically deploy large spot beams which can limit capacity levels available for customers. Also power link budgets can be 'fragile' unless carefully designed antennas are used.

It is important to note that broadband solutions based on mobile technologies (such as MiFi, or LTE 4G mobile, or potentially 5G mobile systems – with static directional antennas) will not perform to the same level as purpose-designed FWA solutions.

The latter are engineered to perform with high quality, high capacity links in fixed situations and can support MU-MIMO technology and high order modulation levels[48], unlike mobile solutions in today's market. Mobile technologies, which may be used in static situations, will typically result in relatively poorer quality radio links and higher cost structure (than with FWA), as they are designed to offer mobile services – a very different use case.

[46] Source: Plum private dialogue with UK operators and network equipment vendors.

[47] See: https://www.nic.org.uk/wp-content/uploads/Cost-analysis.pdf

[48] Note: modern FWA solutions typically support 16-QAM or higher modulation orders across radio sectors.

3.5 Cost assessment

We assess the comparative incremental cost structure across both point-to-multipoint FWA and FTTC network solutions for broadband service deployment, with particular focus on rural areas within the UK.

Our analysis here is based on a bottom-up FWA network architecture and costing model, inclusive of modified radio engineering models, purpose-built by Plum to support this study – using engineering design and costing parameters pertaining to current commercially available solutions. Our model has been developed based on updated dialogue with vendors and service providers, and is checked with Plum's own experience in radio systems engineering and financial analysis in the telecommunications sector. An overview of our modelling approach is shown below (Figure 3.6).

In our analysis, we exclude spectrum costs as these are either nominal as with current 5 GHz deployments, or may be developed with alternative business models (see section 4).

We also assume that backhaul costs can be minimised with use of radio links (e.g. 'in-band' meshed options, or established and cost efficient microwave point-to-point links[49]). In addition, other Government programmes such as BDUK[50] and LFFN[51] (including vouchers) can play a role in delivering fibre backhaul into communities to serve wireless access networks.

We note that previous studies have addressed similar issues[52],[53],[54]. We are interested in providing updated results, based on current commercial dialogue and modern available technologies, and assessment of costs likely, including those in 'hard-to-reach' areas.

In particular, we note that the data capacity and cost per site pertaining to FWA solutions in the August 2017 report[55] from Ofcom are somewhat lower and higher, respectively, than those assessed during this study. We suspect that this is due to the earlier assessment on older, less capable wireless equipment, and loss of contextualisation.

In any cost assessment, care is required to interpret results carefully. Costs associated with FTTC/P solutions can appear low in some situations where low incremental cost is required – such as may be the case in urban and densely populated areas. In other areas, cost structure will vary significantly; development of new trenching and fibre installations can be very expensive. As Ofcom has noted, in extreme cases, costs can be as high as £45,000 per line with fixed cable installations. Neither is it useful to consider mean or averaged costs with large scale; assessment on a regional, contextualised basis will give a truer indication of reality.

We therefore urge caution in the interpretation of costs per line (or connected premise) when assessing costs comparatively across various study reports.

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[49] Note: we assume nominal investment costs for microwave backhaul links, and that sufficient backhaul capacity exists for each access point. Typical microwave point-to-point links can provide capacity in excess of 1 Gbps, enough for a four sector FWA site providing typical front haul (customer serving) capacity (e.g. c. 500 Mbps).

[50] See: https://www.gov.uk/guidance/broadband-delivery-uk

[51] See: https://www.gov.uk/government/publications/local-full-fibre-networks-challenge-fund

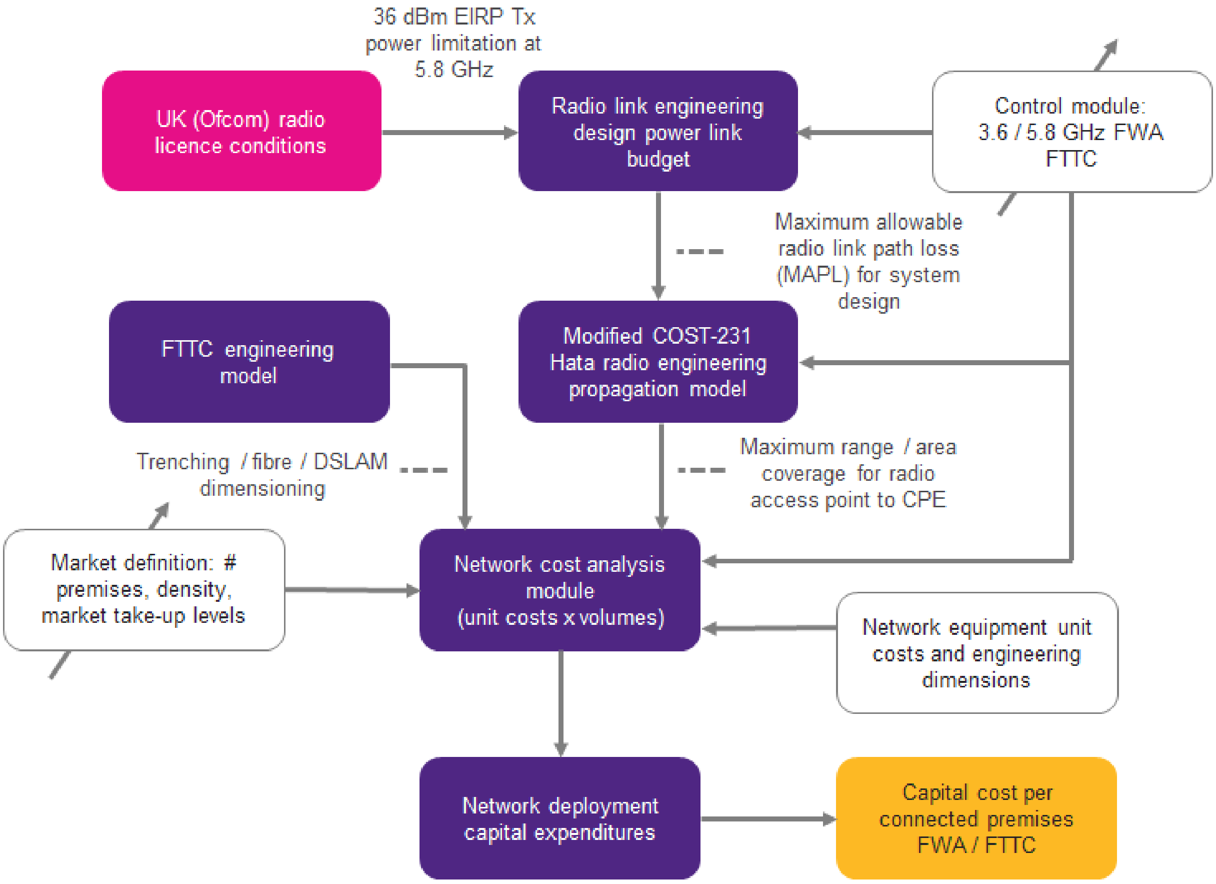
[52] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0015/105342/Technical-advice-on-a-broadband-USO-Updated-cost-estimates.pdf

[53] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0025/105685/Annex-10-Cartesian-Report.pdf

[54] See: http://plumconsulting.co.uk/impact-broadband-universal-service-obligation-uk/

[55] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0025/105685/Annex-10-Cartesian-Report.pdf

Figure 3.6: Cost analysis modelling - overview



Cost per connected line is variable according to scale of deployment.

