Enabling mmWave spectrum for new uses

Annexes 5-8: supporting information

Redacted for publication -- [✂] indicates redaction

Publication date: 9 May 2022

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Annex

A5. Legal framework

A5.1 Ofcom's statutory powers and duties in relation to spectrum management are set out primarily in the Communications Act 2003 (the **"2003 Act"**) and the Wireless Telegraphy Act 2006 (the **"WT Act"**).

Duties under the Communications Act 2003

A5.2 Our principal duties under the 2003 Act, when carrying out our functions and exercising our powers, are to further the interests of citizens and consumers, where appropriate by promoting competition. In doing so, we are also required (among other things) to secure the optimal use of spectrum and the availability throughout the United Kingdom of a wide range of electronic communications services.

A5.3 We must also have regard to: (i) the desirability of promoting competition in relevant markets; (ii) the desirability of encouraging investment and innovation in relevant markets; (iii) the desirability of ensuring the security and availability of public electronic communications networks and services; (iv) the different needs and interests, so far as the use of the electro-magnetic spectrum for wireless telegraphy is concerned, of all persons who may wish to make use of it; and (v) the different interests of persons in the different parts of the United Kingdom, of the different ethnic communities within the United Kingdom and of persons living in rural and in urban areas.

A5.4 In performing our duties, we are required under section 3(3) of the 2003 Act to have regard in all cases to the principles under which regulatory activities should be transparent, accountable, proportionate, consistent and targeted only at cases in which action is needed, and any other principles appearing to Ofcom to represent the best regulatory practice.

A5.5 In carrying out certain regulatory functions, including Ofcom's spectrum management functions, section 4 of the 2003 Act requires Ofcom to act in accordance with the following requirements: a) to promote competition in communications markets; b) to promote the interests of all members of the public in the United Kingdom; c) to act in a manner which, so far as practicable, is technology neutral;[1] d) to encourage, to the extent Ofcom considers it appropriate, the provision of network access and service interoperability for the purpose set out in s.4(8);[2] e) to encourage such compliance with certain international standards as is necessary for the purposes set out in s.4(9);[3] and f) to promote connectivity

[1] According to s.4(6A) of the 2003 Act, this requirement does not apply to the imposition, in relation to a wireless telegraphy licence, of a limitation of a kind falling within section 9ZA(1) of the WT Act; or (b) the review, variation or removal of such a limitation.

[2] The purpose of securing: (i) efficiency and sustainable competition, (ii) efficient investment and innovation, and (iii) the maximum benefit for the customers of communications providers and of persons who make associated facilities available.

[3] For facilitating service interoperability, end-to-end connectivity, the changing by end-users of their communications provider, the retention by end-users of their telephone numbers after a change of communications provider; and securing freedom of choice for the customers of communications providers.

and access to very high capacity networks by members of the public and businesses in the United Kingdom.

Duties under the Wireless Telegraphy Act 2006

A5.6 Additionally, in carrying out our spectrum functions we have a duty under section 3 of the WT Act to have regard in particular to: (i) the extent to which the spectrum is available for use, or further use, for wireless telegraphy; (ii) the demand for use of that spectrum for wireless telegraphy; and (iii) the demand that is likely to arise in future for such use.

A5.7 We also have a duty to have regard to the desirability of promoting: (i) the efficient management and use of the spectrum for wireless telegraphy; (ii) the economic and other benefits that may arise from the use of wireless telegraphy; (iii) the development of innovative services; and (iv) competition in the provision of electronic communications services.

Harmonised technical conditions

The 26 GHz band

A5.8 Certain European decisions continue to have effect in domestic UK law, following the UK's exit from the EU, by virtue of section 3 of The European Union (Withdrawal) Act 2018. These include, in particular, the Implementing Decision issued by the European Commission in 2019 to open up the 26 GHz band for wireless broadband under harmonised technical conditions, which it then amended in 2020 (the **"26 GHz Decision"**).[4]

A5.9 The 26 GHz Decision harmonises the essential technical conditions for the availability and efficient use of the 24.25-27.5 GHz frequency band (the "**26 GHz band**") in the European Union for terrestrial systems capable of providing wireless broadband electronic communications services (Art. 1) and requires the UK (and the EU Member States) to designate and make available on a non-exclusive basis that frequency band for such systems by 30 June 2020 (Art. 2).

