Report D3.3 Cost-benefit findings and regulatory tools

Spectrum sandbox project Work Package 3 deliverable

A report from Real Wireless

Real Wireless Ltd
PO Box 2218
Pulborough
West Sussex
RH20 4XB
United Kingdom

t +44 207 117 8514
f +44 808 280 0142
e info@real-wireless.com
w real-wireless.com
real-wireless

Issued to: DSIT **Issue date:** April 2025 **Version:** 2.1

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independent telecoms experts

Version control

Item	Description
Source	Real Wireless
Client	DSIT
Report title	Deliverable D3.3 Cost-benefit findings and regulatory tools
Sub title	Spectrum sandbox project Work Package 3 deliverables
Issue date	April 2025
Document status	Final
Comments	

Version	Date	Comment
1.0	13/02/2025	Interim version issued to DSIT
2.0	12/03/2025	Final version issued to DSIT
2.1	07/04/2025	Updated final version issued to DSIT

Document management	Date	Name	Position
Document 1st draft	03/02/2025	Ade Ajibulu	Regulatory Economist
Document reviewed	07/04/2025	Dr. Abhaya Sumanasena	Project lead
Document reviewed	07/04/2025	Simon Fletcher	Project Director

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For details contact us at:

e info@real-wireless.com

w www.real-wireless.com

real-wireless

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1. Introduction

DIST has commissioned a Real Wireless-led consortium, consisting of Digital Catapult, Freshwave and Qualcomm to develop spectrum-sharing solutions under the spectrum sandbox project. The project consists of three work packages:

- Work package 1 (WP1) – Field trials in a sandbox environment to assess the feasibility of intensive spectrum sharing between different technology pairs.
- Work package 2 (WP2) – Simulation and modelling to assess the applicability of the sharing solutions to a wider range of technical parameters, locations, frequencies and technologies.
- Work package 3 (WP3)—Economic and regulatory assessment aiming to assess the economic value of sharing solutions and suggest options for exploring potential regulatory mechanisms and tools.

Overall, this work could inform Ofcom and DSIT's policy thinking and help shape new regulatory approaches related to how spectrum is authorised in the UK.

In WP3 we will assess the following technology pairs:

1. Technology pairs informed from the field trials:
    a. Independently operated private networks in the upper n77 band (3.8-4.2 GHz)
    b. Wi-Fi and mobile in the upper 6 GHz band (U6, 6425-7125 MHz)
2. Other technology pairs:
    a. Mobile and fixed links in the upper 6 GHz band (U6, 6425-7125 MHz)
    b. Mobile and satellite – Direct to device satellite in 2.6 GHz band (2500-2690 MHz) [**1**][**2**]
    c. Mobile and airborne non-terrestrial network (NTN)

Each work package consists of a number of deliverables, each focusing on a different aspect of the project. This report - deliverable D3.3 WP3 report provides findings from Cost Benefit Analysis (CBA) and regulatory Tools for scenarios (both factual and counterfactual[1]) modelled and associated cost-benefit parameters and assumptions. It focuses on the economic and regulatory assessment work planned for the project and sets out the WP3 overall modelling approach.

All deliverables from WP3 and their due dates are listed in **Table 1**.

Table 1: Summary of WP3 deliverables

Description	Due by
D3.1 Specification of scenarios (both factual and counterfactual) to be modelled, and associated cost-benefit parameters and assumptions	Issued
I3.3 Interim report	Issued
D3.2 Workbook with cost benefit analysis of scenarios tested in WP1 and WP2 against the counterfactual	Issued

[1] The counterfactual sets out what would have happened if a change (in this case the use of each sharing technology) had not taken place, i.e. if the status quo had continued

D 3.3 WP3 Report CBA Findings and Regulatory Tools	This report

1.1 Objective of the document

The purpose of this document is to present an assessment of the economic value of sharing solutions to spectrum users, using a case study approach for which the key inputs are test results on system performance from WP1 and scaling factors from WP2. We present:

- Scenarios to be evaluated in the cost benefit analysis looking at different ways of implementing sharing solutions, and potential mitigation actions spectrum users could take as assessed in the WP2 simulations.
- Methodology to be used to conduct the cost benefit analysis for each of the five technology pairs in the study; and
- The scenarios, which have been agreed with WP2, take measurements and results from the WP1 testbeds, where relevant, and simulate results for three environments, urban, suburban and rural.
- The outcomes of the CBA and plausible regulatory tools.

In the methodology description, we set out the calculation stages, and the relationships between the key input parameters in the models. This includes parameters that describe the markets and use cases targeted in each pair, i.e. demographics, consumer attributes (spending/willingness to pay) and service provider attributes (relevant network cost elements and unit costs). We also set out the inputs provided by WP2 in its simulations for each specified scenario.

1.2 Organisation of the document

Section 2 presents our description of the methodology for each technology pair and the model data that has already been collected for the analysis.

Section 3 presents the results of our cost benefit analysis and commentary on those results and which sharing techniques or options might maximise the benefits of spectrum sharing.

Section 4 discusses the implications of the cost benefit analysis for future policy development relating to spectrum sharing and the learnings for potential regulatory mechanisms in order to maximise the benefits to the economy and society from spectrum sharing.

2. Methodology

2.1 Overview of methodology

The diagram below gives an overview of the methodological approach that we shall apply to each technology pair.

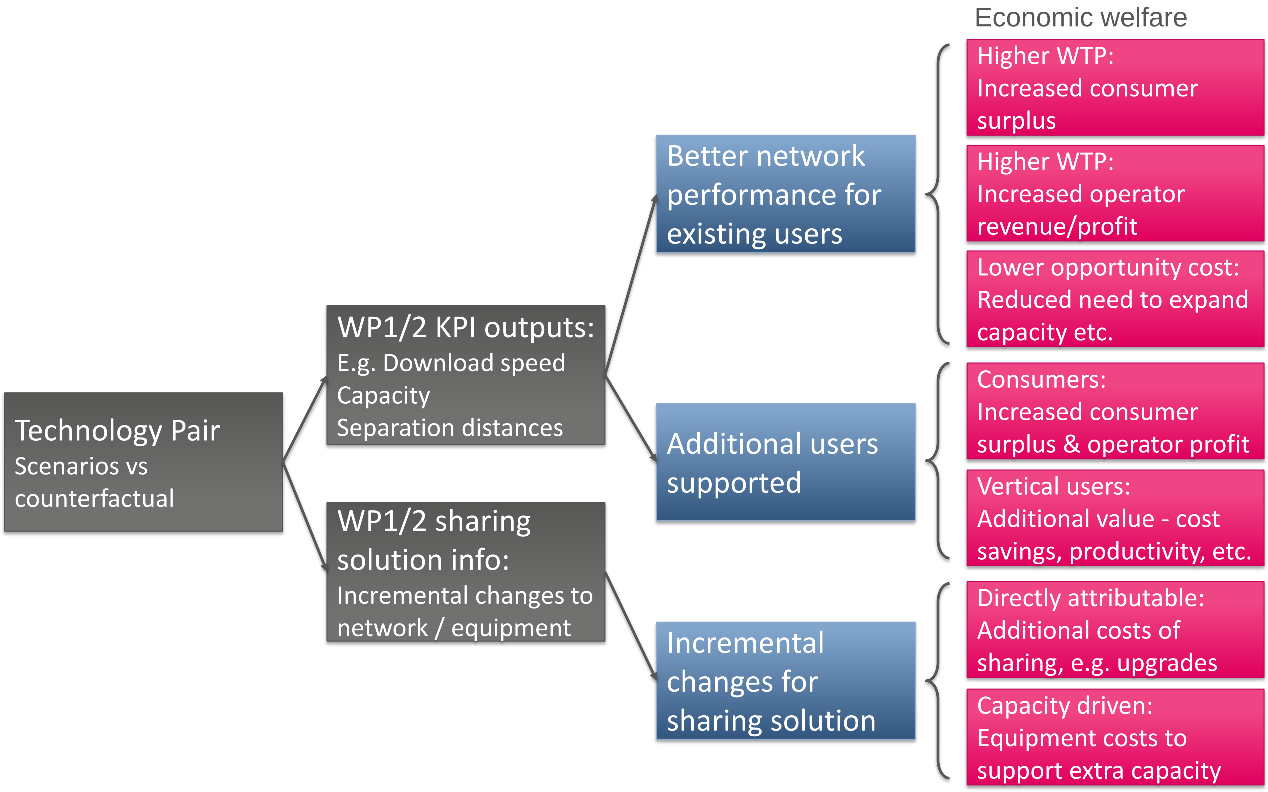

Figure 1 – Overview of methodology

Note: not all the benefits or costs may be relevant in each technology pair.

We note that our analysis provides results for the whole UK and by geotype – urban, suburban and rural. Where necessary, we scale up the results of the WP2 simulation which are for generic urban, suburban and rural environments to the equivalent geographic areas for the whole UK. Simulation results by area type are scaled up to total urban, suburban and rural geotypes pro rata on the basis of population. In the case of private mobile network sharing in the n77 band, separation distances are applied to the geographic area of the three geotypes to calculate the maximum number of networks that are permitted. The UK total is then the sum of the geotype sub-totals. Where relevant, we make assumptions on the rate of deployment or take-up over time of shared spectrum access.

In some cases, sharing is not appropriate in a certain geotype, for an individual technology pair. We explain why this is the case and hence there are no technical results to be analysed in the economic analysis.

2.2 Wi-Fi and mobile in the upper 6 GHz band

This technology pair looks at potential benefits of allowing both mobile and Wi-Fi to use the upper 6 GHz band. The use cases are providing additional mobile and fixed broadband capacity respectively. The question this raises for policy makers is whether the overall net benefit from sharing would be greater than allowing mobile or Wi-Fi to use the band on its own (putting aside other uses such as fixed links for the purposes of this analysis). Hence, we model two counterfactual scenarios to reflect this (as opposed to one counterfactual in the other technology pairs), though we do not compare one counterfactual against the other:

- Only Wi-Fi is allowed into the upper 6 GHz band;
- Only International Mobile Telecommunications (IMT) is allowed into the upper 6 GHz band.

In each case, the benefits from improved performance accrue to only one service, and there is no harmful interference between mobile and Wi-Fi.

We then assess the impact of sharing solutions that enable both mobile and Wi-Fi to coexist in the upper 6 GHz band and assess the implementation options that are simulated in WP2. We call these the factual scenarios and we assess them incrementally against each counterfactual. In principle, enabling shared use generates greater benefits than single use as two technologies can operate in the band. However, this may cause interference which will reduce the overall benefits, plus the costs of the sharing solution must also be taken into account. Our factual scenarios expose the key policy decisions in determining how to share the burden of mitigating interference over mobile and Wi-Fi. They are as follows:

- Both IMT and Wi-Fi with mitigation by Wi-Fi (Wi-Fi vacates) given a base Equivalent Isotropic Radiated Power (EIRP) of 73 dBm;
- Both IMT and Wi-Fi with mitigation by IMT (Wi-Fi vacates and IMT is at alternative powers):
    - 65 dBm;
    - 58 dBm;
    - 83 dBm.

Transmitting at reduced power will entail some degradation in performance and we go on to explain how this is taken into account in the economic analysis.

We have performed a high level analysis of the costs and benefits and make a number of simplifying assumptions in order to isolate the impact of the sharing technology and their benefits. First, we assume that alternatives to improving mobile and Wi-Fi performance and capacity, such as deploying other spectrum bands, have already been implemented and that the most spectrally efficient technologies are in place. We also assume that upper 6 GHz deployment and diffusion of compatible end user devices develops at the same rate across mobile and Wi-Fi users. This also helps isolate the impact of sharing on the high level welfare benefits. The following sections give more details on these and our other key assumptions.

Benefit assessment

The benefits of sharing arise from the fact that both mobile and Wi-Fi can use 6 GHz as opposed to only one service. Hence, both mobile and Wi-Fi services benefit from the improved network performance that 6 GHz delivers. However, we also have to take into account of the fact there will be performance degradation, in the areas where mobile and Wi-Fi potentially interfere, for some users (though the sharing solution attempts to minimise this).

Hence, we calculate the total incremental benefit based on the overall improvement for mobile or Wi-Fi performance once the impact of interference and any mitigation measures has been factored in. We assess consumer benefits from improved mobile and Wi-Fi performance and operator benefits for mobile (in terms of potential cost savings) as explained below.

The benefits we calculate here are private benefits to consumers and operators arising from their direct use and provision of services. Non-private benefits, such as societal benefits, could arise depending on how mobile and Wi-Fi services are used. However, we have not attempted to calculate such benefits because better mobile and Wi-Fi performance does not intrinsically generate a specific social benefit, particularly since the effect in rural areas (potential benefits of inclusion) is likely to be negligible according to our technical analysis. Moreover, our analysis is not granular enough to identify social benefits from specific IMT or Wi-Fi use cases.

Consumer benefits

We base our estimate of the consumer benefits of improved mobile and Wi-Fi performance on the increase in average performance consumers experience from the addition of U6 GHz to existing IMT frequencies. However, the WP2 simulations model the impact of cross technology signalling for a U6 GHz only network. As a result, we take the following approach for IMT:

- Estimate a proxy for the average download speed consumers may experience when U6 GHz is deployed alongside existing spectrum. This represents the benefit in the IMT only counterfactual.
  - Since U6 GHz has not been deployed we choose a proxy as an indicator of average download speed for existing spectrum + U6 GHz – i.e. the change in average download speed during the period when 3.4-3.8 GHz was deployed (2018-24) is a good indicator of the impact of U6 GHz.
- For each sharing scenario, the WP2 simulations provide the change in average throughput per active user compared to IMT only (U6 GHz taken separately). This relative change in average throughput is used to estimate the average download speed for the sharing scenario.
- Econometric studies (stated preference[2]) on willingness to pay for mobile is used to derive a relationship between changes in download speeds and the willingness to pay per consumer [3].
- The number of consumers able to benefit from U6 GHz is assumed to grow linearly over time reaching 100% in 5 years, starting from 2026. This assumes consumers refresh their phones every four years or so [4] and that a reasonable range of U6 GHz capable handsets come to market to satisfy this demand.
- The simulations model urban and suburban areas. We assume the U6 GHz band will most likely be deployed in urban and suburban areas to opportunistically relieve capacity in mobile networks on the same or similar footprint as the 3.4 GHz band. The U6 GHz band is less likely to be deployed as a coverage layer in rural areas.