- With incremental FTTC deployments, significant cost can be incurred with new ducting and fibre cabling – required to connect access network cabinets to regional exchanges. Additional costs are also required with installation of digital subscriber line (DSL) equipment. However, with dense levels of premises served, access network backhaul costs can be amortised over a high number of customers. Access backhaul links must be installed of sufficient length to accommodate digital subscriber line capacity capability levels in the 'last mile' of the copper access network. DSL electronics units – at the local cabinet (PCP) level – typically scale up to several hundred line card connections. Beyond this level, additional backhaul fibre trunking can be required.
- With new FWA deployments, backhaul ducting and fibre cabling costs can be minimised, providing that radio access points are deployed with designs to enable 'good' radio distances in the 'last mile'. With our dialogue with FWA service providers and our own independent analyses, 'good' means several kilometres for point-to-multipoint FWA systems – allowing attractive cost structure in the access network. Backhaul costs can be driven down if in-band or low cost point to point radio backhaul solutions can be used. Cost per connected line is then largely dependent on radio system costs in the access network.

A key benefit in the deployment of FWA systems can be cost avoidance in trenching, ducting, and fibre cabling.

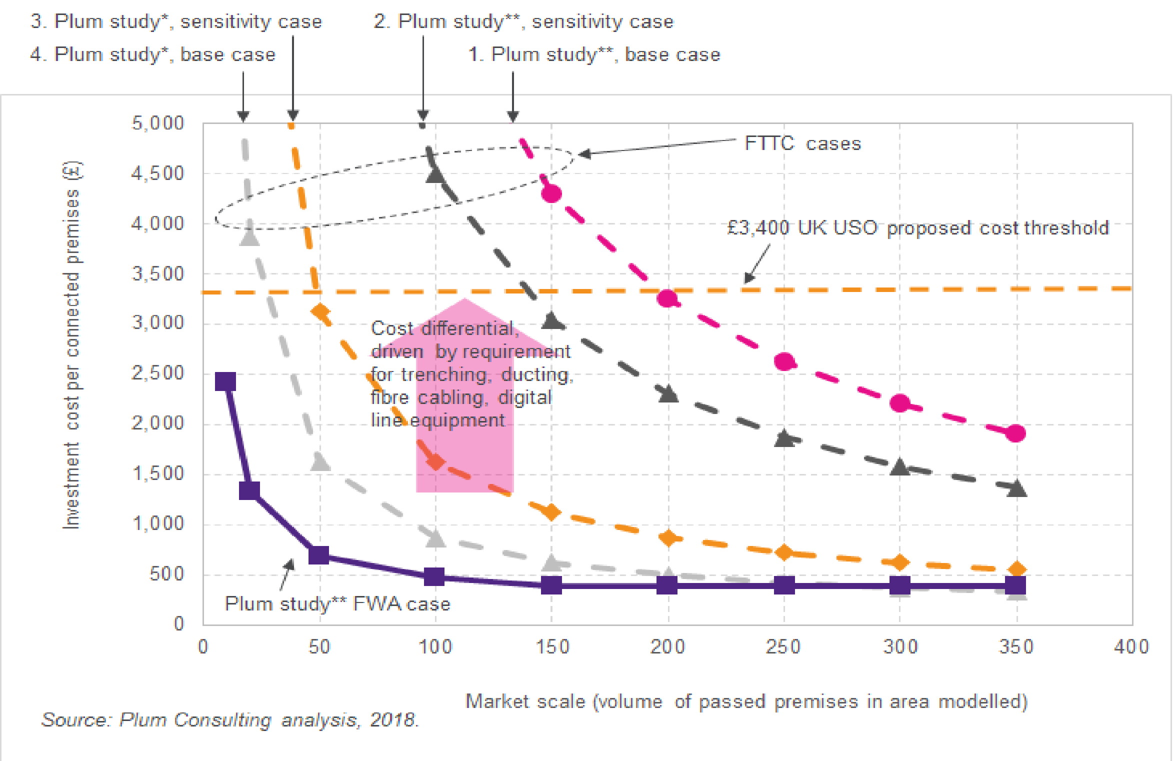
It must be noted that compromises can often be required in network designs to enable acceptable costs. In both fixed and radio based systems, multiplexing of access links with trunking back to core networks is typically invoked with some level of contention being applied (i.e. advertised data rate speeds may not be guaranteed to customers at all times). Typical contention factors are included in our model[56].

In any case, customers' willingness to pay for broadband services will be driven by 'headline' advertised data rates and perceived quality levels. With market precedents largely set for bitstream broadband products, service providers' free cash flow (FCF) levels and new build investment cases will be significantly influenced by investment cost structures. Excessive costs will naturally lead to a reluctance from private investors and firms to roll out in under-served areas, with potential for market failure, or at least very long lead times to acceptable broadband service levels.

With no public funding available for the Government's broadband USO implementation, it will be critical to find and deploy broadband solutions that can provide both acceptable time and cost to market.

Below (see Figure 3.7) we illustrate the dynamics of investment cost for both FWA and FTTC solutions according to market scale in a given area. In both cases, we assume that a line connection is made available to customers with a downlink data rate of at least 24 Mbps[57], in line with UK Government 'superfast' broadband targets.

Figure 3.7: Cost comparison between FWA and FTTC deployments



Source: Plum Consulting analysis, 2018.

56 Note: we assume contention at 10:1, i.e. a more stringent design than in the USO specification at 50:1.

57 Data rate is explicitly modelled in our analysis for FWA systems. For FTTC, we assume that 'last mile' copper lines are available with sufficiently short loop length to support downlink data rates of 24 Mbps or higher (e.g. via VDSL2 and/or vectoring digital subscriber line technologies or similar). If this were not the case, additional costs could be required in the FTTC case.