A5.10 It also contains provisions about the co-existence between terrestrial systems for wireless broadband and other spectrum users. In particular:

a) it should be analysed at national level whether it is necessary to impose additional technical conditions to ensure appropriate co-existence with other services in the band (Art. 2);

b) terrestrial systems for wireless broadband must appropriately protect other spectrum users operating in the same band or adjacent bands, including certain earth exploration satellite services, radio astronomy services, space research services and satellite systems (Art. 3);

[4] See this unofficial consolidated version of Decision 2019/784, as amended by Decision 2020/590.

c) fixed links may be allowed to continue to operate within the band, if the terrestrial systems for wireless broadband can co-exist with them through managed shared spectrum use (Art. 4);

d) the number and locations of new earth stations must be determined so as not to impose disproportionate constraints on terrestrial systems for wireless broadband. Subject to market demand, the continued deployment of earth stations must be made possible for certain uses within the 26 GHz band (Art. 5); and

e) the progress on co-existence should be monitored, and the findings reported to the European Commission to allow for a timely review of the 26 GHz Decision (Art. 7).

A5.11 Cross-border coordination agreements should be facilitated to enable the operation of terrestrial systems for wireless broadband (Art. 6).

The 40 GHz band

A5.12 In April 2020, the European Commission issued a mandate to the European Conference of Postal and Telecommunications Administrations ("**CEPT**"), asking CEPT to develop least restrictive harmonised technical conditions allowing use of the 40.5-43.5 GHz band for terrestrial wireless systems capable of providing wireless broadband electronic communications services.[5] In January 2022, CEPT produced draft technical conditions for the 40.5-43.5 GHz band,[6] and it is currently expected that CEPT will publish a report with proposed technical conditions in 2022, which will form the basis of a harmonising Commission Decision in early 2023. For the avoidance of doubt, any such decision will not be part of UK law. However, Ofcom may consider it appropriate to authorise spectrum use of the relevant frequencies on the basis of technical conditions reflecting the CEPT harmonisation.

Ofcom's licensing framework

A5.13 Ofcom is responsible for authorising use of the radio spectrum. We permit the use of the radio spectrum either by granting wireless telegraphy licences under the WT Act or by making regulations exempting the use of particular equipment from the requirement to hold such a licence. It is unlawful and an offence to install or use wireless telegraphy apparatus without holding a licence granted by Ofcom, unless the use of such equipment is exempted.[7]

A5.14 The proposals set out in this consultation document concern (among other things) our approach to existing users of the 26 GHz and 40 GHz bands and the licence conditions to be included in any future licence authorising use of these bands for 5G and other wireless

[5] See Annex 1 to CEPT Report 78.
[6] See ECC PT1(22)074 ANNEX VIII-04 _Working doc for draft ECC Dec 40.5-43.5 GHz MFCN. Note that this set of draft conditions are due to be finalised in 2023 and so are subject to further change.
[7] Section 8 of the WT Act.

services. Below we explain the legal framework under which we can impose conditions in new spectrum licences and revoke or vary existing licences.

Licence conditions

A5.15 A wireless telegraphy licence may be granted subject to such terms, provisions and limitations as Ofcom think fit (WT Act, s. 9(1)). However, this power is subject to certain constraints. In particular:

a) the terms, provisions and limitations of a spectrum licence must not duplicate the obligations already imposed on the licensee by the general conditions set by Ofcom under section 45 of the Communications Act 2003 (WT Act, s. 9(6));[8] and

b) Ofcom may only impose terms, provisions and limitations which are: a) objectively justified in relation to the network and services to which they relate; b) not unduly discriminatory; c) proportionate to what they are intended to achieve; and d) transparent in relation to what they are intended to achieve (WT Act, s. 9(7)).

A5.16 Section 9(4) of the WT Act sets out a non-exhaustive list of the terms, provisions and limitations that Ofcom may impose.