We use data from Ookla's Speedtest Global Index to obtain the average (median) download speeds for mobile and fixed broadband in the UK from 2018 to 2024 [5]. The simulations provide the average throughput (downlink and uplink) for an active user.

In linking the potential impact of adding U6 GHz to existing frequencies to the historical impact of adding C-Band, we do not explicitly consider the additional impact of technology change. This is because it is difficult to separate the impact of spectrum and technology in the historical data and the future impact of change is

[2] A statistical technique where data on the interaction between product prices, attributes and demand is drawn from consumer responses to surveys where they have to choose between alternative combinations, thereby "stating" which they prefer,

uncertain. 6G and other technology could in theory considerably increase future network performance. Therefore our assessment should be considered conservative.

In calculating the relative change in average throughput per active user, we use simulation results for both uplink and downlink. This is because they both affect the average download speed experienced by the consumer. The approach we took was to take the minimum percentage change out of downlink and uplink for the cross-technology signalling (XTS) scenario relative to IMT only.

We take a similar approach for Wi-Fi as for IMT:

- As for IMT, since Wi-Fi has not been authorised for U6 GHz we choose a proxy as an indicator of average download speed for existing spectrum + U6 GHz;
  - We again refer to the historic change observed with the introduction of a similar band for Wi-Fi – in this case the lower 6 GHz band which was authorised in 2020 in the UK [6];.
  - Again, we acknowledge that other technology and market trends will also have and may in future affect consumer experience for fixed broadband and Wi-Fi, but believe that our approach provides a reasonable indication of the potential impact of U6 GHz;
- Econometric studies on willingness to pay for fixed broadband were used to derive a relationship between changes in download speeds and the willingness to pay per consumer [7] that benefits from the use of U6 GHz for Wi-Fi;
- In the sharing scenarios, the mitigation policy to enable co-existence is that a Wi-Fi AP will vacate the channel if certain conditions on interference with IMT are met (depending on the proximity between Wi-Fi and IMT devices and their transmit power). This means that fewer active Wi-Fi users are supported compared to a Wi-Fi only counterfactual;
  - We apply the WP2 simulation results for the proportion of active users that vacate the channel to the fixed broadband users in our analysis to calculate the number of users that remain served in the sharing scenario.
- We assume that U6 GHz capability diffuses across the user base linearly over 5 years, starting from 2026, until all devices are capable of using the band.

Similarly to mobile, Ookla's Speedtest data is used to estimate the historic trend in average download speed for fixed broadband for the relevant years covering the authorised of the indicative Lower 6 GHz band (L6), i.e. 2020 [8] and 2024 [9].

The number of mobile end-users in the urban and suburban geotypes is based on the total number of mobile subscribers (excluding Machine Type Communications (MTC)) from Ofcom's Communications Market Interactive data [10] for the UK and apportioned pro rata on the basis of population data by geotype (cross checked against population distribution data from Ofcom's Mobile Call Termination models). Similarly, the total number of fixed broadband users in the UK (also Ofcom Communications Market Interactive) is allocated pro rata to our population figures to get the number of Wi-Fi users per geotype.

There is relatively little empirical data on willingness to pay for improvements in mobile and fixed broadband quality. However, we were able to derive relationships from two econometric studies on mobile and fixed broadband (cited above). These examined how willingness to pay varies with download speeds as well as for the basic service. Since these studies are from outside the UK, the results were normalised by expressing the willingness to pay in relation to the Average Revenue per User (ARPU) for the country studied. Other studies, such as [11] broadly supported the relationships we derived, though the data was not detailed enough to feed in directly to our estimation of the relationship.

Some studies have modelled and found support for a diminishing relationship between the willingness to pay for increases in download speeds, i.e. the incremental change in WTP gets smaller as download speed increases. Others have modelled a linear relationship between WTP and speed. We consider that a diminishing relationship between download speeds and WTP is more plausible given that mobile ARPUs have not increased significantly despite the improvements in mobile broadband performance over the past decade. We found that a constant relationship between percentage changes in download speed and WTP fits the econometric results quite well. For example, a 100% increase in download speed leads to a 5% (low case) and 10% (high case) increase in WTP. This is applied to both mobile and fixed broadband.

Operator benefits

Operators benefit from the increase in network performance delivered to customers. Operators may hope to capture some of the increase in consumer WTP for increased performance through raising prices which would lead to higher profits. However, the relatively flat trends in ARPU in many countries over the past decade suggest this will prove difficult. Instead, operators may be forced to deploy upper 6 GHz capacity as a defensive strategy to maintain competitiveness and market share. Given the uncertainty over this, we consider it better to measure the total WTP effect as described above, rather than arbitrarily split it between consumers and service providers without concrete evidence.

However, mobile operators will also benefit from upper 6 GHz because they can meet their capacity needs more cheaply than the next best alternative which may be to densify the network. The net cost saving would be equal to the cost of network densification which is avoided minus the cost of upgrading existing sites to 6 GHz. In urban areas, macrocell densification is likely to be of very limited impact given network design issues and it could also be very difficult in practice to find and gain access to appropriate sites.

Hence, we instead estimate the indicative opportunity cost at a UK level, based on extrapolating from the amount operators have paid in the past for similar spectrum, e.g. at mid-band. This is not a perfect measure of the opportunity cost of 6 GHz because it reflects the demand and supply of spectrum at the time of the auction and not at the point when 6 GHz may become available. Arguably, demand for additional mobile broadband capacity would be lower than at the time of the previous C-Band auction. In addition, differences in propagation by frequency band will also affect the opportunity cost.

Caveats to the benefits assessment

It may be the case that end-user demand increases at a rate that does not require some or all of the network capacity increase that sharing provides. This is difficult to build into the quantitative analysis because future spectrum availability, technological developments affecting spectrum efficiency and future demand which are all highly uncertain and to some extent interlinked.

Hence, the evidence base for projecting forward demand and capacity is weak and we consider it better to address the impact of demand trends and their potential impact on capacity demand qualitatively. The most important issue is whether past trends in mobile data growth will continue (in the 2010s, exponential growth of 50% per annum was not unusual). Alternatively, mobile data growth might better fit a saturation curve model, where the rate of growth is initially slow, speeds up to a maximum where growth is exponential growth, before tailing off and ultimately usage tends towards a maximum. This is supported by a recent downswing in mobile data growth: as reported by Ericsson annual mobile data growth in Western Europe fell to 21% in 2023 [12].

Future growth could be driven by developments in end-user applications for mobile services. Widespread adoption of augmented/virtual reality based services – or other applications may develop of which we are currently unaware – would spark another cycle of exponential growth. Widespread deployment of mmWave spectrum could also significantly change the current trend. But if the status quo continues, the market may be heading towards saturation.

In other words, mobile data demand is highly path dependent, hence our qualitative approach. It leads us to say that there is a risk that the benefits for mobile from sharing are at risk of being lower than estimated if growth does move to a saturation curve model.

If data growth were to increase by a step change, e.g. due to the successful development of apps using AR/VR, we might expect to see a jump in the underlying willingness to pay for a standard mobile service and also increased performance.

Cost assessment.

We assess the direct costs of the sharing solution. This includes upgrades to enable cross-technology signalling – automated databases for dynamic sharing, mobile base station upgrades and (most likely) Wi-Fi access point and mobile handset upgrades to work with cross-technology signalling as necessary. We assume that software upgrades will be possible for end-user devices rather than the more costly alternative of a hardware upgrade which is not attractive to industry. Hence, both the XTS system costs and device upgrade costs will be largely fixed and not vary with the key benefit drivers, i.e. the IMT & Wi-Fi users benefitting from improved performance due to U6 GHz.

There is also an impact on mobile network costs in deploying 6 GHz. In line with the technical view on deployment, we assume that the 6 GHz layer can be delivered by upgrading existing base stations, and without deploying additional base stations. The base station upgrades are assumed to be phased in over 5 years. This cost is also fixed and largely independent of the key benefit drivers though there could be a linkage if MNOs decided initially to target U6 GHz deployments on areas where usage was most intense, delivering the highest benefit.

Table 2 below shows the cost parameters relating to base station upgrades as used in the model. We have included the cost of a new macro site to provide further context, though it is not used in the calculation.

Table 2. Cost parameters

Parameter	Capex (low)	Capex (high)	Opex % of Capex	Asset lifetime
Macro cell upgrade	20,000	28,000	10%	20 years
New macro site	52,000	99,000	10%	20 years

Sources [13]

Network element costs can vary significantly by area type in particular new site costs and site upgrades. In rural areas, costs are significantly greater than in urban areas due to the longer distances involved for connecting to the national power grid, transport and logistics. We use the higher bound estimate for rural areas, and the lower bound for urban and suburban to take account of this variation.

Economies of scale linked to an international rollout of cross-technology signalling could also impact on the direct costs. The level may depend on the extent to which use of this technology is coordinated internationally.

According to Ofcom's Connected Nations Report, there were 81,000 cell sites in the UK in 2024 [14]. We apportioned this total to geotypes based on an ONS report on the number of cell towers in the UK [15]. We took the number of cell towers per head of population for urban and non-urban areas from this report, applied it our respective data on population, then adjusted by the ratio of cell sites to cell towers. This leads to the following breakdown.

Table 3. Cell sites by geotype

Parameter	Urban	Suburban	Rural	UK total
Cell sites	14,029	55,904	11,068	81,000
Population	11,747,700	47,540,400	9,411,900	68,700,000

Sources – as in preceding paragraph and internal Real Wireless data on population split by geotype

2.3 Independently operated private networks in the upper n77 band (3.8-4.2 GHz)

This technology pair investigates whether private mobile networks could tolerate more interference than currently assumed under Ofcom's interference prediction model for Shared Access Licences without impacting service, thus enabling private networks to be deployed closer to each other. Implementation may require a database solution deployed at the regulator's premises to store data regularly.

The benefits of this technology pair arise from being able to deploy more private mobile networks within a given area compared to two counterfactuals, one each for to compare medium and low power scenarios:

- Base separation distances, assuming medium power and low power, using Ofcom interference to Noice (I/N) targets.

The field trials examine whether the sharing solution and less conservative assumptions on separation distances could be used to avoid interference and unacceptable levels of performance degradation (based on 20 Mbps level of service) – i.e. more private networks could be supported in a given area without compromising individual performance.

The WP2 simulations then provide results for the minimum allowed separation distance between two Private Mobile Networks (PMN)s for the following six scenarios which are compared against the respective counterfactual (medium or low power). These look at how separation distance varies as the threshold for acceptable interference, i.e. the proportion of customers affected, varies:

- Lower separation distance: medium power, informed by more accurate service impact measurements and assumed threshold for coverage degradation of 2%, 5% and 10% of a 20 Mbps service;
- Lower separation distance: low power, informed by more accurate service impact measurements and assumed threshold for coverage degradation of 2%, 5% and 10% of a 20 Mbps service.

Benefit assessment

We calculate the net benefit as the increase in the number of private mobile networks actually deployed (and projected to rise over time) multiplied by the average value added per private mobile network user.

- In the counterfactual, the maximum number of private networks that can be deployed in a particular area is derived from the separation distances from Ofcom's current interference prediction model.

- The factual scenarios evaluate the maximum number of private networks that would be permitted according to the new geographic separation distances estimated.
    - The radius of the resulting exclusion area for each PMN is the sum of: the radius of the PMN plus half the separation distance – see Figure 2 below;
    - The resulting exclusion area (assuming it forms a circle) divided into the area of the relevant geotype gives the maximum number of PMNs that can be allowed in that area.

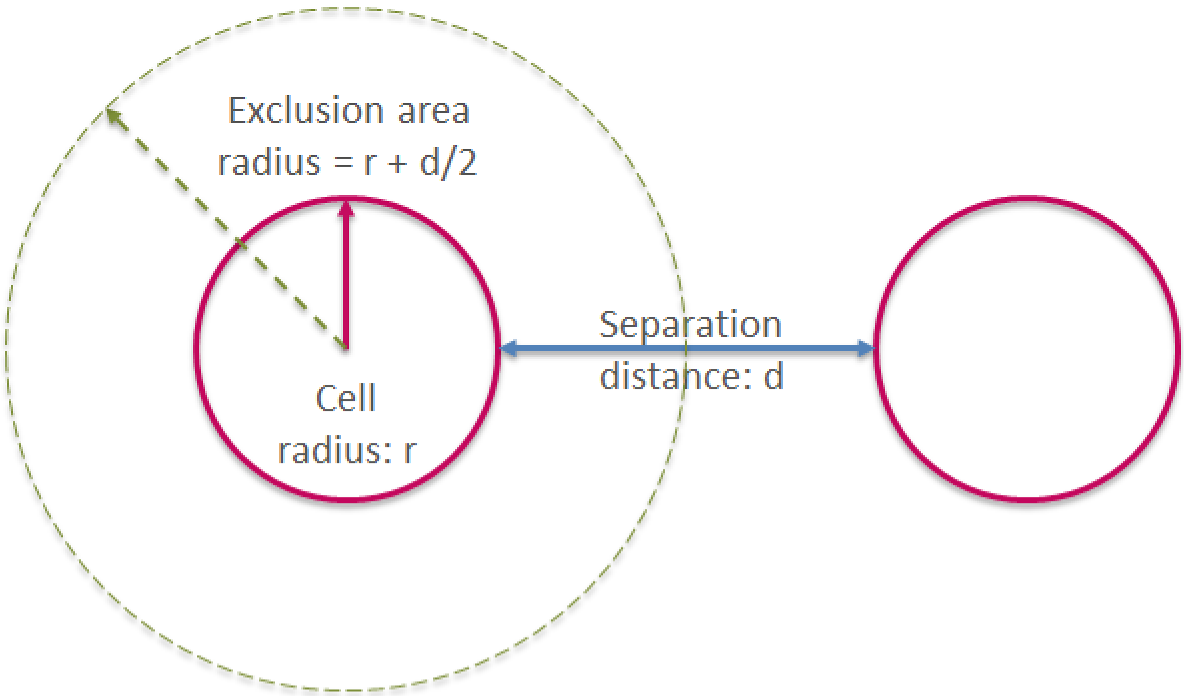

Figure 2 – Illustration of exclusion areas between private mobile networks

For each scenario, we estimate the likely number of additional PMNs that may be deployed given the increase in supply, i.e. the number permitted, due to the lower separation distance.