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In Figure 3.7, we show results for various scenarios, with varied scale of demand aggregation, and cost structure:

- FWA base case, as described above;
- FTTC cases[58]:
  1. Current study, FTTC fibre / trenching backhaul at £100/m, 5km average;
  2. Current study, FTTC fibre / trenching backhaul at £70/m, 5km average;
  3. Plum study, FTTC fibre / trenching backhaul at £30/m, 4km average;
  4. Plum study, FTTC fibre / trenching backhaul at £20/m, 3km average.

The various FTTC cases show variability in fibre and trenching backhaul cost structure, which can change according to area types. Typically, higher costs will be required in more rural areas.

With our analysis, FTTC solutions become significantly less cost efficient as market scale reduces (i.e. with increasingly rural areas).

With modern FWA solutions, significant investment cost advantage is likely – over FTTC solutions addressing equivalent demand side needs, providing that:

- backhaul costs and radio spectrum can be contained to reasonable levels;
- any new fibre cabling and trenching costs cannot meet regional scale (demand aggregation) and area type requirements; and
- suitable radio spectrum is available to ensure robustness of radio links and corresponding reasonable cost structure in the radio system design.

In addition, flexibility in investment cost structure should be considered; as FWA solutions can be scaled with access points, lower initial investments are possible than with fibre based installations. With FWA solutions, investment levels can be increased as market needs develop. This can provide a more risk-averse approach to business development for investors.

Further, FWA systems operating with existing spectrum regulations – allowing use in the 5.8 GHz band C block – are becoming subject to band congestion and increasing levels of interference. To enable robust and efficient FWA solution implementation, operation in bands below 5 GHz can be considered.

Access to appropriate spectrum is thus a key issue in enabling FWA solutions to market.

3.6 Implementation issues

In its December 2016 Statement on USO design[59], Ofcom used preliminary data to estimate the cost of addressing a UK broadband USO. Four scenarios were considered with:

1. a 'basic' 10 Mbps downlink service;

[58] Note: in Figure 3.7, '*' cases per Plum BSG study; see: http://plumconsulting.co.uk/impact-broadband-universal-service-obligation-uk/ . '**' cases refer to the current Plum study, as here. Cost variations dependent on fibre backhaul assumptions.

[59] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0028/95581/final-report.pdf

2. 10 Mbps downlink / 1 Mbps uplink / contention at 50:1;
3. 'superfast' broadband at 30 Mbps downlink / 6 Mbps uplink / committed rate at 10 Mbps; and
4. 'intermediate' at 20 Mbps downlink / 2 Mbps uplink (later scenario added).

As of 2016, Ofcom estimated the scale of addressing under-service for these scenarios as, respectively (in numbers of UK premises to be served) (scenarios 1-3): 1.4m (5%), 2.6m (9%), 3.5m (12%). With these analyses, Ofcom estimated that the cost of implementing the USO would amount to £1.1bn for 'standard' broadband, to £2.0bn for 'superfast' service, based on mixed technology use. Scenario 4 was added in July 2017[60], with revised (higher) costs for FTTC solutions.

With the Statement, Ofcom recognised that:

> *"Given these modelling uncertainties, policy choices that can reduce the risk of substantially higher than expected costs (e.g. setting a reasonable cost threshold) should be considered".*

At the time of its 2016 analysis, Ofcom stated that wireless technology would be unsuitable due to capacity limitations. With our analysis (see section 3), we disagree, and we note the preliminary nature of the 2016 Ofcom analyses. With the July 2017 update, Ofcom's data was revised to reflect capability to serve the defined scenarios with wireless technologies as *'Yes'* and *'Potentially'*. The paper noted that as of 2017, c. 1.8m (6%) UK premises would qualify for the USO, based on Scenario 2.

Ofcom's analysis was picked up in December 2017 in a Commons Briefing Paper[61] which essentially used much of the data to make similar points, recognising a target date of 2020 for implementation, and scenario 2 as above as the preferred technical specification, with an implementation cost at c. £1.5bn (i.e. c. 2 year programme), considerably higher than BT/Openreach's own estimates of £450-600m *'depending on technology mix and volumes'*, in its UBC offer[62] (since rejected by Government on grounds that it may not have delivered the level of legal enforceability sought and may have interfered with market competition). In its consultation response during the wholesale local access (WLA) review (August 2017), BT provided clarifications on these costs (associated with USO implementation):

> *'BT estimates it would cover around 750,000 premises, with around 1% (or 300,000) covered via wireless. The costs of wireless technologies are not included in the £450-£600 million. This gives a cost per premises passed by fixed technologies of around £1,000-£1,333. The USO Report [Ofcom's December 2016 Statement[63]] forecasts around 600,000 premises by 2020 would not receive the service proposed by BT, and that covering these would cost around £1bn, giving a cost per premises passed of £1,666. However, this includes the most expensive premises. The USO Report highlights that, as of 2016, the final 1% of premises are likely to cost £690 million [est. £2300 per premise, on average]. Assuming the same premises and costs represent the final 1% in 2020, removing these premises and costs from the USO Report's 2020 forecast leaves 320,000 premises costing £310 million, or just under £1,000 per premises passed'.*

[60] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0015/105342/Technical-advice-on-a-broadband-USO-Updated-cost-estimates.pdf

[61] See: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-8146

[62] See: https://www.openreach.co.uk/orpg/home/updates/downloads/Deliveringuniversalbroadbandcoverage.pdf

[63] See: https://www.ofcom.org.uk/consultations-and-statements/category-1/broadband-uso

BT's comments recognise that serving premises in hard-to-reach areas can be expensive (with an average cost per connected line of £2,300). With appropriate use of technology, investment costs required to serve such areas could be reduced, with significant impact to overall USO implementation costs[64].

The briefing paper also noted that industry will be obligated to build out links up to a cost threshold of £3,400 per link. Costs are expected to be borne by industry. A higher threshold would enable greater coverage, but would give rise to even greater costs to industry – which, in all likelihood, would be passed on to consumers in the form of higher bills.