A5.17 Examples of conditions that we may impose in spectrum licences under s.9 WT Act include:

a) limitations as to the position and nature of a station (s.9(2)(a));

b) limitations as to the apparatus that may be installed or used (s.9(3)); and

c) terms, provisions and limitations as to strength or type of signal, as to times of use and as to the sharing of frequencies the strength or type of signal (s.9(4)(a)).

Ofcom's powers to vary or revoke licences granted under the WT Act

A5.18 Ofcom has a broad discretion under paragraph 6 of Schedule 1 of the 2006 Act to vary or revoke licences, subject to certain limitations. Specifically, the legislation provides that Ofcom may not vary or revoke a licence unless the proposed variation or revocation is objectively justifiable (WT Act 2006, para. 6A of Sch. 1). We also have a general duty not to discriminate unduly between operators and to ensure that our interventions are proportionate, consistent and targeted only at cases in which action is needed (2003 Act, s.3(3)). Ofcom must act in accordance with its statutory duties and general legal principles, including the duties to act reasonably and rationally when making decisions and to take account of any legitimate expectations.[9]

A5.19 Schedules 1 of the WT Act set out the process which Ofcom must follow where it proposes to vary or revoke a wireless telegraphy licence. In summary, Ofcom is required to take the following steps (WT Act, para. 7 of Sch. 1):

[8] Ofcom's General Conditions of Entitlement.

[9] Further potential limitations may derive from (i) any UK obligations under international agreements, particularly where use of spectrum has been harmonised, and (ii) any ministerial direction under section 5 of the 2003 Act or section 5 of the WT Act.

a) notify the licensee of the reasons for the proposed variation or revocation;

b) specify a period of at least 30 days in which the licensee may make representations about the proposal; and

c) decide whether or not to vary or revoke the licence within one month of the end of that period.

A5.20 Where a proposal to vary or revoke a wireless telegraphy licence is made with the consent of the licensee, Ofcom is not required to follow the above process.

A5.21 Ofcom may include in a wireless telegraphy licence terms restricting the exercise of its power to revoke or vary licences (WT Act, para. 8 of Sch. 1), such as requiring a certain notice period for revoking a licence for spectrum management reasons. However, Ofcom may at any time revoke or vary a licence if it appears to be necessary or expedient in the interests of national security, or for the purpose of securing compliance with an international obligation (WT Act, para. 8(5) of Sch. 1).

Licence awards

A5.22 Ofcom may allocate spectrum by way of auctions having regard to the desirability of promoting the optimal use of spectrum (WTA 2006, s. 14). In making auction regulations, Ofcom must satisfy itself that the criteria for spectrum allocation are:

a) objectively justifiable in relation to the frequencies to which they relate;

b) not such as to discriminate unduly against particular persons or against a particular description of persons;

c) proportionate to what they are intended to achieve; and

d) in relation to what they are intended to achieve, transparent (WTA 2006, s.14(3B)).

A5.23 Auction regulations may make provisions with respect to the grant of the relevant licences and also the terms, provisions and limitations subject to which such licences are granted (WTA 2006, s. 14(2) and s. 14(3)(h)). When designing competitive awards, Ofcom may impose a specified level of use requirement if doing so would promote the optimal use of spectrum (WTA 2006, s.14(3C)).

A6. Coexistence assessment between 5G and fixed services in the 26 GHz and 40 GHz bands

Introduction

A6.1 This annex explains the technical analysis we have undertaken to assess coexistence between new uses operating in the 26 GHz (24.25-27.5 GHz) and 40 GHz (40.5-43.5 GHz) bands to fixed services in those bands.

A6.2 The analysis in this annex also investigates how much spectrum in our proposed high density areas would be available for new uses taking into account existing fixed services. We use standard coexistence parameters in our analysis as well as an additional factor to adopt a more realistic approach in line with the approach set out in our Spectrum Strategy.

A6.3 We have considered two outdoor 5G deployment scenarios which we believe are likely to be representative of real deployments:

a) Low power deployments: these are similar to the hotspot deployment model used in previous studies, which we expect to be representative of some new mmWave 5G deployments.[10] [11] They are typically deployed below rooftop height and provide coverage to an area within a few tens of metres of the base station; and

b) Medium power deployments: these could be representative of the fixed wireless access (FWA) model considered in our previous studies.[10] They are typically deployed above rooftop and provide coverage to an area within a few hundreds of metres of the base station in urban environments, and a few kilometres in rural environments.