We have approached this in two ways, because the potential demand for additional PMNs that could arise from different approach es to sharing is fundamentally uncertain.

Approach 1. Our main approach is to assume that demand will expand to make use of the extra supply, but subject to two constraints.

- First, demand will rise over time in line with the rate of take-up of PMNs in the overall market.
- Secondly, over the time horizon of the model, the number of additional PMNs should be similar in magnitude to that the growth in PMNs implied by current market forecast data, i.e. assuming no change in current separation distances
    - We do this by applying a 10% constraint across each geotype so that the incremental increase in PMNs facilitated stays within this reasonableness constraint.

Approach 2 (sensitivity). Our second approach assumes that PMN demand will grow according to the predicted take-up we derive from third party market forecasts – Grandview Research [16] and Analysys Mason [17].

We assess whether the limitations implied by existing separation distances would constrain this demand and calculate the impact of lower separation distances on enabling this projected demand for PMNs to be met. Demand for PMNs is expressed as the penetration among medium and large enterprises, i.e. those with 50 or more employees using data UK government data [18].

Private value of additional PMNs. For both approaches, we calculate the value to the economy of the additional number of private mobile networks facilitated. As it is difficult to predict private mobile network use by type of businesses or use case, benefits are estimated as the average business value derived from the private mobile network.

We consider the most important source of private benefit from PMN use to be the potential increase in productivity delivered. We have looked at a variety of indicators of potential for productivity gains, though estimates differ significantly depending sometimes on context and source:

- Recent (2024) survey research by Nokia [19] suggests significant benefits – 75% of respondents reported productivity benefits of at least 10%;
- Vodafone's 5G Manufacturing Report (2021) suggested productivity gains in manufacturing of 1-3% from 5G [20].
- UK5G (2019) predicted initial productivity benefits for manufacturing of 1% based on information from its programme of 5G trials [21]
- Older research (2016) by PWC predicted efficiency savings of 4% from industry 4.0 applications and digitalisation [22];

These differing predictions can perhaps be reconciled in that higher estimates relate to early adopters who are likely to be those who most benefit from 5G and PMNs, whereas the lower benefits estimated for manufacturing may represent a more broadly based picture of the truer picture across the economy. As a result, we believe the medium term impact of PMNs is likely to be towards the bottom of the range of views expressed, 2%.

We note that it can be difficult to separate the effects of the private mobile network as opposed to related innovations such as process automation, digital twins, big data and AI/machine learning. We have therefore taken a cautious approach and assumed that only a fraction of these productivity increases relates to private mobile networks. EU research project 5G-NORMA [23], found evidence suggesting 10-15% of the total benefits from IoT and other advanced communications technologies could be attributed to communications itself. As a result we assume a productivity gain of 0.25% per PMN user. This figure is applied to data on the average turnover by business size class for the UK [24].

We also factor savings into our analysis the potential savings on overall mobile communications costs identified in the Nokia survey – PMN users reported savings of about 10% on overall mobile network costs. These cost savings are applied to data for average private mobile network spend from third party market assessments of the UK private mobile network market (Grandview Research and Analysys Mason).

Another benefit arises from the use of an automated system instead of a licence application process. Ofcom saves the administrative costs of assessing requests for licence access and spectrum users save the costs of applying for licences. This may also provide more of an incentive for innovation because it reduces the risk of incurring costs in the process for no benefit if an access/licence request is rejected.

Finally, we include a high level assessment of the potential social benefits that could arise. The 5G NORMA economic analysis found that social benefits in a selection of use cases including smart energy and connected vehicles could equal 20% of the private benefits estimated. We apply this figure to the productivity benefits estimated in this study.

Cost assessment

We estimate the capital expenditure and operating costs for each new PMN, based on the simulation analysis which assumes each network has 20 cell sites.

We also estimate the initial and ongoing costs of an automated database system and spectrum observatories to provide measurement data on spectrum use. We assumed that the number of spectrum observatories needed in the UK would rise from 30 to 50 over the period of the model. This was based on CEPT discussions of spectrum occupancy measurement stations, specifically relating to France and the Netherlands [25]. Although the data comes from 2014, we believe it is a good proxy for how the number that might be required in the UK and note the lack of more recent information in this area.

Table 4 below sets out the unit costs and lifetime assumptions for each of these cost elements.

Table 4. Cost parameters for private mobile networks (£)

Parameter	Capex (low)	Capex (high)	Opex % of Capex	Asset lifetime
Private mobile network cell	4,000	5,000	10%	-1%
Automated database	5,000	10,000	10%	0%
Spectrum observatory	5,000	10,000	10%	0%

Sources: Spectrum Observatories – CEPT Workshop on Spectrum Occupancy Measures, 2014; other – Real Wireless internal data from industry.

We note that part of the costs are variable, i.e. the cost of PMN cell sites, and hence linked to the key benefit driver of the number of additional PMNs facilitated by more intensive sharing. Automated database and spectrum observatory costs vary much less with the volume of new PMNs supported in our scenarios.

Further sensitivities

Our results rely on the potential increase in private mobile networks actually being taken up by the market – due to relaxing the current administratively imposed constraints. However, it may be the case that demand does not expand as much as potential supply. Hence, we will explore running a scenario to calculate what level of take-up would lead to a break even on the cost benefit analysis.

2.4 Other technology pairs

This section reports on how we could apply some of the principles and learnings from WP1 to additional technology pairs in other frequency bands. Note we did not conduct any field trials for these additional technology pairs therefore the limited technical analysis relies only on the outcomes of the simulation activities. We limit our assessment to applying learnings from the sandbox experiments to benefit from them. We selected 3 additional technology pairs for this assessment:

1. Mobile and satellite – Direct to device satellite in 2.6 GHz band
2. Mobile and airborne non-terrestrial network (NTN)

3. Mobile and fixed links in the upper 6 GHz band

The following sections provide a CBA conducted for the above 3 technology pairs.

2.4.1 Mobile and fixed links in the upper 6 GHz band (6425-7125 MHz)

This technology pair looks at the benefits of allowing mobile communications to operate in the upper 6 GHz band (to deliver additional mobile broadband capacity) alongside fixed links, the current incumbents, for which the primary uses are: mobile backhaul (particularly Scotland); financial services (mostly London); programme making and special events; and petrochemicals (mainly offshore).

The counterfactual is:

- Fixed links only.

In the factual scenarios, mobile services are allowed in the band. However, we assume that mobile base stations must maintain a certain separation distance from incumbent fixed links to protect them from interference. The scenarios, which we consider cover the most important policy choices, are as follows:

- IMT and fixed links operate in the band: no additional mitigation - Point to Point (PTP) fixed link illuminates directly IMT;
- IMT and fixed links operate in the band: no additional mitigation - PTP fixed link operates at 180 degrees to IMT.

Consistent with the analysis of the mobile Wi-Fi technology pair, we assume that MNOs will not deploy U6 GHz in rural areas since they are unlikely to be capacity constrained in these areas. If, as some industry stakeholders suggest, U6 GHz were a pioneer band for deploying 6G, this situation could evolve differently.

Benefit assessment

The private benefits to mobile broadband consumers are based on the increase in average throughput delivered by deployment of capacity in the upper 6 GHz band. The methodology is the same as for the mobile Wi-Fi technology pair, i.e. taking the historic increase in average download speed due to 3.4-3.8 GHz as a proxy for the increase for U6 GHz.

We then apply the same relationship for WTP and increases in mobile broadband average throughput, as set out in the section on the mobile and Wi-Fi technology pair above. We recognise that this is an approximation since users whose premise is in an exclusion zone may benefit from increased mobile performance when they are outside the exclusion zone, and vice versa. This gives a benefit per subscriber for all those areas where IMT can operate without harmful interference to the incumbent fixed links.

The WP2 simulations estimate the minimum separation distances (varying by geotype) between the mobile network and the fixed link end to protect fixed links under each scenario. In the CBA, we calculate the exclusion area as a circle whose radius is the separation distance and multiply by the total number of fixed link ends to get the total area from which IMT is excluded.

In its consultation on hybrid sharing in U6 GHz, Ofcom notes that there are 500 fixed links (1,000 link ends) in the band [**26**]. The consultation shows approximately 30 fixed links in the financial sector mostly around London. We take these as indicative of the number of fixed links in urban areas. We distribute the remaining fixed links between suburban and rural areas on the basis of their geographic area. This skews the distribution towards rural areas which we believe is appropriate given the largest category of links in the band – for communications networks and utilities – are more likely to be used in less densely populated areas where fixed connectivity alternatives are much more expensive.

The implicit assumption in our approach, that fixed links are randomly distributed, probably over estimates the exclusion area, since fixed links may overlap, particularly in more densely populated areas. With access to actual coordinates of fixed links, a better picture of the exclusion area could be calculated.

The final step is to calculate the number of mobile subscribers able to benefit from U6 GHz given the exclusion areas and multiply by the WTP for increased download speed.

Similar to the Mobile / Wi-Fi technology pair, the spectrum has an opportunity cost for mobile operators as by deploying in the upper 6 GHz band they avoid densifying their networks to increase capacity. Again, we base our estimate of this value on the price per MHz of 3.6GHz spectrum auctioned in the UK in 2023, with the same caveats as above.

Cost assessment

The main cost impact is the cost of the additional mobile network equipment needed for 6 GHz, which is largely a fixed cost centred on rolling out U6 GHz capacity to the cell sites outside exclusion zones. To estimate the additional mobile network costs, we take information on the number of site upgrades required in each of our three geographic area types in the areas outside the exclusion zones (pro rata to the geographic area of the whole geotype). We will use the same unit equipment costs and related data as set out before for the mobile and Wi-Fi technology pair.

We note that, since we assume in all scenarios that fixed links are protected, so that there is no material impact on their performance, no direct costs are imposed on fixed link users.

2.4.2 Mobile and satellite: direct to device satellite in mobile bands (i.e. in the 2600 MHz band) / Mobile and airborne NTN: airborne base stations in mobile bands (i.e. in the 2600 MHz band)

As the methodology for these two technology pairs is very similar, we set out only a common methodology and set out the limited occasions when there are differences e.g. in parameters and some assumptions.

The benefits from these technology pairs are expected to arise from the ability to provide a coverage in-fill service to notspots, areas that are not currently covered by mobile networks, through direct to device satellite (D2D) or airborne NTN technology (High Altitude Platforms for IMT Base Stations (HIBS)).

This use case would be complimentary to existing mobile services as opposed to competing. The most likely business model would be for mobile operators to offer a combined service to the end user with the NTN provider supplying wholesale connectivity. Since the NTN service would operate in an existing mobile band, end user devices would not need to be updated to use the service.

The counterfactual is:

- Mobile only continues to operate in the 2.6 GHz band.

In the factual scenario(s), D2D satellite/airborne NTN service providers are able to use the band to provide direct to device connectivity to mobile handsets in areas where mobile networks are not transmitting or where NTN could deliver superior connectivity. We assess the following scenario quantitatively:

- Both mobile and satellite operate in the band, but satellite is rural only.

Two further scenarios are assessed qualitatively:

- Elevation angle over which interference from the NTN D2D service impacts the IMT performance;
- Lower separation distances: informed by more accurate service impact measurements.

Benefits assessment

The WP2 simulations identify the separation distances that would need to be in place for mobile and NTN to share the band according to Ofcom I/N interference targets. The results show significant separation distances, particularly for satellite.

Table 5. Separation distances (km) with Ofcom I/N interference targets

Area Type	Satellite	HIBS
Urban	377.3	269.6
Suburban	287.6	180.7
Rural	287.3	179.7

The implications are that shared operation is only likely in rural areas given the scale of the separation distances. Hence, we only quantify the scenario where satellite is restricted to rural areas. In particular, the notspot areas which we expect this use case to address should be significantly far away in remote and rural areas.

The WP2 simulations identify the proportion of active mobile users in the simulated IMT network who would be served by an NTN in-fill service when coverage quality is greater than the IMT network and this is multiplied by the proportion of premises in notspot areas. The table below shows our assumptions for the number of mobile subscribers in notspot areas by geotype based on [27].

Table 6. Notspot coverage in the UK

Area Type	Premises not covered by any operator
Urban	0.5%
Suburban	0.5%
Rural	5%

We apply the result to the number of mobile subscribers across the geotype to calculate the addressable market. Take-up is assumed to follow a similar path to 4G take-up [28].

Finally, the number of coverage in-fill customers is multiplied by an estimate of the WTP for enhanced coverage. This is based on a study by RAND Europe for DEFRA [29] which estimated the amount of consumers that would be willing to pay (in addition to any existing mobile subscription) to have mobile coverage in a not spot area. Although such consumers live in a notspot area, a large majority have a mobile subscription nonetheless because of the value of coverage in adjacent areas, e.g. for work, emergencies etc. We express the willingness to pay as a percentage of the ARPU at the time of the study and apply it current mobile ARPU. The NTN in-fill service may cover not spots and areas where IMT coverage is poor, hence we have reduced the WTP by 50% to account for this.

Although the RAND Europe study is not recent, it is one of the few that attempts to estimate the incremental benefits to consumers from increases in coverage/reduction in not-spots. We believe it is appropriate to use it as a proxy for access to the contemporary mix of mobile services since mobile ARPU has not changed significantly since then, though it has declined.