The consumer campaign group Which? has queried whether the Government has adequately justified the proposed £3,400 cost threshold[65,66]:

> *"…Although Which? recognises the need for a cost threshold to ensure the USO is delivered cost effectively, the consultation nor the Impact Assessment (IA) provides enough evidence to support the proposed level (of £3,400) for the cost threshold. The Government must determine the level that will deliver the highest net benefit for the UK".*

In March 2018, the DCMS published its response on consultation on the USO[67], noting that:

> *"Given the proposed specification of the USO, we agree with Ofcom's 2016 assessment that FTTP, FTTC (VDSL), fixed wireless and mobile technologies can meet the proposed specification to deliver universal affordable broadband, but based on its current capabilities, that satellite may not".*

It was also recognised that comments were received stating that:

> *"wireless operators, particularly community wireless operators, can achieve connections for a fraction of this [£3,400 per premise] amount".*

Given the Government's ambitious target of USO implementation by 2020, it will be critical to invoke use of solutions that not only meet or come in below cost targets, but offer rapid roll-out capability.

During our discussions, several wireless access based service providers advised us that it is possible to set up new wireless access points and service coverage within days or weeks.

In hard-to-reach areas, build-out of new trenching, ducting, and fibre cabling is unlikely to prove cost and time effective. In its response, the DCMS notes that:

> *"Technological neutrality is one of the fundamental principles underlying the EU electronic communications regulatory framework, intended to promote effective and fair competition by avoiding distortions of the market caused by the regulatory regime favouring some technologies over others".*

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[64] See also: https://www.nic.org.uk/wp-content/uploads/Cost-analysis.pdf

[65] See: http://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-8146

[66] See: Which? response to DCMS Consultation: A new broadband Universal Service Obligation: Consultation on Design, 9 October 2017.

[67] See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695121/USO_consultation_government_response_28_March.pdf

4 Looking ahead

In the previous section, we assessed the relative investment costs across both FWA and FTTC solutions, and implementation issues, together with radio spectrum band requirements.

There will be significant benefit in enabling broadband connectivity for all in the UK, with timely and cost effective access.

Below, we consider radio spectrum management options, and review briefly recent study on economic benefits likely with widespread broadband connectivity.

We also address the requirement for timely delivery of broadband services.

4.1 Radio spectrum management options

Access to both appropriate access network cost levels and radio spectrum bands has been noted above as important for enabling widespread broadband for UK users.

Management of the UK's radio spectrum resource will have bearing on both service access levels and costs.

In the UK, and other markets, radio spectrum suitable for mobile services, with national licensing, has typically attracted high prices[68], as mobile network operators (MNOs) have seen spectrum as a key enabler for deployment of new mobile services and business continuity.

However, there are problems with this 'traditional' approach. Aside from a need for national licences to support national mobile roaming, radio spectrum is typically not used equally across different geographic regions, and this is likely to be the case with 5G network roll-outs, as it has been with previous generations of mobile technology. Understandably, infrastructure based service providers tend to roll out networks to areas where high revenues are expected, to recoup investment costs more quickly. Typically, this means that urban areas are initially targeted. Consequently, nationally licensed radio spectrum, awarded on the basis of value largely attributable to urban usage, may not be effectively used in non-urban areas by established mobile network operators. Whilst additional spectrum is likely to be required to support 5G mobile services in urban and sub-urban areas, this is unlikely to be the case in other parts of the UK, where access to nationally licensed spectrum already exists.

Further, 5G technology, still under development, is now widely and importantly recognised as a set of connected systems – which must co-exist. A detailed review of 5G systems is beyond our scope here, but it is important to note that increments alone, over previous technologies, in mobile radio access network coverage and capacity levels, are unlikely to promote strong business cases for mobile service providers (as cost efficiency improvements are not expected to be sufficiently substantive).

Thus, the question arises – how best to regulate radio spectrum, so as to enable a balanced and healthy ecosystem with various user types:

[68] For example, in the UK, the 3G radio spectrum auctions held in the year 2000 yielded a total bid value of £22bn. Later, in the year 2013, the UK 4G spectrum auctions resulted in a value of £2.3bn. 'Excessive' 3G prices for spectrum may have been due to the UK's early leadership in 3G launching to market, with no availability of reasonable benchmarks; operators were thus willing, at the time, to 'bet the farm' to acquire what was seen as a critical business asset, almost at any cost.

- FWA radio network systems can provide an attractive solution for broadband connectivity for non-urban areas, but require access to appropriate radio spectrum, if attractive cost structure and service quality are to be enabled;
- radio spectrum in the 3.5 GHz bands is becoming available in the UK market, and appropriate regulatory measures will need to be considered.

Instead of national licensing, sub-national or regional licensing, secondary usage, and leasing models can be considered. In these cases, spectrum can be licensed with a geographic consideration to licence terms, or on the basis of prioritised or leased usage.

In fact, alternative spectrum management models already exist in the UK with television (TV) band licensing in the 'white space' (WS) bands[69], and in some other areas[70].

Management of radio spectrum on a dynamic and geographic basis can be supported with database technologies. Such technologies are available today, are commercially proven, and can be used across a wide range of frequency bands. However, such methods are not widely deployed in the UK currently. We understand that Ofcom is considering innovative methods for spectrum management in the 3.8 – 4.2 GHz region, but not in the 3.6 – 3.8 GHz band.

As part of our stakeholder dialogue, we spoke with both BT Group and a large UK-based mobile operator on approaches to spectrum management in the UK[71].

BT provided us with the following statement:

> *"BT aims to have a single integrated all-IP fibre based network that enables seamless converged access across fixed, WiFi, and mobile".*

BT also advised that it is already deploying fixed wireless solutions – with its 4GEE broadband home router[72].

A major UK-based mobile operator advised us that FWA is not currently a part of its business strategy in the UK, but, in principle, is supportive of equality of access (to spectrum), is not opposed to other entities using spectrum in areas where it remains under-utilised, and would be 'happy' to explore leasing options, subject to regulatory permissions from Ofcom. However, the mobile operator commented that it would not support 'neutral host' (wholesale access network) models where entities were able to acquire and monopolise spectrum use unfairly.

Whilst there is some precedent for spectrum leasing in the UK, application of this approach is on a case by case basis, i.e. dependent on particular licence terms. In its guidance documentation[73], Ofcom states:

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[69] That is: television radio bands which are not used in particular geographical areas.

[70] Regulatory precedent exists in the UK for radio spectrum sub-licensing; for example in Ofcom licence number 0307337, the licence terms state that "The Licensee may:

(a) confer the benefit of the Licence (which is hereinafter referred to as a "lease") on another person (referred to as the "leaseholder") in respect of any wireless telegraphy station or wireless telegraphy apparatus to which the Licence relates;

(b) in his contract with the leaseholder permit the leaseholder to confer the benefit of the Licence (hereinafter referred to as "sub-lease") on any other person ("sub-leaseholder"),

provided that the conditions set out in Schedule 2 to this Licence are met".