A6.4 We also expect to see low power, indoor deployment of mmWave spectrum. However, we assessed the impact of low power, indoor 5G deployments on fixed services in the 26 GHz bands when we put in place our indoor Shared Access framework,[12] and we concluded that the risk of interference to fixed services was low. We believe that the same conclusions apply to the 40 GHz band, as we consider that 26 GHz and 40 GHz spectrum have very similar charateristics, and so we do not consider low power, indoor deployments further in this annex.

A6.5 We have structured the annex as follows:

- **Modelling outdoor mmWave 5G deployments:** in which we discuss the characteristics that future mmWave 5G deployments may have and their importance for our coexistence analysis;

[10] Ofcom, *Protecting passive services in the 23.6 – 24 GHz from 26 GHz uses*, 2 December 2021, accessed February 2022.
[11] ECC Report 307, *Toolbox for the most appropriate synchronisation regulatory framework including coexistence of MFCN in 24.25-27.5 GHz in unsynchronised and semi-synchronised mode*, version approved March 2020, accessed May 2022.
[12] Ofcom, *Enabling wireless innovation through local licensing, Annex 1 to 5 – supporting information*, 25 July 2019, accessed March 2021.

- **Modelling of fixed links in the 26 and 40 GHz bands:** in which we set out the parameters important for modelling coexistence with fixed links including protection criteria;
- **Modelling coexistence between outdoor mmWave 5G and fixed links:** in which we set out our approach to modelling coexistence between these two services;
- **Increasing realism in our modelling:** in which we acknowledge how the dynamic nature of modern mobile systems and resilience of modern fixed links receivers may reduce the risk of interference;
- **Spectrum availability results:** in which we assess the amount of spectrum which could be available in high density areas for new uses during the period when fixed links remain in 26 and 40 GHz; and
- **Conclusions:** in which we summarise our spectrum availability results and discuss how those results might change depending on the modelling assumptons used.

Modelling outdoor mmWave 5G deployments

A6.6 We have based the mmWave 5G outdoor characteristics and simulation parameters we have modelled on the ITU-R document used for the sharing and compatibility studies leading to the 2019 World Radio Conference (WRC-19).[13]

Low power deployments

A6.7 The main deployment type for 26 GHz considered at WRC-19 was the hotspot deployment model, which we refer to here as 'low power deployment'. We have modelled low power base stations using the modelling parameters for hotspots from ECC Report 307[11] which are the same technical parameters, such as transmit power, as used in the ITU's 5G parameters.

Medium power deployments

A6.8 We believe that some operators may also wish to deploy medium power base stations which might support deployment types like macro sites and integrated access and backhaul (IAB). These can provide more extensive geographical area coverage and can have larger, more directional antennas than low power base stations. To model such deployments, we have modified some of the parameters we used to model low power deployments, including greater transmit power and deployment height, based on our review of published field trials and stakeholder discussions.

A6.9 In particular, we have made the following adjustments to the parameters we used to model low power deployments:

a) We have modelled the total radiated power (TRP) of medium power base stations to be 5 dB above the power of low power base stations.

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[13] ITU-R R15, *Annex 1 to Task Group 5/1 the Chairman's Report document TG 5-1/478: System Parameters and Propagation Models to be used in Sharing and Compatibility Studies*, accessed May 2022.

b) We also expect the EIRP difference to be greater for medium power base stations than for low power base stations. This is because we expect medium power base stations may use four times more antenna elements than low power base stations. This means that the difference in EIRP could be up to 11 dB (5 dB greater TRP + 6 dBi additional antenna gain). We also note that despite the smaller transmit power levels we have considered, the EIRP values for medium power base stations in the mmWave bands are likely to be higher than those authorised for medium power uses in other bands in order to achieve similar coverage.[14] The explanation on the derivations of the power levels are set out in Table A6.1.