Cost assessment

The WP2 simulations assume that sharing between NTN and IMT is managed so that it does not cause unacceptable levels of performance degradation to the IMT service. Hence, we do not calculate the costs of interference from the NTN D2D service to the mobile network.

For satellite NTN, we estimate the cost of the carrying the coverage in-fill traffic. We base this on Euroconsult analysis of the (monthly) cost per GB of providing connectivity in Europe of LEO networks [**30**] and apply it to the average data traffic per mobile subscriber reported in Ofcom's Communications Market Report 2024 (updated to the model start year).

The costs of HIBS are expected to be significantly less than LEO systems, however it has not been possible to find comparable information. Therefore, for HIBS we report only the benefits but note that, if costs are a fraction of those for LEOs, the impact on the overall net benefit will be limited.

3. Results

This section presents the results of our cost benefit analysis of the scenarios and of the sensitivities of technical options and other factors. We report our results for the net benefits of each scenario in terms of the net present value (NPV) for a 20 year period, using a social discount rate of 3.5%, as specified in HM Treasury Green Book [**31**]. We also modelled 30 year NPVs, though we consider a 20 year time horizon is most relevant to our analysis given that the longest equipment lifetime in the model – for IMT base station upgrades – is 20 years.

3.1 Wi-Fi and mobile in the upper 6 GHz band (6425-7125 MHz)

The results of our high level cost benefit analysis are presented as net present values calculated across a 20 year period. They assume that upper 6 GHz starts being exploited for Wi-Fi and mobile from 2026.

3.1.1 Input parameters.

Table 7 shows the inputs that were provided from the WP2 simulations on the various sharing scenarios and for dense urban and suburban areas. The key input data were:

- Throughput per active mobile user;
- Reference throughput for IMT only;
- Active Wi-Fi users;
- Total Wi-Fi users.

XTS source device	IMT XTS BS beam choice	IMT scenario	IMT BS EIRP [dBm/100MHz]	Size of simulated area [kmsq]	IMT BS sector density [sectors/kmsq]	Active mobile users [num]	Throughput per active mobile user (average) [Mbps]	Reference throughput (IMT-only) [Mbps]	Tput Degradation for IMT [%]	Wi-Fi RX scenario	Wi-Fi AP location	Wi-Fi users [Num]	Active Wi-Fi users (average) [num]	Wi-Fi active user percentage	
UE	N.A.	DL	58	3.33	17.12	57	280.8	281.1	0.1	Omni	Colocated	57	0	0	Dense urban
UE	N.A.	DL	65	3.33	17.12	57	339.5	339.8	0.1	Omni	Colocated	57	0	0	
UE	N.A.	DL	73	3.33	17.12	57	381.3	381.6	0.1	Omni	Colocated	57	0	0	
UE	N.A.	DL	83	3.33	17.12	57	408.4	408.6	0.1	Omni	Colocated	57	0	0	
UE	N.A.	DL	58	3.33	17.12	57	274.9	276.3	0.5	Omni	Random	57	51	89.5	
UE	N.A.	DL	65	3.33	17.12	57	334	334.7	0.2	Omni	Random	57	51	89.5	
UE	N.A.	DL	73	3.33	17.12	57	376.7	377.4	0.2	Omni	Random	57	51	89.5	
UE	N.A.	DL	83	3.33	17.12	57	406.6	406.9	0.1	Omni	Random	57	51	89.5	
BS	Broadcast	UL	58	3.33	17.12	57	32.9	34.4	4.4	Omni	Random	57	20	35.1	
BS	Broadcast	UL	58	3.33	17.12	57	29.9	34.3	12.9	Omni	Colocated	57	21	36.8	
BS	Broadcast	UL	65	3.33	17.12	57	33.3	34.4	3.3	Omni	Random	57	14	24.6	
BS	Broadcast	UL	65	3.33	17.12	57	31.2	34.3	8.9	Omni	Colocated	57	15	26.3	
BS	Broadcast	UL	73	3.33	17.12	57	33.4	34.4	3.1	Omni	Random	57	9	15.8	
BS	Broadcast	UL	73	3.33	17.12	57	31.8	34.3	7.4	Omni	Colocated	57	10	17.5	
BS	Broadcast	UL	83	3.33	17.12	57	33.4	34.4	3	Omni	Random	57	5	8.8	
BS	Broadcast	UL	83	3.33	17.12	57	31.8	34.3	7.2	Omni	Colocated	57	7	12.3	
UE	N.A.	DL	58	13.33	4.28	57	113.3	113.3	0.1	Omni	Colocated	57	0	0	Suburban
UE	N.A.	DL	65	13.33	4.28	57	201.2	201.3	0	Omni	Colocated	57	0	0	
UE	N.A.	DL	73	13.33	4.28	57	283.7	283.7	0	Omni	Colocated	57	0	0	
UE	N.A.	DL	83	13.33	4.28	57	346.4	346.4	0	Omni	Colocated	57	0	0	
UE	N.A.	DL	58	13.33	4.28	57	114.5	115.2	0.5	Omni	Random	57	55	96.5	
UE	N.A.	DL	65	13.33	4.28	57	203.4	203.8	0.2	Omni	Random	57	55	96.5	
UE	N.A.	DL	73	13.33	4.28	57	286.5	287	0.2	Omni	Random	57	55	96.5	
UE	N.A.	DL	83	13.33	4.28	57	346.5	346.8	0.1	Omni	Random	57	55	96.5	
BS	Broadcast	UL	58	13.33	4.28	57	17.3	17.6	1.4	Omni	Random	57	34	59.6	
BS	Broadcast	UL	58	13.33	4.28	57	15.8	17.4	9.1	Omni	Colocated	57	33	57.9	
BS	Broadcast	UL	65	13.33	4.28	57	17.5	17.6	0.6	Omni	Random	57	25	43.9	
BS	Broadcast	UL	65	13.33	4.28	57	16.7	17.4	4.4	Omni	Colocated	57	24	42.1	
BS	Broadcast	UL	73	13.33	4.28	57	17.5	17.6	0.4	Omni	Random	57	16	28.1	
BS	Broadcast	UL	73	13.33	4.28	57	16.9	17.4	3	Omni	Colocated	57	16	28.1	
BS	Broadcast	UL	83	13.33	4.28	57	17.5	17.6	0.3	Omni	Random	57	9	15.8	
BS	Broadcast	UL	83	13.33	4.28	57	16.9	17.4	2.7	Omni	Colocated	57	9	15.8	

Table 7. Input parameters and descriptions from simulation for Urban and Suburban environments

3.1.2 Total Urban Areas

The charts below display the NPV results for urban areas scaled up using the dense urban results for omni-directional Wi-Fi Rx gain and the random Wi-Fi Access Point (AP) location assumptions. We reiterate that the focus of our analysis is the incremental impact of sharing compared to the counterfactual of single use and that we have carried out a high level, top down analysis extrapolating the results of the simulations to the total urban areas (and similarly for the subsequent results for total suburban areas).

In terms of the input parameters on IMT throughput and the proportion of Wi-Fi APs that vacate in the XTS sharing scenarios, we take the worst cases out of the downlink and uplink results from the simulations.

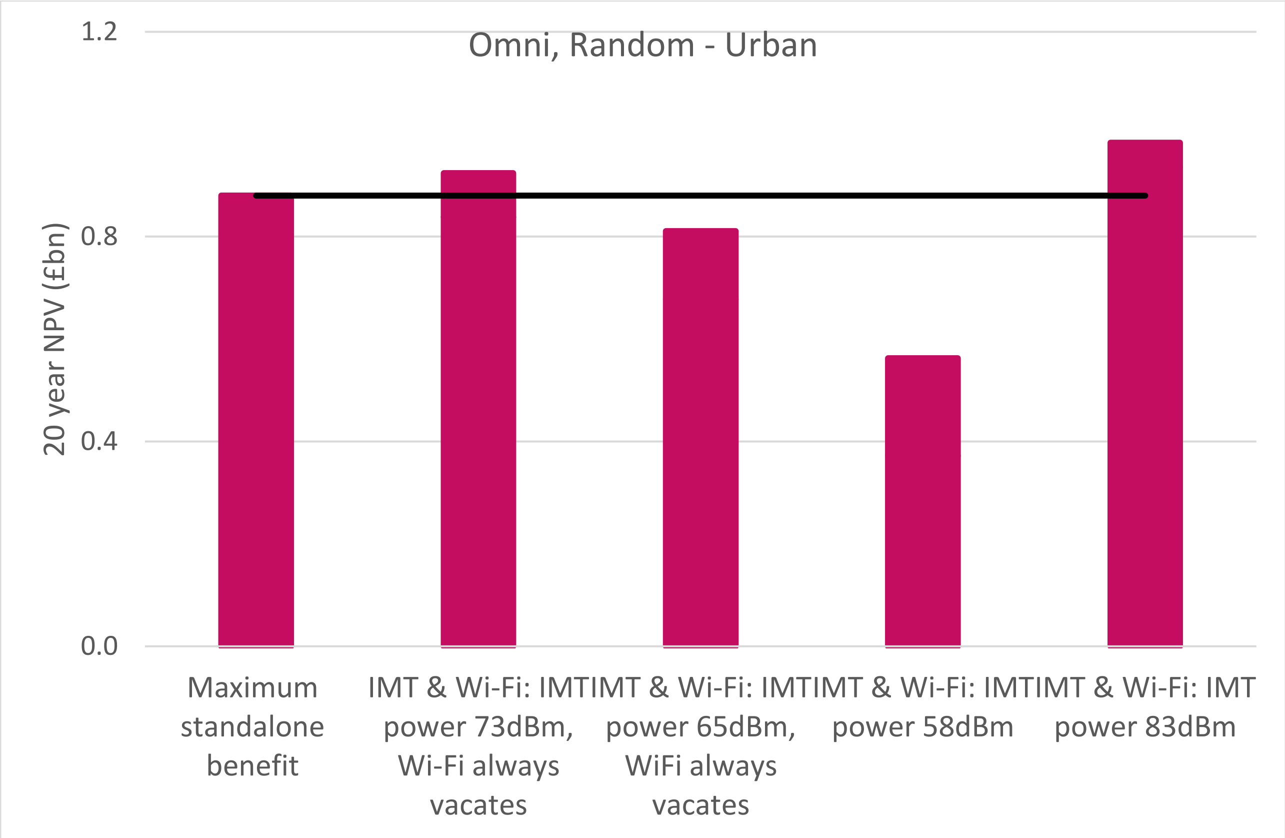

Figure 3-1. 20 year NPV - Omni, Random – Urban

Note that figures are rounded to the nearest £100 million, in accordance with the high level nature of the results, and this may result in minor discrepancies when calculating the incremental net benefits from sharing compared to single use.

3.1.3 Total Suburban Areas

The charts below display the NPV results for urban areas scaled up using the suburban results for omni-directional Wi-Fi receiver gain and the random Wi-Fi AP location assumptions.

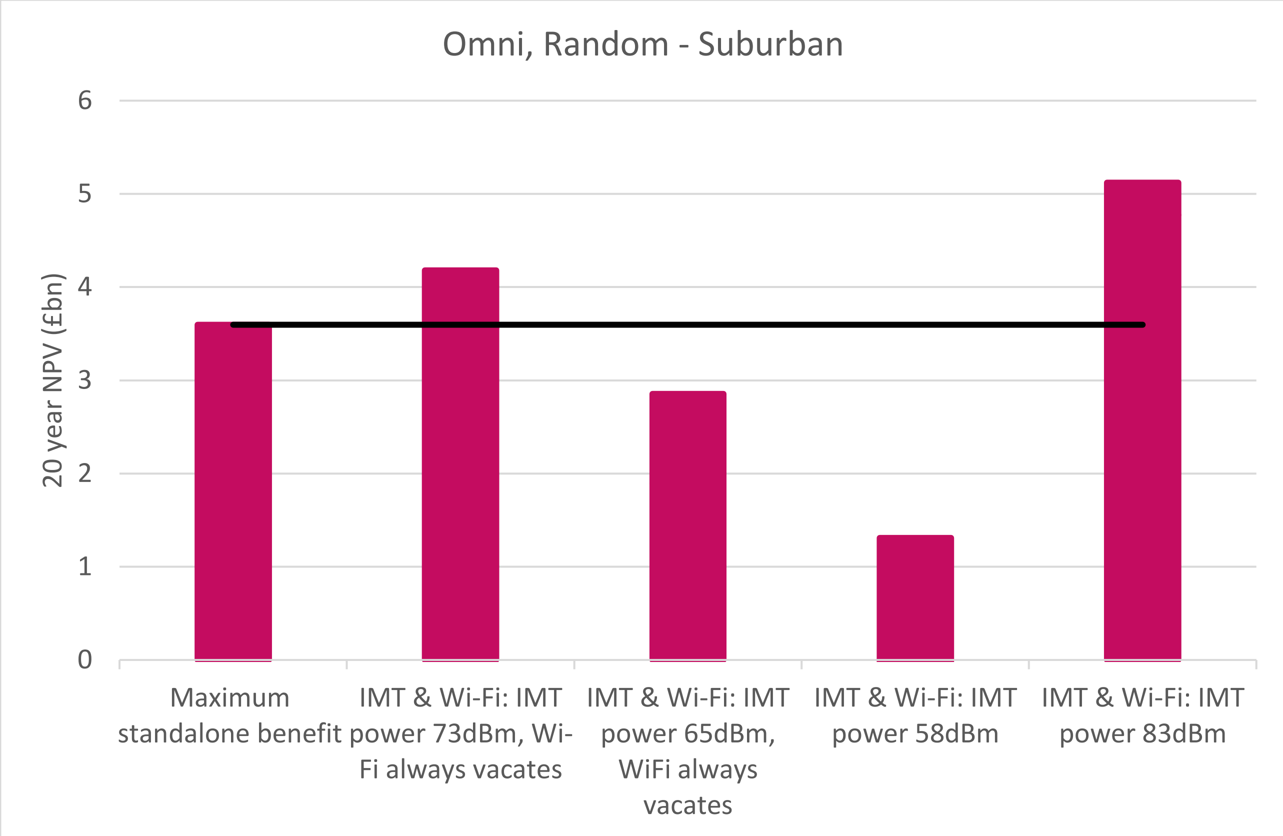

Figure 3-2. 20 year NPV - Omni, Random – Suburban

The key messages from our results are as follows.