[71] Source: Plum private dialogue with BT Group and major UK-based mobile operator, pertaining to this study.

[72] See: https://shop.ee.co.uk/broadband/4g-home-broadband

[73] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0029/88337/Trading-guidance-doc-jul15v0-1-2.pdf

"You may grant spectrum leases only if your WT licence contains terms that expressly allow you to do so".

Operators generally view the current leasing options as commercially unworkable, as excessive levels of commercial risk are seen as likely.

In our discussions with TVWS database operators, we were advised that current commercial models using dynamic radio spectrum management tools incur only nominal annual fees[74].

Such approaches are also being considered in the United States with the so-called Citizens' Broadband Radio Service (CBRS) approach to spectrum management. According to the US FCC[75]:

"The new rules will provide a number of tangible benefits for consumers, businesses, and government users. First, the new rules will support important national defense missions by protecting incumbent radar systems from interference. Second, the new rules will make additional spectrum available for flexible wireless broadband use, leading to improved broadband access and performance for consumers. Finally, we expect to see wide deployment of wireless broadband in industrial applications – advanced manufacturing, energy, healthcare, etc. – supporting innovation and growth throughout our economy.

The Citizens Broadband Radio Service is governed by a three-tiered spectrum authorization framework to accommodate a variety of commercial uses on a shared basis with incumbent federal and non-federal users of the band. Access and operations will be managed by a dynamic spectrum access system, conceptually similar to the databases used to manage Television White Spaces devices. The three tiers are: Incumbent Access, Priority Access, and General Authorized Access.

The Priority Access tier consists of Priority Access Licenses (PALs) that will be assigned using competitive bidding within the 3550-3650 MHz portion of the band".

CBRS is not yet commercially launched in the US, with FCC qualifications ongoing, but is attracting considerable attention for the provision of regional cost-effective broadband services. Commercial CBRS services are expected in the US market from 2019. Benefits of the CBRS may include access to spectrum by those who need it, and will use it, with subsequent benefits for consumers in access to broadband services.

In addition, it is important to note the considerable increase in interest in private enterprise networks (e.g. private LTE, 5G), driven by commercial motivations to reduce cost, and gain greater control over network operations and services than are possible with established solutions (e.g. leased, hosted services) – as available from telecommunications service providers. That is, increased flexibility in solution neutral services is being sought in the market. Such approaches may be applicable in varied geographic regions, and call for innovative use in spectrum management.

With innovative management of spectrum, regional value of the resource will be attributable to regional demand – a much fairer system for consumers. Modest demand levels in sparsely populated areas will drive modest regional value of radio spectrum – directionally in line with cost efficiency, possible with FWA radio systems. Such an approach also removes barriers for new entrants, enabling increased competition.

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[74] Source: Plum study dialogue with UK based TVWS business providers.

[75] See: https://www.fcc.gov/wireless/bureau-divisions/broadband-division/35-ghz-band/35-ghz-band-citizens-broadband-radio

With such innovation, the question can arise as to whether impact would ensue, relative to existing models of use. Spectrum value is typically associated with population (demand) coverage; unless population is removed from the coverage area as a whole, impact is unlikely. Innovative spectrum management may give rise to regional valuation of spectrum, but it is unlikely to deplete whole (national) value. In fact, the opposite is likely: if greater population is covered, greater overall value of the national radio spectrum resource is likely.

4.2 Benefits of widespread broadband connectivity

The benefits of broadband connectivity, at national scale, have been widely assessed by many; for example, in 2014, the Government's own study[76] indicated that availability of faster broadband internet connections supports productivity benefits.

More recently, Ofcom has noted that it is widely held that increased investment in broadband, and therefore access to such, is related to economic growth[77]. This view has been endorsed in a study carried out by Oxford University[78], commissioned by Ofcom, which concluded a causal, positive relationship between broadband investment and growth (i.e. that investment in broadband caused economic growth). A detailed review of the econometric methods used in the study is beyond our scope here; however, we note the key findings:

> *"broadband as a network technology has a measurable effect on economic output".*
>
> *"the impact on UK GDP of broadband investment and speed improvements was on average 0.47% per annum. The cumulative total was an addition of around 6.7% to UK GDP as a result of improvements in broadband networks over the [15 year] period [studied]".*

Other studies have revealed similar benefits. For example, in the US, a study carried out by the Council of Economic Advisors in March 2016[79] suggested that as competition increases (amongst internet service providers), so does take-up of internet services, as greater competition typically gives rise to consumer benefits in the form of lower prices and higher quality services.

In a paper produced by the Centre for European Economic Research[80], benefits were observed with broadband development, including positive effects on employment, GDP, productivity and performance, and regional development.

4.3 Ensuring timely delivery for high performance services

With these known benefits, a key issue for UK Government will be ensuring both cost and time effective delivery of broadband to enable connections for the country as a whole.

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[76] See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/274633/UK_Broadband_Impact_Study_-_Baseline_Report_-_Jan_2014_-_Final.pdf

[77] See: https://www.ofcom.org.uk/research-and-data/telecoms-research/broadband-research/economic-impact-broadband

[78] See: https://www.ofcom.org.uk/__data/assets/pdf_file/0025/113299/economic-broadband-oecd-countries.pdf

[79] See: https://obamawhitehouse.archives.gov/sites/default/files/page/files/20160308_broadband_cea_issue_brief.pdf

[80] See: http://ftp.zew.de/pub/zew-docs/dp/dp16056.pdf

In alignment with USO policy, this means that effective broadband will be required for 'the last 5%' by 2020. However, the credibility of the USO has already been called into question by many in the industry.

Beyond the USO, roll-out of broadband services at 'superfast' or higher service levels will be important for many consumers.

Taking into account build-out rates, consumer access to high speed broadband services will vary.

If a two year programme was feasible, (taking data from Ofcom's Connected Nations report – Spring 2018 update, based on data collected in January 2018), build rates as below would be required – to pass unconnected premises:

- at 10 Mbps ('decent' broadband, per DCMS USO spec.), 0.925m (3%) UK premises [0.46m/yr];
- at 24 Mbps (DCMS definition of 'superfast'), 1.5m (5%) UK premises [0.75m/yr];
- at 30 Mbps (Ofcom definition of 'superfast'), 2m (7%) UK premises [1m/yr]; and
- at 300 Mbps ('ultrafast'[81]), 16m (55%) UK premises [8m/yr].

Rates of fibre roll-out will, of course, vary by region and area types. Ofcom's reported data on UK mean rates of progress suggests that it will be difficult to meet the USO target by 2020 with deployment of fibre only.

If universal UK consumer access to broadband at 'superfast' and above service levels is required, this could take well over a decade, leaving the UK at risk of lagging behind other nations in broadband connectivity.

Government is recently on record[82] as stating that roll-out of full fibre is likely to reach only c. 50% of premises by 2025. That is, with current deployment rates and strategy, c. 50% will not be reached by 2025.

It is also important to note that demand levels may increase. The need for ongoing review of the USO specification is recognised in the DCMS response[83] on consultation.

Given our analysis covering both cost and build rates, as set out in the various sections above, we believe that Government must seek and promote innovative options to meet broadband roll-out needs.

Such options should include modern access network technologies and innovative means for radio spectrum management – able to support rising service demand levels, with acceptable cost levels and roll-out rates.

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[81] Note: there is no formal definition of 'ultrafast' broadband in the UK; we assume a 300 Mbps downlink here, per Ofcom's Connected Nations Update – Spring 2018.

[82] See: https://www.gov.uk/government/speeches/chancellor-speech-cbi-annual-dinner-2018

[83] See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695121/USO_consultation_government_response_28_March.pdf

Appendix A: Radio access capacity and coverage analysis

Deployment and operational costs for telecommunications networks are typically driven heavily by access network costs – those costs associated with connecting customers to the edges of national networks (e.g. local exchanges and edge switches). These edge connections are often loosely referred to in the industry as the ‘last mile’ connection.

Radio access technologies, whether used for fixed or mobile service provisioning, are basically characterised by two key dimensions: coverage and capacity (together, of course, with unit costs – for access nodes and links). The extent to which coverage and capacity must be supplied to meet demand therefore drives annualised network related costs significantly.

A.1 Fixed wireless access link capacity assessment

Capacity supplied (in terms of bits per second, bps, data rates – uplink and downlink) with radio access nodes is a function of radio access node technology types and deployment configurations.

Different radio access technologies may offer different levels of capacity, supportable with varied levels of radio spectrum bandwidth (measured in Hertz – Hz), and capacity performance (at the radio access node level) may be expressed in terms of spectral efficiency per radio node sector and carrier band used (e.g. ‘N’ bps/Hz).

Link capacity attainable per sector-carrier at the physical radio link level is typically driven significantly by digital baseband engineering (e.g. modulation orders – QPSK, N-QAM, information coding algorithms), and multiple antenna element configurations, together with radio engineering. Use of multi-user multiple input multiple output (MU-MIMO) antennas can increase capacity levels beyond single channel link configurations (by a factor theoretically proportional to the number of elements in the antenna arrays, though capacity levels realised in practice can be limited).

At a radio system level, capacity efficiency is limited by the need to plan sectors to avoid interference. This is typically achieved using a method called frequency re-use: sector-carriers are planned such that adjacent sectors use different radio bands; this can be achieved using sectorised and directive gain antennas. A representative case is shown below.

Representative fixed wireless access capacity capability[84]

MU-MIMO antenna array capacity gain	Variable, estimated x8 over single channel on 8x8 MU-MIMO arrays MU-MIMO field degradation, estimated at 50% of theoretical level Higher factors may be possible with narrow beam configurations in FWA systems
Radio band per sector-carrier	20 MHz
Frequency re-use factor	1:2 (90 degrees, orthogonal carrier deployment)

[84] Sources: vendor estimates, public data, Plum analyses.

	Total bandwidth requirement = 40 MHz
Estimated link capacity (aggregated data throughput) per sector-carrier 'beam'	= 20 MHz x 9 bps/Hz x 50% (MU-MIMO gain) = 90 Mbps/sector* (effective throughout)
Estimated link capacity (aggregated data throughput) per two sector site	= 90 Mbps/sector x 2 sectors* = 180 Mbps/site (effective throughput)

Data shown* are supported by our dialogue with equipment vendors (see section 3).

A.2 Fixed wireless access link coverage assessment

Coverage supplied (in terms of area covered – square kilometres, relating to passed and connected customer premises, with market penetration levels) is dependent on technology configuration (especially radio beam widths) and usable range – from the serving radio node or access point (AP) to the customer premises equipment (CPE).

To assess coverage capability, we include analysis below using a modified COST-231 Hata radio propagation model[85]. COST-231 Hata is a well-known mathematical representation, developed from empirical studies, which can be used to estimate usable radio communications link ranges; it is frequently applied in high level analyses (such as for strategic planning and network cost estimations), though more accurate radio planning methods and tools would typically be invoked in commercial system deployments[86].

The COST-231 Hata model is not proven for use above the 2 GHz band, and therefore, we apply modifications based on our dialogue with equipment vendors and reference to relevant studies. From our discussions, we estimate that an additional 12dB of path loss attenuation will typically be experienced at the 5.8 GHz band due to clutter over that at 3.6 GHz. In addition, we apply a correction factor to accommodate the model for use in fixed wireless access scenarios – based on Ofcom field studies in the UK[87].

For a rural environment, our modified COST-231 Hata model equation for path loss (PL) in dB is:

$$PL = 46.3 + 33.9\ \log_{10}(f) - 13.82\log_{10}(h_b) - ah_m \\ + (44.9 - 6.55\log_{10}(h_b))\log_{10} d + c_m + \Delta + \nabla$$

Where,

f = carrier frequency (MHz),

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[85] COST Action 231, "Digital mobile radio towards future generation systems, final report," tech. rep., European Communities, EUR 18957, 1999.

[86] During our discussions with vendors, it was noted that ITU-R models as in Recommendations P.530 and P.833 are typically used in FWA radio planning tools, as used in planning commercial deployments – as discussed in section 3. (Note: Plum has been directly involved in the development of these models).