- First, in our base sharing case with an EIRP of 73 dBm, there is an incremental benefit from sharing compared to either of the counterfactuals, IMT only and Wi-Fi only. However, the incremental benefit is relatively modest (5%) for the urban area but larger (16%) for the suburban area.
  - Note, there is a small reduction in the IMT component of the net benefits due to a small reduction in IMT throughput even though the proportion of Wi-Fi APs that vacate the channel is high;
- Increasing IMT power leads to a higher overall net benefit, whereas lower IMT power gives a lower net benefit overall. Although, Wi-Fi benefits more when IMT power is reduced – because fewer Wi-Fi APs vacate the channel under the XTS system, lower power reduces average IMT throughput which reduces the benefit for IMT.
  - Note that the costs for upgrading IMT to U6 GHz almost equal the benefits in the suburban case at 58dBm.
- The IMT net benefit is significantly higher than the corresponding Wi-Fi net benefit in each sharing scenario. This is due to the large proportion of Wi-Fi APs vacating the channel under XTS.
- The relative impact on IMT vs. Wi-Fi users is more balanced in suburban than urban areas the lower density reduces the potential for IMT UEs or Wi-Fi APs affecting the other's performance.

3.1.4 Sensitivity Analysis

- Our base assumptions is that Wi-Fi APs are located randomly with respect to IMT User Equipment (UE). However, this may not hold true in all locations, particularly the higher the density of users.
- Hence we carry out a sensitivity analysis to assess the corner case where the Wi-Fi AP is collocated with the UE.
- If XTS is UE based, the end result is that 100% of the Wi-Fi APs vacate the channel and there is no benefit to Wi-Fi based on sharing. Hence, we do not estimate economic benefits on this basis, i.e. using downlink parameters because it is only driven by IMT.

In contrast, if XTS is deployed at the IMT base stations, some Wi-Fi does not vacate under the Collocated assumption. We based our sensitivity on this case, i.e. taking the uplink parameters for the impact on IMT throughput and Wi-Fi APs. It is important to remember that this is a partial view, because the consumer experience depends on both downlink and uplink performance. However, we believe it offers a useful comparison to the Random case.

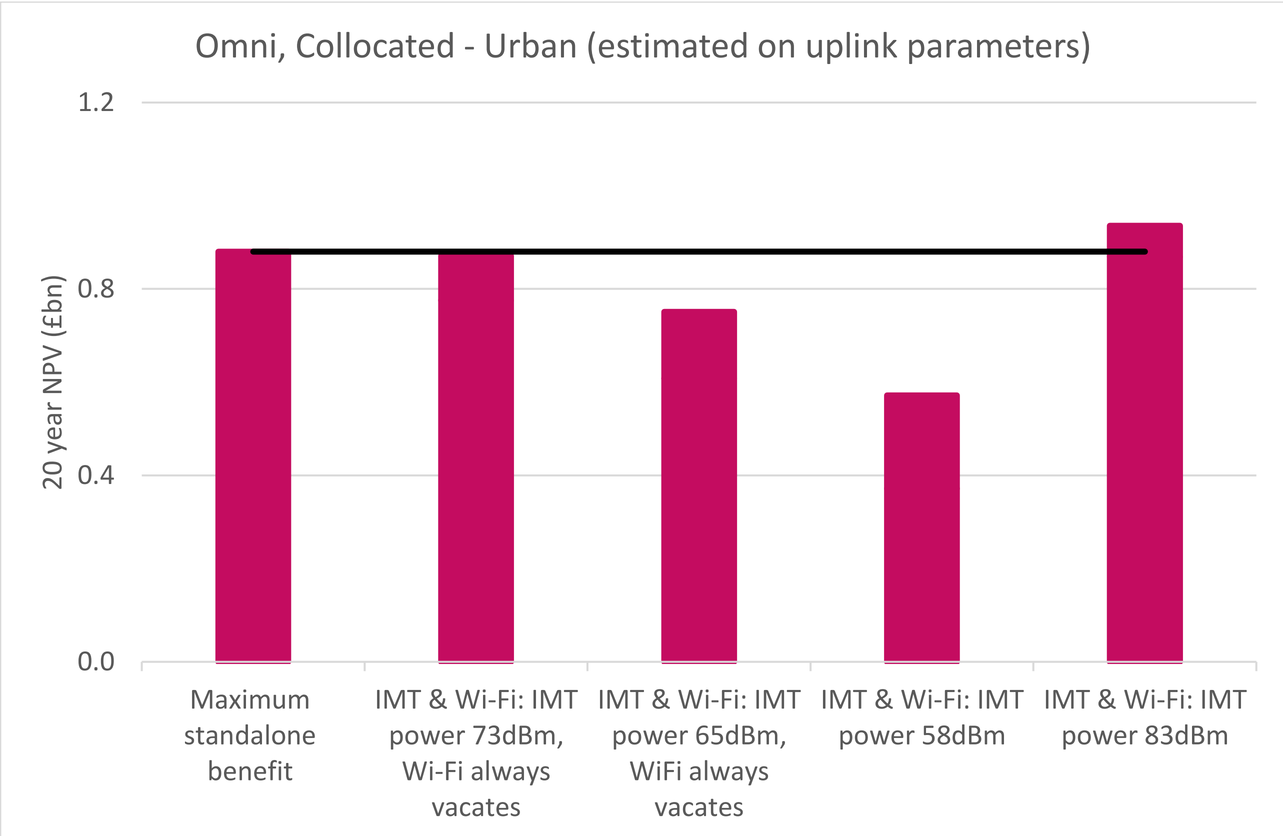

Figure 3-3. 20 year NPV - Omni, Collocated – Urban (estimated on uplink parameters)

- The pattern of results for this partial view of the Collocated case is similar to the Random case with some minor differences:

    - The contribution from Wi-Fi is similar, however that from IMT is smaller than the Random case.;
    - Overall, the sharing scenarios perform relatively worse compared to IMT only in this Collocated example compared to Random;
- Overall, net benefits in the sharing scenarios are roughly 6% lower compared to the Random location case – for 73dBm:
    - This is because the reduction in uplink IMT throughput is higher in Collocated (7.3%) than Random (2.9%) – for 73dBm.

3.1.5 The opportunity cost of operators of access to additional spectrum

As stated in the previous section, we were unable to assess directly the cost savings from access to U6 GHz spectrum to mobile operators since we did not have data on the impact of a lack of spectrum on networks without U6 GHz. In addition, we believe the ability of MNOs to densify their networks will be highly constrained in dense urban areas and would not be relevant for that geotype. However, the 2023 auction of 3.6-3.8 GHz spectrum in the UK provides a good comparator of the value per MHz of U6 GHz spectrum, though it is not an exact measure of the hypothetical avoided cost of densification for the reasons also discussed above.

Together three MNOs paid £512 million for 120 MHz of spectrum in the 3.6-3.8 GHz band in the auction [32]. Applying the average price recorded in the auction of £4.27 million per MHz to the 700 MHz available in U6 GHz suggests that operators could receive a hypothetical benefit of up to £2.99bn from avoiding the need to densify their networks. Hence, total net benefits would increase across the board significantly for all our scenarios except for Wi-Fi only.

3.1.6 Further context on our analysis

The principal question we investigate is the incremental benefits of sharing over 20 years. Over this long period, we can assume both technologies will have wider deployments. The outcome may vary depending on the starting year and the adoption rate. There may also be some differences in the deployment areas. For instance, mobile deployments may not reach 100% in sub-urban areas; however, MNOs would like to have the flexibility of deploying the technology and the carriers where they need, i.e. congestion relief. This may vary from MNO to MNO. Other bands could also add capacity for mobile. However, the use of other bands depends on the growth of traffic and developments in end-user applications which are uncertain, and on equipment cost/availability. These variations are difficult to specify and are subjective to the service provider. For these reasons, we focused our analysis on the principal question i.e. can these two technologies share spectrum in the same geographical area in the same channel?

3.2 Independently operated private networks in the upper n77 band (3.8-4.2 GHz)

3.2.1 Input parameters

The table below shows the main input data from the simulations for each sharing scenario and the medium and low power counterfactuals. We also used the simulation data for the area of the PMN modelled – 5.764 km^2 – and the number of base stations per PMN – 20.

Scenarios	Medium power: separation distances, km			Low power: separation distances, km		
Scenario description	Urban	Suburban	Rural	Urban	Suburban	Rural

SI/N target [Ofcom] (counterfactual)	3.85	4.2	5.8	1.55	1.65	3.5
2% coverage degradation of the 20 Mbps service	1.3	1.23	1.17	1.3	1.23	1.17
5% coverage degradation of the 20 Mbps service	0.68	0.64	0.68	0.68	0.64	0.68
10% coverage degradation of the 20 Mbps service	0.28	0.27	0.31	0.28	0.27	0.31

Table 8. Input parameters – separation distances - from simulations for simulated environments

3.2.2 Total Urban Areas

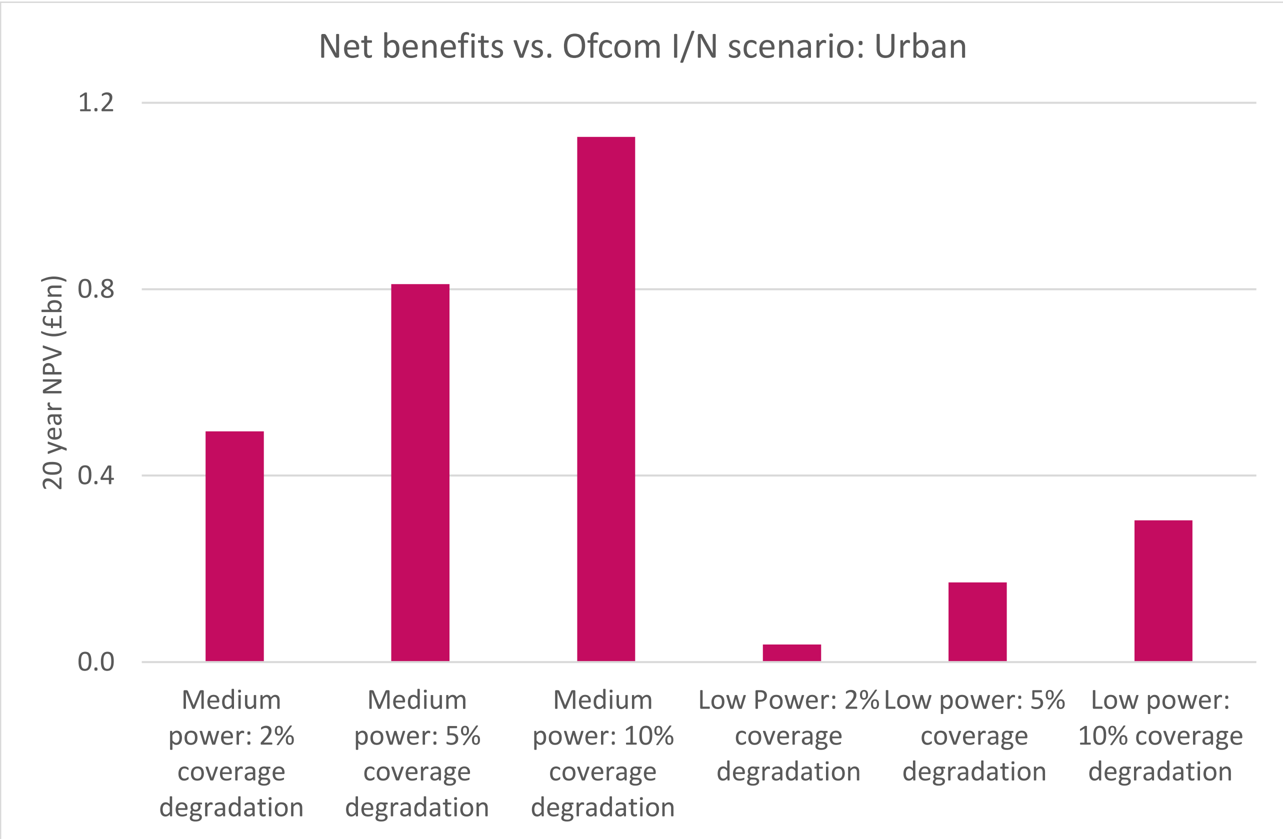

Figure 3-4. 20 year NPV - Urban (assuming additional PMN demand)

As expected, the results shows that net benefits increase as the allowed level of interference (percentage coverage degradation of a 20Mbps service) increases. In practice, we would expect the increases to tail off a little as more users of the PMN are affected by interference, but the information necessary to estimate this was not available from the simulation.

The net benefit for medium power is significantly higher than for low power – remembering that medium (low) power scenarios are compared to separation distances with the medium (low) power Ofcom I/N target respectively.

There will be further downside for low power on the cost side as we did not have the necessary information to model cases where substantially more base stations will be necessary for a PMN at lower power. The simulations assumed that each PMN covered an area just under 6 km^2, with 20 base stations and we modelled this cost. However, in some areas, where the lower range of low power signals actually has an impact on coverage, this assumption will not apply.