[87] 'Comparison of empirical propagation path loss models for fixed wireless access systems', VS Abhayawardhana, IJ Wassell, D Crosby, MP Sellars, MG Brown, Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st 1, 73-77. See: http://www.cl.cam.ac.uk/research/dtg/www/publications/public/vsa23/VTC05_Empirical.pdf

d = distance between the radio access point (AP) and the customer premises equipment (CPE) (km),

h_b = AP antenna height above ground level (metres), and

for rural and open environments,

c_m = 0 dB,

Δ = modification factor (pronounced: *delta*), based on Plum dialogue with equipment vendors; (0 dB at 3.6 GHz, +12 dB at 5.8 GHz, due to direct attenuation effects (e.g. tree foliage) at 5 GHz),

∇ = correction factor (pronounced: *nabla*), based on Ofcom supported field studies on fixed wireless radio propagation in the UK market; (-35 dB applied[88]: modification for reduced clutter in FWA, relative to mobile scenarios),

$ah_m = (1.1 \log_{10}(f) - 0.7)h_r - (1.56 \log_{10}(f) - 0.8)$, and

h_r = CPE antenna height above ground level (metres).

Antenna heights and link paths will normally be designed taking into account sufficient Fresnel zone clearance[89].

The maximum allowable path loss (MAPL) is typically a function of the radio link engineering design, which can be expressed as a radio power link budget[90]. A representative (reasonably conservative) link budget assessment is shown below. This is derived from experience of commercial mobile systems deployments, with revisions applied to show the case for a typical fixed wireless access deployment. Data has been confirmed with selected FWA equipment vendors. Clearly, deployment parameters will vary according to particular commercial products and particular installations. Our purpose here is to show the scale of performance feasible with currently commercially available products.

With static radio links, FWA solutions are able to benefit significantly from directional antennas and lower fading levels which allow lower transmitter power levels and less stringent receiver sensitivity designs than with mobile radio systems; these benefits can yield unit cost advantages over mobile cellular radio access network architectures.

Representative radio link power budget for fixed wireless access[91]

Radio link parameter	Uplink (CPE to AP)	Downlink (AP to CPE)
Transmitter (Tx)		
Tx antenna height	7 m	14 m
Tx power	19 dBm	19 dBm

[88] Based on analysis of path losses in free space.

[89] Clutter extending into the Fresnel zone of a radio link can cause unwanted signal attenuation due to radio wave scattering and interference effects.

[90] Radio link power budgets (with receiver sensitivity levels) will typically be designed to support the lowest 'level' of modulation order acceptable in the system (at the sector edge). Overall sector capacity is normally expressed based on averaging of capacity levels supported by various modulation orders that may exist across the sector.

[91] Sources: vendor estimates, public data, Plum analyses.

Tx diversity gain	0 dB	0 dB
Tx antenna gain	20 dBi	20 dBi
Insertion losses	3 dB	3 dB
Tx EIRP[92]	**36 dBm**	**36 dBm**
Receiver (Rx)		
Required SINR	10 dB	10 dB
Thermal noise power	-101 dBm	-101 dBm
Receiver noise figure	7 dB	7 dB
Receiver noise floor	-94 dBm	-94 dBm
Receiver sensitivity	**-84 dBm**	**-84 dBm**
Link gains and losses		
Baseband / coding gains	0 dB	0 dB
Antenna diversity gain	3 dB	3 dB
Cable losses	0 dB	0 dB
Rx antenna gain	20 dBi	20 dBi
Rx LNA gain	0 dB	0 dB
Fade margin	3 dB	3 dB
Indoor penetration margin	0 dB (not required for FWA)	0 dB (not required for FWA)
Net margins	**20 dB**	**20 dB**
Overall link budget:		
Link allowable pass loss	**140 dB**	**140 dB**
Maximum allowable path loss (MAPL)	**140 dB**	

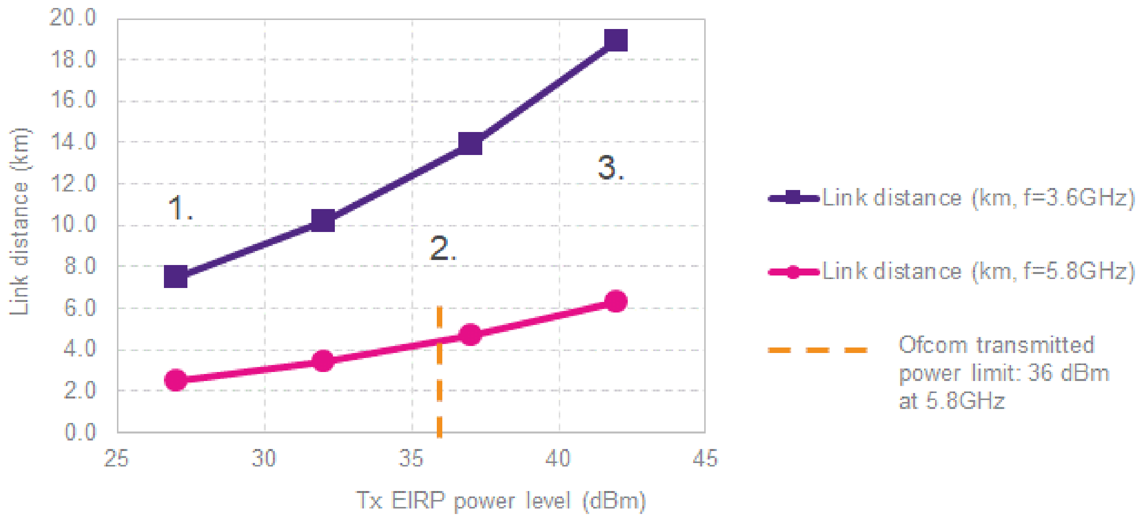
[92] Note: Ofcom currently limits transmit power levels within Band C (5725 MHz to 5850 MHz) to a maximum of 4 Watts (36 dBm) EIRP. See: https://www.ofcom.org.uk/manage-your-licence/radiocommunication-licences/fixed-wireless-access

The value derived from the bi-directional link budget design can be used with the modified COST-231 Hata model to estimate maximum allowable link distance: *d* (km).

Results are shown below for alternative FWA radio configurations:

1. lower power design (representative of village coverage deployments);
2. selected interim designs; and
3. higher power design (representative of sparse, long range coverage deployments).

Estimated radial link distances for representative FWA system designs



Source: Plum Consulting analysis, 2018.

Estimated useful link distances are higher (i.e. greater coverage areas are attainable), for given transmitted power levels and radio link designs, with lower carrier frequencies, due to the improved physical radio propagation characteristics with lower carrier frequencies (*f*).

For the scenarios illustrated, radial distance estimated at 3.6 GHz extends by around x3 over that attainable at 5.8 GHz. This equates to an area coverage improvement at the lower frequency of around x9. Subject to capacity planning requirements, this enables an equivalent level of cost benefit (see section 3).

Note that due to current Ofcom licensing restrictions in Band C (5725 MHz to 5850 MHz), radial link distances achievable with equipment operating in this band are correspondingly limited.

The scenarios shown are provided for illustration of link distances and coverage areas that could be attainable with typical FWA solutions, currently commercially available.

We have noted, during our dialogue with FWA equipment vendors, that considerably longer link distances (e.g. 10-20 km) may be possible at 5.8 GHz with more advanced (and therefore more costly) radio equipment (subject to licensing limitations). Whilst such equipment may be useful in some situations, higher range (lower radio beam angle) configurations are likely to be beneficial where very isolated and sparse customer premises are located. Such situations are likely to lead to rather higher (and case-specific) costs per connected line than we would expect with typical FWA configurations suited for ‘blanket’ service coverage.

We have focused our analyses on ‘low to middle scale’ FWA equipment, currently commercially available, with capability to provide ‘blanket’ service coverage from APs to rural or open areas with reasonable scale over limited distances (several kilometres, as illustrated in the above analysis).

Thus, typical configurations are seen as AP-CPE distances of several kilometres, with full or near line-of-sight radio link installations (similar, in principle, to rooftop installations of UHF TV aerials on residential or business premises – with near line-of-sight to regional TV transmitter sites).

Analytical data, as here, are supported with our separated dialogue across multiple FWA equipment vendors and service providers.

Appendix B: List of stakeholders providing study inputs

For this study, we have spoken with a wide range of stakeholders with varied interests and market positions.

Throughout, our intent has been to represent facts accurately and maintain balance in our work, with independent checks in relevant cases.

Below, we provide a list of the stakeholders that have provided written or verbal input to support the production of this report.

Table 4.1: List of stakeholders that have provided input to the report

Study commissioned by:	**Network equipment vendors:**
• UKWISPA Executive	• Cambium Networks Ltd (UK)
• INCA Executive	• Blu Wireless Technology Ltd (UK)
	• Mimosa Networks Inc (USA)
UK based national service providers	
• BT Group plc	• Major UK-based mobile operator
UK based wireless internet service providers (UK WISPs) and related companies	
• Boundless Networks Ltd	• M24Seven (M247 Ltd and companies)
• TxRx Communications Ltd	• Quickline Communications Ltd
• Nominet Ltd	• Kencomp Internet Ltd
• Pure Broadband Ltd	• W3Z Broadband Ltd
• Air Broadband Ltd	• JHCS Ltd
• Cybermoor Networks Ltd	• Caudata Ltd
• Lothian Broadband Networks Ltd	

Appendix C: Glossary of terms

ADPCM	Adaptive Differential Pulse Code Modulation
AP	Access Point (radio network base station)
CBRS	Citizens' Broadband Radio Service
CPE	Customer Premises Equipment (customer connection)
DP	Distribution Point
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
EIRP	Effective Isotropic Radiated Power
FCC	Federal Communications Commission (agency of the United States Government)
FCF	Free Cash Flow
FTTC	Fibre To The Cabinet
FTTP	Fibre To The Premise
FWA	Fixed Wireless Access
GDP	Gross Domestic Product
INCA	Independent Networks Co-operative Association
LIC	Line Interface Card
LOS	Line Of Sight
LRIC	Long Run Incremental Cost
LTE	Long Term Evolution (4G technology)
MDF	Main Distribution Frame
MNO	Mobile Network Operator
PCP	Primary Connection Point
R&D	Research and Development
TDMA	Time Division Multiple Access
TV	Television
TVWS	TV White Space
UHF	Ultra-High Frequency
UKWISPA	UK Wireless Internet Service Providers Association
USO	Universal Service Obligation
VDSL	Very-high-bit-rate DSL
WISP	Wireless Internet Service Provider
WLA	Wholesale Local Access

About Plum

Plum is a leading independent consulting firm, focused on the telecommunications, media, technology, and adjacent sectors. We apply extensive industry knowledge, consulting experience, and rigorous analysis to address challenges and opportunities across regulatory, radio spectrum, economic, commercial, and technology domains.

We support our clients' needs with a range of consulting solutions including regulation and policy, radio spectrum management, applied economics, commercial and technology strategy development and implementation, due diligence and transactions, financial and technical modelling, change and performance improvement, and specialist engineering and technical support.

Based in London, we are proven and experienced in delivering to diverse needs and approaches globally, including for governments, regulators, service providers, vendors, professional investors, and legal firms.

About the authors

Ian Corden is a Director with Plum, based in London.

Previously with PwC TMT Strategy & Economics Consulting London, Coopers & Lybrand MCS Telecoms Consulting London, Lucent Bell Labs Systems Engineering and Economics Modelling divisions, Nokia New Systems division, and Oracle Telecommunications Strategy Consulting, he brings over 25 years of UK and international experience in telecommunications fixed and wireless systems engineering research and product development, technology programmes management, plus international strategy and policy consulting.

He has advised operators, regulators, governments, vendors, investors, and legal firms across technology, commercial, and financial domains.

Most recently, he advised Ofcom in providing a detailed review of its Wholesale Local Access (WLA) bottom-up and top-down LRIC models for FTTC charge control in the UK. Previously, he has held NGN programme director and CTO roles for operators in Europe, with accountability for c. €10m cost savings on a €300m network programme.

Ian holds PhD and BSc(1st Class Hons) degrees in electronic engineering, PgD in management and finance, UK C.Eng and FIET, and is Vice-Chair of the techUK Communications Infrastructure Council.

Laura Wilkinson is an Analyst with Plum.

She has provided research assistance for a number of spectrum related consulting projects for regulators and industry clients, focusing on market trend analysis and regulatory practices. More recently, she has gained experience in benchmarking practices whilst working on several spectrum valuation projects.

Laura holds MSc and MA degrees in economics, from the Universities of Bristol and Edinburgh.

Tony Lavender is Plum's Managing Partner.

He specialises in regulatory and policy issues across telecommunications and radio spectrum with a particular focus on the business and strategy implications of regulatory change. Tony has undertaken studies for governments and regulators, operators, and equipment vendors in many parts of the world.

He has consulted on many technical issues and their impact on regulation advising particularly in the area of next generation networks and network access and on the use of radio spectrum. Tony's advice has been used by clients to further influencing work for changes in regulation, for example, access to new frequency bands for mobile services at WRC15. He was a member of the expert panel established by the UK Government to consider incorporation of social value into spectrum allocation decisions.

Tony holds a BSc (Hons) degree in electrical and electronic engineering, plus UK C.Eng, MIET. He is currently chair of the UK Spectrum Policy Forum (SPF) – a leading policy development group.