3.2.3 Total Suburban and Rural Areas

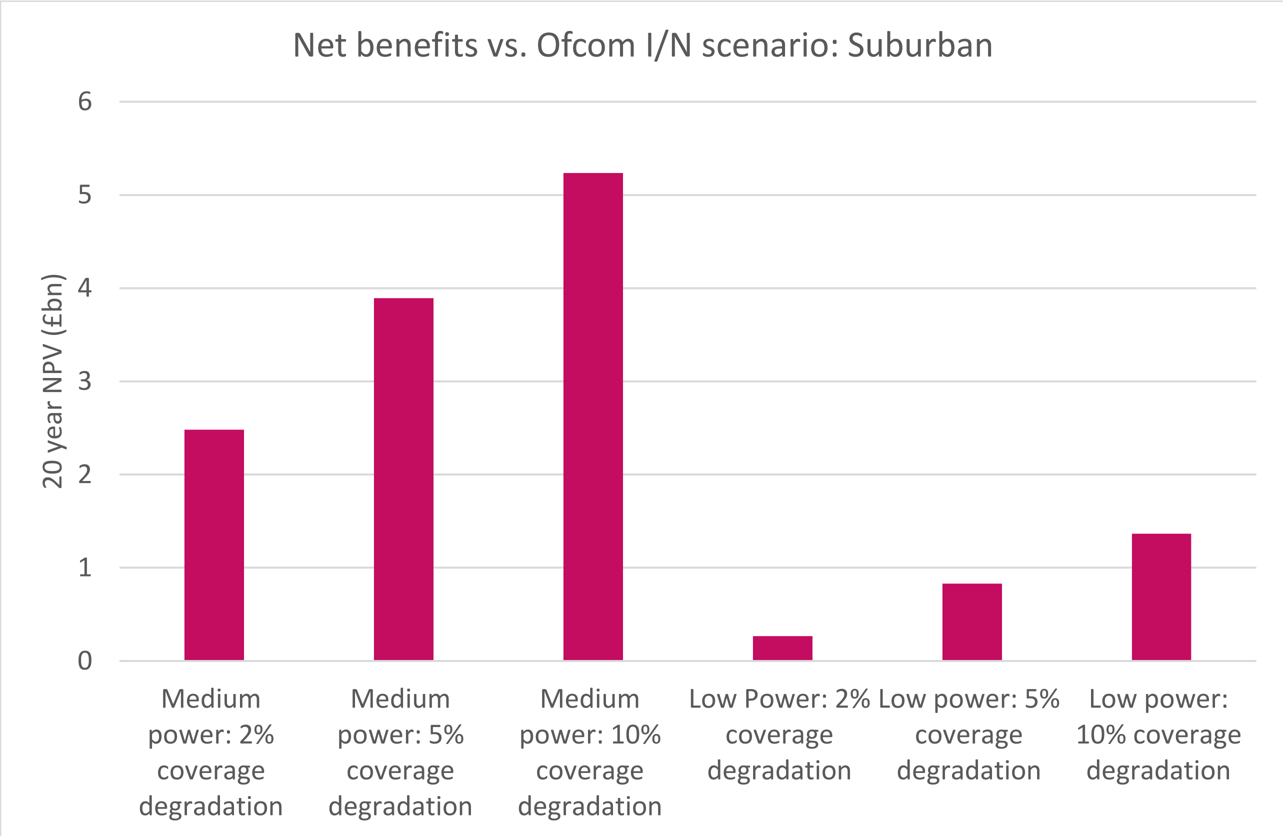

Figure 3-5. 20 year NPV - Suburban (assuming additional PMN demand)

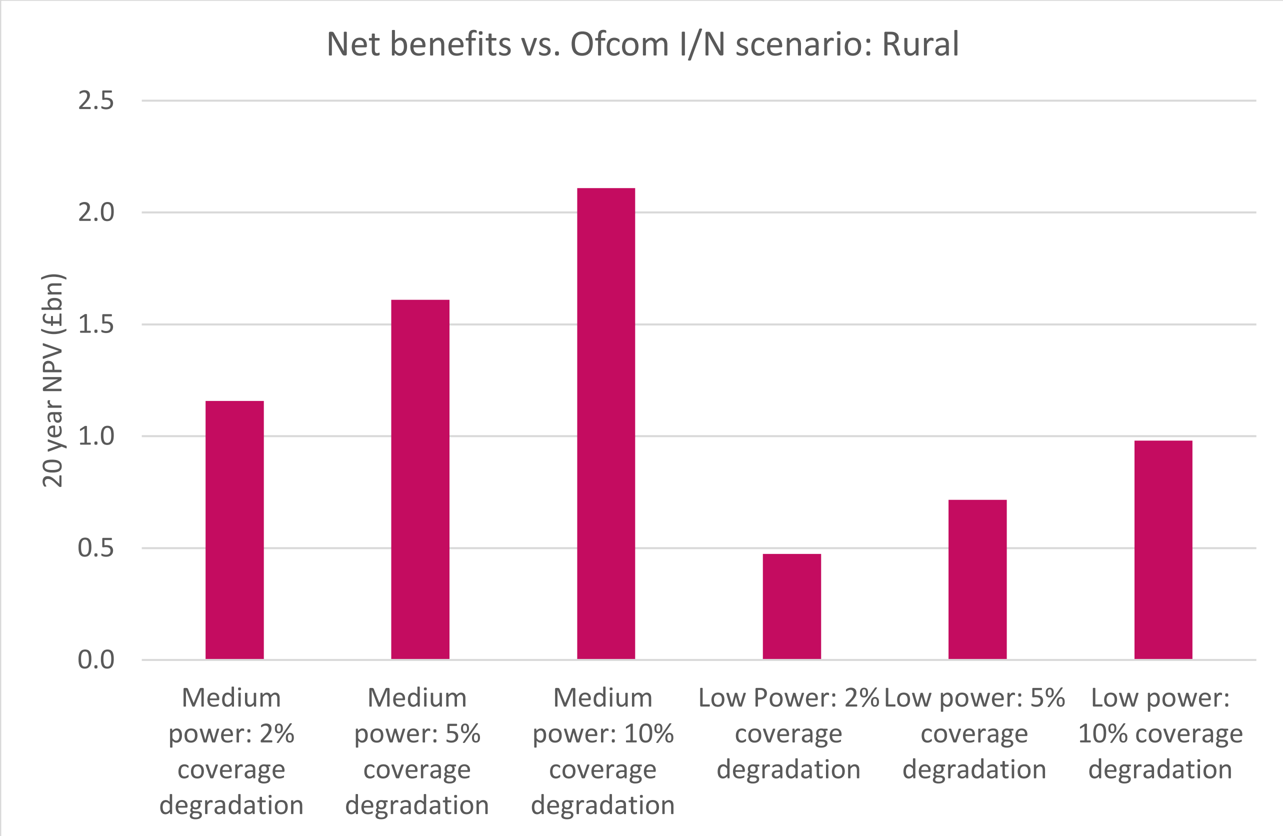

Figure 3-6. 20 year NPV - Rural (assuming additional PMN demand)

The results in suburban and rural areas follow the same pattern as for urban areas with some exceptions:

- The net benefits are higher in suburban areas reflecting the greater number of potential PMN users (or addressable market) compared to urban areas;
- In the rural area, net benefits for the low power scenarios are more significant relative to medium power than in urban and suburban areas. This reflects the fact that separation distances for the counterfactual for low power using Ofcom I/N targets is more than twice as high as for the other two areas. In contrast, separation distances for the sharing scenarios in rural are much closer to those for urban and suburban. Hence, the benefits for low power in rural are proportionately larger.

We note that the number of PMNs permitted in rural areas, even under the Ofcom I/N targets, is large relative to the number of medium and large businesses in rural areas. In other words, the density of businesses in rural areas is much lower. This raises the question of whether the current approach to separation distances in rural areas would actually be a constraint on demand. We look at this – across all area types – in the sensitivity analysis in the next section.

3.2.4 Sensitivity tests: demand for PMNs is limited to our current market projection

Our analysis shows that if demand for PMNs were limited to our market growth forecasts, the number of PMNs that can be accommodated under the existing separation distances (based on Ofcom I/N targets) is large enough that it never constrains our demand forecast for rural PMNs. Put differently, reducing separation distances in rural areas on the basis of more accurate measurements is not needed to accommodate demand under this assumption. This is also true if we increase the implied saturation level in our market growth forecast by 50%.

In urban and suburban areas, the picture is different and we present the results below.

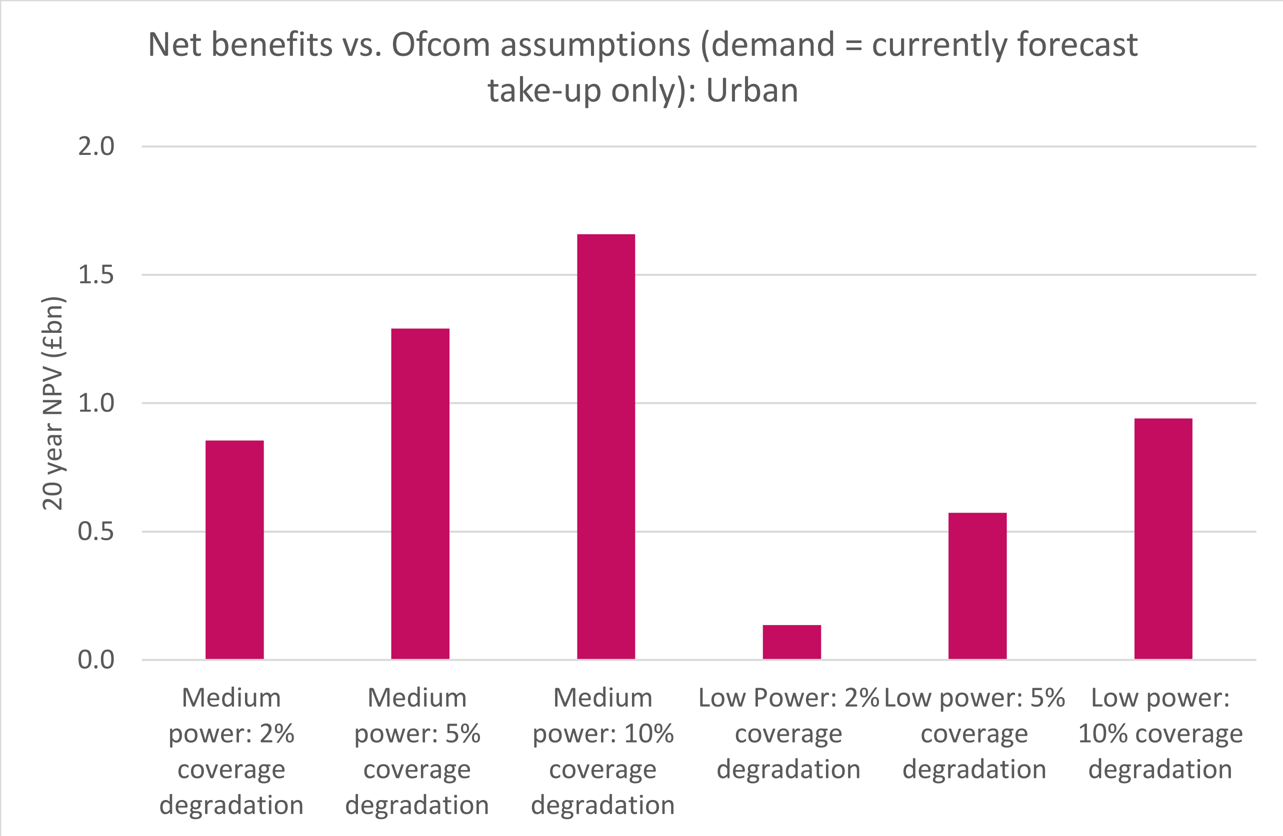

Figure 3-7. 20 year NPV - Urban (demand constrained to current forecast take-up)

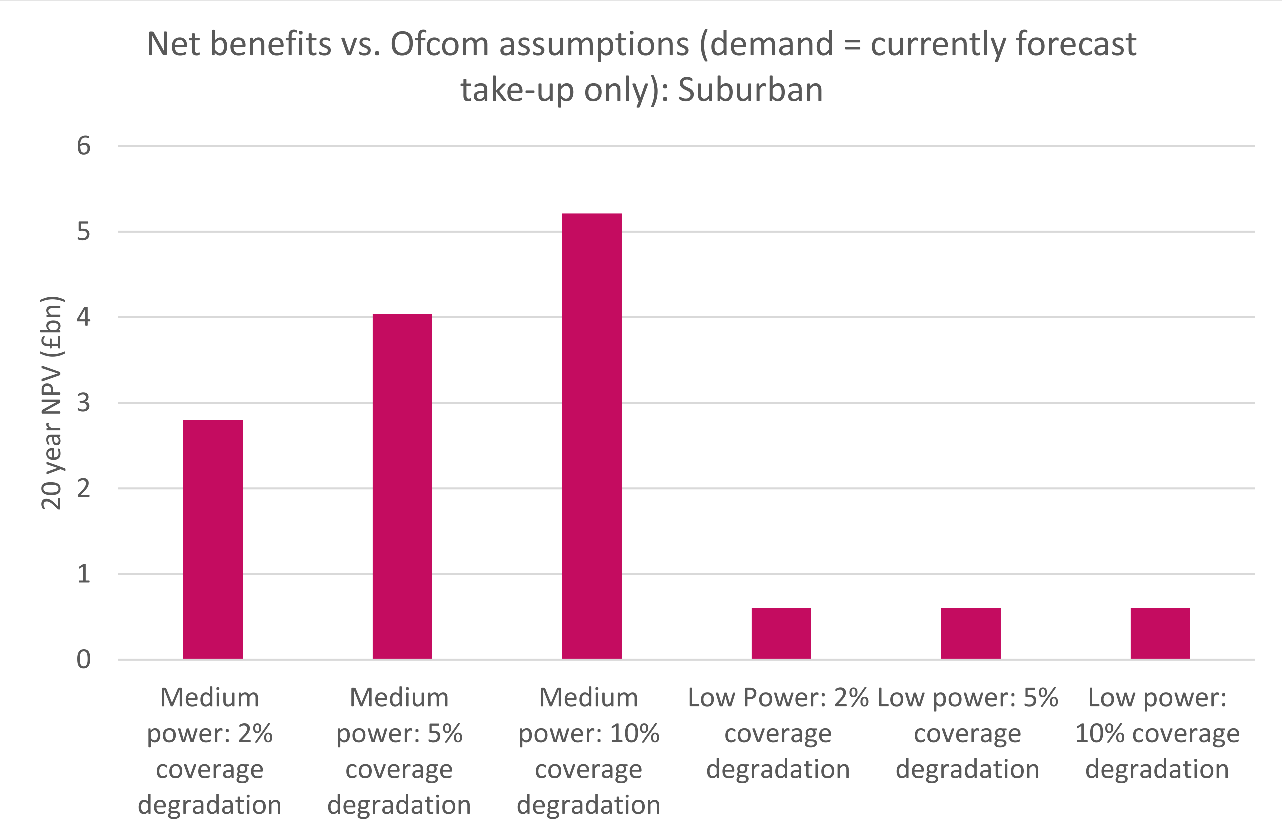

Figure 3-8. 20 year NPV - Suburban (demand constrained to current forecast take-up)

In urban areas, we can see that the current approach to separation distances would be a constraint even where demand is limited to our current market growth forecast, as would be expected given the high density of businesses. Otherwise, the net benefits are similar to the main set of scenarios, though low power is relatively more significant suggested that there is more of a constraint under low power to accommodate existing projections of demand.

In suburban areas, the main difference is that once separation distances are relaxed under the 2% performance degradation threshold, moving to a less strict threshold is not necessary to accommodate current projections of market growth.

3.3 Other technology pairs

3.3.1 Mobile and fixed links in the upper 6 GHz band

Input parameters

The following table shows the separation distances we input into the CBA model from the WP2 simulations.

Table 9. Separation distances (km) per scenario

	PTP Azimuth towards IMT network	PTP Azimuth away from IMT network

Urban	67.5	0.46
Suburban	69.0	0.32

20 year NPV, Urban, Suburban and Rural Areas

The table below shows the **sizeable net benefit that could arise from allowing IMT to share with fixed links** with exclusion zones to protect existing fixed link deployments. This depends critically on whether the azimuth of the fixed link is oriented towards or away from the IMT network. If the former, the required separation distances to avoid unacceptable interference to the PTP link is so much higher that it would not be possible to deploy IMT base stations, if the fixed links were randomly distributed.

These figures are likely to be a substantial underestimate as exclusion zones for fixed links would not be randomly distributed and would overlap more, particularly in urban areas. This is an area where further analysis with data on actual fixed link deployments would be useful.

Table 10. Total Net Benefits vs the counterfactual – 20 year NPV – £bn

	PTP Azimuth towards IMT network	PTP Azimuth away from IMT network
Urban	0	1.02
Suburban	0	4.29

In addition, and as with the mobile Wi-Fi technology pair, operators could receive a benefit because access to the U6 GHz band may enable them to avoid additional network expansion. As before, based on the prices achieved in the 3.6-3.8 GHz auction, operators could receive a hypothetical benefit of up to £2.99bn.

3.3.2 Mobile and NTN: direct to device satellite and airborne base stations (HIBS) in mobile bands (i.e. in the 2600 MHz band)

Input parameters

The table below shows the inputs derived from the WP2 simulations on the number of active mobile UEs supported by the NTN platform.

Table 11. Separation distances (km) with Ofcom I/N interference targets

	Satellite	HIBS
Active users on the NTN platform (average)	28	40

Total Benefit, IMT and Satellite share in Rural Areas

Our results show that **there is a significant positive benefit from allowing satellite and IMT to share in rural areas**, though smaller in relation to other technology pairs.

The costs of Low Earth Orbit (LEO) satellite data transmission, assuming that rises in data use are offset by falling cost per GB of transmission, are 12.5% of the benefits, thus have a substantial impact on the overall NPV.

Table 12. Total net benefit satellite coverage in-fill (£ million)

Results	20 year Net Present Value
Benefits	160
Costs	20
Total NPV	140

Total Benefit, IMT and HIBS share in Rural Areas

The benefits for HIBS are slightly higher than for LEO satellite and directly reflect the greater number of active IMT users that could receive better performance by being carried on the HIBS platform.

If the costs of HIBS data transmission were known, the NPV would reduce, however the impact should be significantly lower than for LEO satellite because HIBS costs including launch costs and payload costs are expected to be much lower than for satellite.

Table 13. Total net benefit HIBS coverage in-fill (£ million)

Results	20 year Net Present Value
Benefits	220
Costs	n/a
Total NPV	220

4. Implications of our evidence for future policy development and regulation

4.1 Wi-Fi and mobile in the upper 6 GHz band (6425-7125 MHz)

The question we have examined in our economic analysis is whether sharing the U6 GHz band between mobile and Wi-Fi, facilitated by cross technology signalling, will lead to a larger benefit than assigning the band to either mobile or Wi-Fi only.

The study found that the benefits of sharing between mobile and Wi-Fi were greater than not sharing for standard IMT power and higher power deployments. The benefits are proportionately greater for IMT than Wi-Fi, particularly with higher IMT transmit powers. Note that we only considered consumer use cases for Wi-Fi and mobile and did not consider enterprise and business to business (B2B) use cases. Additionally, the economic analysis assumed that the band would be available for use by IMT and Wi-Fi simultaneously, ensuring fair treatment for both mobile and Wi-Fi users. The relative benefits depend on the underlying assumptions, some of which are forward looking and still uncertain. In particular, the following factors should be considered when considering policy development in the U6 GHz:

- Possible emergence of new applications could change the WTP for both mobile and fixed broadband. If such applications are unique to one service e.g. require mobility or very high data rates, it could again affect how benefits are split between IMT and Wi-Fi.
- The potential importance for deploying U6 GHz in allowing MNOs and Wi-Fi service providers to deploy larger channels in mid-band spectrum; Larger channels compared to those available in current harmonised bands would be particularly beneficial for targeted innovative new services that require larger bandwidth.
- Foundational technologies and associated new applications of 6G and Wi-Fi7 have the potential to radically change the benefits for IMT and Wi-Fi.
- Rollout, and more importantly, adoption of 6GHz capable equipment could happen at different speeds for IMT and Wi-Fi.

Furthermore, there is a need to explore the challenges of making XTS a reality in consultation with relevant stakeholders to allow IMT and Wi-Fi to operate effectively in a shared scenario. XTS functionality must be standardised, harmonised and compliance tested as a pre-condition for deployment. This effectively minimises any potential technology barriers and risks to any deployments. Moreover, harmonisation would allow development costs to be shared and minimise the impact on equipment costs.

Our study explored the most commonly discussed options within CEPT PT1. While reduced IMT power was not a popular option, it was still analysed as a boundary case to illustrate its potential outcomes. Other Wi-Fi and mobile sharing options may arise as a result of the ongoing CEPT study on this topic. At the time of this report, we considered the most commonly discussed options for sharing. As new options emerge, conducting the technical analysis and conducting CBA to assess the relative net benefits of the sharing solutions would be helpful.

4.2 Independently operated private networks in the upper n77 band (3.8-4.2 GHz)

The issue examined in this analysis is whether moving from sharing the n77 band with separation distances based on Ofcom’s I/N target to separation distances based on more accurate interference measurements, underpinned by an automated system for accessing the spectrum could increase the overall welfare benefit.

Our analysis strongly suggests that an automated system based on more accurate interference measurements will lead to a significant increase in the benefits from private mobile network use and this policy direction should be pursued.

Though subject to some caveats over the assumptions made, our analysis also suggests that the current Ofcom approach will be a brake on PMN deployment in urban and suburban areas as currently forecast, as well as restricting the potential for the PMN market to grow beyond this level.

Costs appear quite low in comparison to benefits, but it would be useful to get a more in-depth view of the potential resources and associated costs of an automated database system, supported either by spectrum observatories or sensors.

We recommend that more research is carried out, along with stakeholder consultation, into acceptable levels of coverage degradation and their use in setting separation distances, as this has a major impact on the projected net benefits. This may require further research on real-world impacts on user experience and private mobile network value under different specifications of coverage degradation.

5. Conclusions

This report has presented a cost benefit analysis of the simulation and modelling activities in the Spectrum Sandbox for the two technology pairs that were part of the testbeds – Mobile & Wi-Fi in U6 GHz and private mobile networks in the n77 band. It also present results for the extension of the test beds to other technology pairs and environments – Mobile & Fixed Links in U6 GHz, and Mobile and NTN (both satellite and HIBS) in the 2.6 GHz band. It has also commented on the implications for policy and regulation for more intensive spectrum sharing.

The key conclusions from the cost benefit analysis are that the benefits to be derived from more intensive spectrum are likely to outweigh the costs and significantly in some cases. However, the technical implementation of sharing is often critical to achieving a net benefit in relation to the counterfactual.

In the mobile Wi-Fi technology pair, the use of cross-technology signalling to manage interference between IMT and Wi-Fi sharing the U6 GHz band, setting the right IMT power levels is essential to maximising the overall benefit according to our analysis. However, IMT power levels also have a negative impact on the benefits for Wi-Fi and this warrants further investigation of the cost and benefit drivers as they develop and of the technical options for cross-technology signalling. It is critical that XTS functionality must be properly standardised, harmonised and compliance tested as a pre-condition for deployment.

Careful attention should also be paid to the types of environments where sharing will have most benefit. For private mobile networks, there are significant benefits from more intensive sharing through more accurate interference measurements. However, the majority of these benefits are likely to lie in urban and suburban areas where the current approach to separation distances based on Ofcom I/N targets is likely to place far more of a constraint on the expansion of private mobile network deployments.

A similar conclusion applies when the sharing model is extended to mobile and fixed links. The benefits of allowing mobile to share the band while protecting Fixed Link deployments could be substantial. However, they will be concentrated in urban and suburban areas where the business case for MNOs to deploy U6 GHz is likely to be strongest due to the band’s propagation characteristics and the density of demand.

In contrast, sharing between mobile and non-terrestrial networks may be most successful in rural areas because the relatively long separation distances required are better accommodated there than in more dense areas. Although the benefits are smaller in comparison to other technology pairs, they will be potentially very significant for the communities they benefit. Providing better connectivity to remote and rural areas may also bring some societal benefit in terms of greater inclusion.

Further work, including field trials, would be useful on the implications of allowing a certain level of coverage degradation to fixed links from mobile in the U6 GHz band or from NTN to mobile in the 2.6 GHz band – in order to reduce the required separation distances. More detailed information on the potential impact on the affected service may allow a better evaluation of the economic advantages and disadvantage of these choices.

We would reiterate the conclusion that standardisation has an important role to play in securing the benefits of more intensive sharing by helping to drive down the development cost of new technical approaches such as cross-technology signalling.

In addition, more clarity on the costs of automated databases and implementing more accurate interference measurements, whether by observatories of by UE based sensors would also help reduce uncertainty over the total net benefits in those technologies pairs where they are relevant.

Appendix A Acronyms

Abbreviation	Meaning
AP	Access Point
ARPU	Average Revenue per User
CBA	Cost Benefit Analysis
D2D	Direct to device
EIRP	Equivalent Isotropic Radiated Power
HIBS	High Altitude Platforms for IMT Base Stations
I/N	Interference to Noice
IMT	International Mobile Telecommunications
LEO	Low Earth Orbit
MNO	Mobile Network Operator
MTC	Machine Type Communications
NPV	Net Present Value
NTN	Non-Terrestrial Network
PMN	Private Mobile Networks
PTP	Point to Point
UE	User Equipment
U6	6425-7125 MHz band
WTP	Willingness to Pay
WP	Work Package
XTS	Cross Technology Signalling

Appendix B Additional Results

B1 Benefit per user for Mobile Wi-Fi sharing in U6 GHz

The table below shows the benefit per user for the urban case, with omni-directional antenna gain and random Wi-Fi AP location. It divides the NPV of net benefit over the total number of IMT and/or Wi-Fi users in the urban area (averaged over the NPV period).

The difference in average benefit (all users) for the 73 and 83 dBm scenarios compared to IMT only indicates the upper limit on any end user based charges for XTS, e.g. for device upgrades.

Table 14. Average Benefits per user Omni Random case (£/year) – Urban Areas

Scenarios (Wi-Fi always vacates if sharing)	Average Benefits all users (IMT + Wi-Fi)	Average Benefit per IMT user	Average Benefits Wi-Fi users
IMT only	57.4	75.8	0.0
Wi-Fi only	34.6	0.0	142.5
IMT & Wi-Fi: IMT power 73dBm	60.2	72.3	22.5
IMT & Wi-Fi: IMT power 65dBm	53.0	58.8	35.0
IMT & Wi-Fi: IMT power 58dBm	37.2	33.0	50.0
IMT & Wi-Fi: IMT power 83dBm	64.0	80.5	12.5

Table 15. Average Benefits per user Omni Random case (£/year) – Suburban Areas

Scenarios (Wi-Fi always vacates if sharing)	Average Benefits all users (IMT + Wi-Fi)	Average Benefit per IMT user	Average Benefits Wi-Fi users
IMT only	57.9	76.5	0.0
Wi-Fi only	34.6	0.0	142.5
IMT & Wi-Fi: IMT power 73dBm	67.1	75.8	40.0
IMT & Wi-Fi: IMT power 65dBm	46.3	41.1	62.5
IMT & Wi-Fi: IMT power 58dBm	20.4	-0.3	85.0
IMT & Wi-Fi: IMT power 83dBm	82.0	101.0	22.5

B2 Sensitivity on private mobile network sharing in n77 – more relaxed demand constraint

The following graph shows the impact on the benefits for PMNs if we assume that demand increases according to current market forecasts, but the saturation level in the addressable market is increased by 50%.

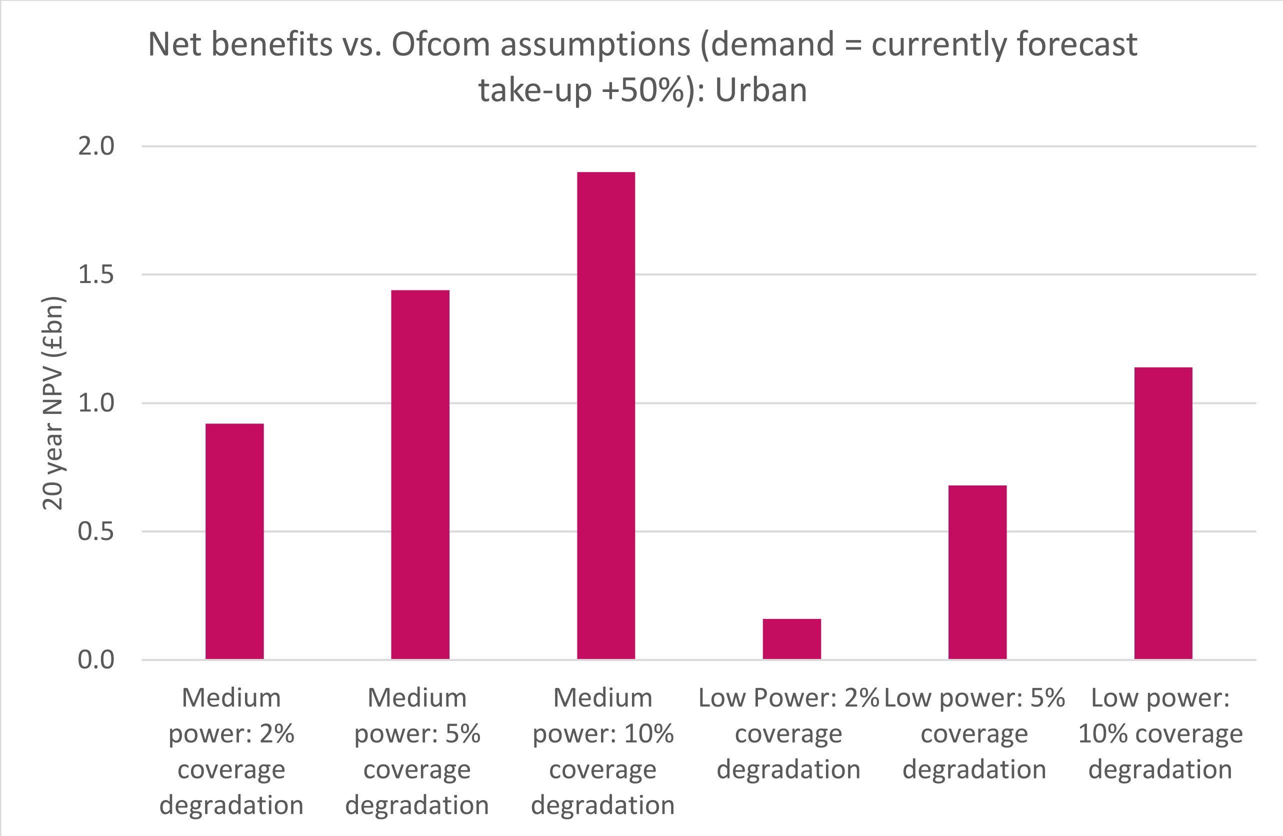

Figure 5-1. 20 year NPV - Urban (demand constrained to current forecast take-up +50%)

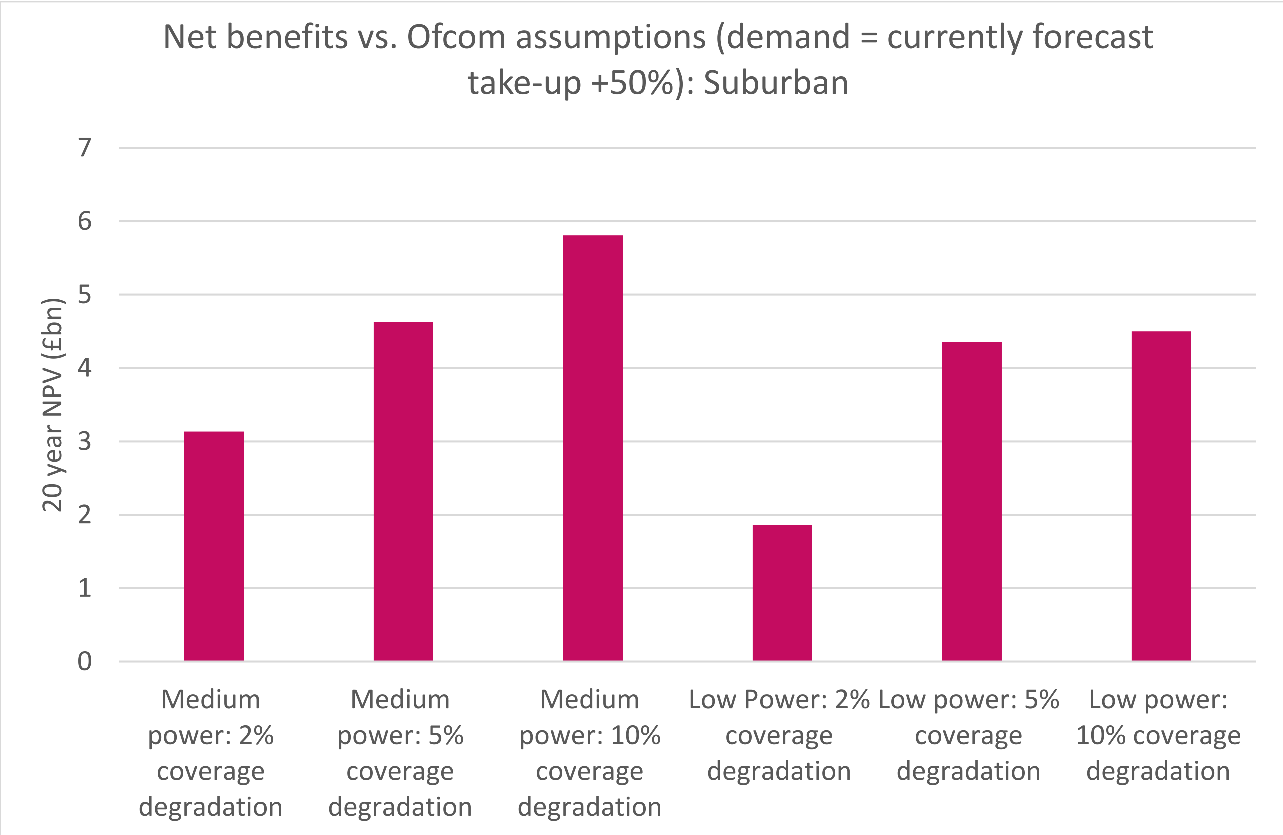

Figure 5-2. 20 year NPV - Suburban (demand constrained to current forecast take-up +50%)

If demand is higher than predicted, the foregone benefits of maintaining the current system would be higher, particularly in suburban areas.

- In urban areas, our sharing scenarios make a marginal difference to the net benefits. As demand is higher across the whole model period, demand reaches the maximum number of PMNs that can be deployed (given the required separation distance) marginally more quickly;
- In suburban areas, demand is significantly higher in the early years of the model and hence more PMNs are able to deployed before reaching the maximum permitted under our assumptions;
- In rural areas, the current approach is not a constraint on meeting demand for PMNs, hence there is no incremental benefit for the sharing scenarios.

References

1 WRC-23 Resolution 253 recommend studies on possible allocations to the MSS in the IMT bands (frequency range between 694/698 MHz and 2.7 GHz)

2 https://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A0000100013PDFE.pdf

3 Discrete Choice Analysis of Japanese 5G Mobile Demand, Takano N., July 2023, https://link.springer.com/epdf/10.1007/s12626-023-00142-2?sharing_token=kUucr5S8b9Z7tv2XU3TGb_e4RwlQNchNByi7wbcMAY6X-buXgXQEm_XiPdPB3yTMcfReav5UpQmEVidjAn9-JQmESncaqoEqgTrsIGa885GfJCjilO21nDb-B6WoGkd5yiA0OKUrhTZy66pglbWMHutA1NQdVpPR1e1qxXUsN6w%3D

4 https://www.vodafone.co.uk/newscentre/press-release/this-is-your-phones-life-lifetime-service-promise/

5 Ookla Speedtest https://www.speedtest.net/global-index/united-kingdom (accessed 17/02/258) gives median download speeds for 2024: 55 Mbps mobile broadband; 112 Mbps fixed broadband. https://www.ispreview.co.uk/index.php/2018/04/uk reports median mobile download speeds from Ookla Speedtest for 2018: 27 Mbps.

6 https://www.ofcom.org.uk/spectrum/frequencies/improving-spectrum-access-for-wi-fi/

7 Distinguishing bandwidth and latency in households' willingness-to-pay for broadband internet speed, 2018, Liu, Y., Prince, J., Wallsten, S. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2942236

8 https://www.ispreview.co.uk/index.php/2020/12/2019-vs-2020-uk-broadband-and-mobile-speeds-vs-the-world.html reports Ookla Speedtest for median fixed broadband download speeds for 2020: 76 Mbps.

9 Ookla Speedtest op. cit.

10 Ofcom Communications Market Report Interactive Data 2024, https://www.ofcom.org.uk/phones-and-broadband/service-quality/communications-market-report-2024-interactive-data/

11 Determinants of fixed and mobile broadband demand in Mexico, Ros, A. J., Information Economics and Policy, September 2023, https://www.sciencedirect.com/science/article/abs/pii/S0167624523000331?via%3Dihub

12 Ofcom Communications Market Report Interactive Data 2024, https://www.ofcom.org.uk/phones-and-broadband/service-quality/communications-market-report-2024-interactive-data/

13 Ofcom MCT statement and model, 2018-2021, https://www.ofcom.org.uk/phones-and-broadband/telecoms-infrastructure/mobile-call-termination-market-review/?language=en

Arcep MCT model 2017, https://en.arcep.fr/news/press-releases/view/n/arcep-publishes-for-consultation-its-draft-analysis-of-fixed-and-mobile-call-termination-markets-from-2017-to-2020.html

Widelity for FCC, 2021, FINAL CATALOG OF ELIGIBLE EXPENSES AND ESTIMATED COSTS, https://docs.fcc.gov/public/attachments/DA-21-947A4.pdf

METIS-II, Deliverable 1.2: 'Quantitative techno-economic feasibility assessment', 2017, https://metis-ii.5g-ppp.eu/wp-content/uploads/deliverables/METIS-II_D1.2_V1.1.pdf

Canalys, Western Europe's smartphone market revival is on the cards for 2024, https://www.canalys.com/newsroom/europe-smartphone-market-q1-2023

14 https://www.ofcom.org.uk/phones-and-broadband/coverage-and-speeds/connected-nations-2024/

15 ONS methodology working paper series number 13 https://www.ons.gov.uk/methodology/methodologicalpublications/generalmethodology/onsworkingpaperseries/onsmethodologyworkingpaperseriesnumber13comparingthedensityofmobilephonecelltowerswithpopulationestimates#toc

16 Real Wireless and UK 5G Innovation Network for Digital Catapult, The UK Private Cellular Networks Market, 2022, https://real-wireless.com/publications/the-uk-private-cellular-networks-market/

17 Spend on private LTE/5G networks will be small but an important opportunity for future IoT growth, 2021, https://www.analysysmason.com/research/content/articles/private-networks-iot-rdme0-rma17/

18 Department for Business and Trade - Business population estimates for the UK and regions 2023: statistical release, https://www.gov.uk/government/statistics/business-population-estimates-2023/business-population-estimates-for-the-uk-and-regions-2023-statistical-release

19 Global Data (sponsored by Nokia), "2024 Industrial digitalization report: Private wireless, edge infrastructure and applications", https://pages.nokia.com/T01249-nokia-2024-industrial-digitalization-report.html

20 https://www.vodafone.co.uk/newscentre/media/5g-manufacturing-report-210726

21 https://www.businessandindustry.co.uk/manufacturing/5g-promises-1-improvement-in-factory-productivity/

22 PWC, "Industry 4.0:Building the Digital Enterprise", 2016, https://www.pwc.com/gx/en/industries/industrial-manufacturing/publications/assets/pwc-building-digital-enterprise.pdf

23 5G NORMA, D2.3, Evaluation architecture design and socio- economic analysis – final report, 2017, https://www.it.uc3m.es/wnl/5gnorma/pdf/5g_norma_d2-3.pdf

24 See Department for Business and Trade - Business population estimates for the UK and regions 2023: statistical release, as previously referenced

25 CEPT Workshop on Spectrum Occupancy Measures, 2014, https://www.cept.org/ecc/ecc-workshop-exploring-spectrum-occupancy-measurements

26 Ofcom, Consultation on Hybrid sharing: enabling both licensed mobile and Wi-Fi users to access the upper 6 GHz band, 2023, https://www.ofcom.org.uk/spectrum/innovative-use-of-spectrum/hybrid-sharing-to-access-the-upper-6-ghz-band

27 A. Clarke and C. Baker, House of Commons Library Research Briefing "Rural mobile coverage in the UK: Not-spots and partial not-spots", 2024, https://commonslibrary.parliament.uk/research-briefings/sn07069/

28 https://omdia.tech.informa.com/pr/2023/feb/omdia-growth-of-4g-over-5g-in-2022-raises-concern-for-5g-evolution

29 Estimating the value of mobile telephony in mobile network not-spots, 2014, https://www.gov.uk/government/publications/estimating-the-value-of-mobile-telephony-in-mobile-network-not-spots

30 EuroConsult, FSS Capacity Pricing Trends 2023, https://nova.space/hub/product/fss-capacity-pricing-trends/

31 HM Treasury, Green Book supplementary guidance: discounting, https://www.gov.uk/government/publications/green-book-supplementary-guidance-discounting

32 https://www.ofcom.org.uk/spectrum/spectrum-awards/spectrum-auction-principal-stage-results/

independent telecoms experts

Real Wireless Ltd
PO Box 2218
Pulborough
West Sussex
RH20 4XB
United Kingdom

t +44 207 117 8514
f +44 808 280 0142
e info@real-wireless.com
w real-wireless.com
real-wireless