High power deployments

A6.10 We have not modelled high power deployments because we are not aware of any mmWave use cases which would require high power. In sub-6 GHz networks, high power base stations are typically used to provide mobile coverage in rural areas but we believe that it is unlikely that mmWave spectrum will be used for this purpose. We believe that medium power is likely to be sufficient for fixed wireless access coverage in both low and high density areas.

A6.11 We list the parameters used in our modelling and the explanation for the choosing the parameters for medium power base stations in Table A6.1.

Table A6.1: Parameters used for modelling outdoor mmWave base stations

Parameter	Low power	Medium power	Comments
Bandwidth	200 MHz	200 MHz	We have used the same values as in previous studies.[10]
Antenna element gain	5 dBi	5 dBi	We have used the same values as in previous studies and do not believe that the per antenna element gain will be different for low and medium power base stations.
Number of antenna elements	8x8	16x16	We anticipate that medium power base stations could have larger arrays than low power base stations to provide wider coverage, typically in the few 100s of metres. We noted from our review of mmWave equipment that the number of active elements can range between 256 and 512.[15] Some commercial products have reported

[14] The limit for a medium power Shared Access 3.8-4.2 GHz licence is 36 dBm / 5 MHz EIRP. Normalising for bandwidth, this is equivalent to: 52 dBm / 200 MHz EIRP.
Our proposal for medium power at mmWave is 30 dBm / 200 MHz TRP. Assuming a 29 dBi antenna gain this is equivalent to: 59 dBm / 200 MHz EIRP.
[15] Microwave Journal, *5G Fixed wireless access array and RF front-end trade-offs*, , February 2018, accessed May 2022.

Parameter	Low power	Medium power	Comments
			the use of 16x16 arrays for covering ranges over 700 m.[16]
Transmit power	25 dBm/200 MHz TRP	30 dBm/200 MHz TRP	For low power we have used the same values as in previous studies.[10] For medium power, we asked Mobile Network Operators (MNOs) [✂] and vendors [✂] about their expectations for transmit power levels. They said they would require EIRP levels in the range of 44 to 70 dBm to provide new uses. We chose a representative value of 65 dBm / 800 MHz EIRP to represent the radiated power for medium power deployment. Assuming a 16x16 antenna array, a 5 dBi gain per antenna element gain, the boresight gain using ITU-R M.2101 is 29 dBi. This leads to the transmit power of 30 dBm TRP/200 MHz (= 65 dBm / 800 MHz EIRP – 6 dB bandwidth adjustment factor – 29 dBi antenna gain).
Mechanical downtilt	10°	2°	We have used the same user equipment (‘UE’) modelling assumptions as in our previous studies[10] where user terminals around an FWA base station are uniformly distributed in azimuth and assume a typical base station coverage of 500 m. We have modelled the user terminals to be distributed at heights of 3, 6 and 9 m to represented deployment across multiple floors. Under these modelling assumptions, a 2° downtilt will allow the boresight of a base station to align with a terminal at 500 m with no electrical tilt.
Beam pointing	Towards UE	Towards UE	In both base station types, we expect the beams to be steered towards the user equipment being served.
Antenna height	6 m	15 m	Hotspots were modelled at a 6 m height in studies leading to WRC-19.

[16] Microwave Journal , *Comprehensive Survey of Commercial mmWave Phased Array Companies*, accessed May 2022.

Parameter	Low power	Medium power	Comments
			Taller masts will enable wider coverage. In Samsung's FWA trial in Romania a 15 m height mast was used.[17]
Maximum antenna gain towards horizon	22 dBi	28 dBi	We derive the maximum gains towards the horizon by considering that the base station generates a single beam which is steered towards cell-edge users for both low power and medium power deployments.

A6.12 We begin our discussion of mmWave 5G base station parameters by examining how we can model beamforming and then we look at out-of-block emissions and the impact they could have on adjacent channel interference. Finally, we turn to the specific coexistence characteristics of low power deployments and medium power deployments.

mmWave Beamforming

A6.13 'Beamforming' (or 'beam steering') is a technique that focuses a wireless signal towards a specific receiving device, rather than have the signal spread in all directions. Both low power and medium power 5G systems are expected to use active antenna systems (AAS) which support beam steering. We expect 5G base stations operating in the 26 GHz and 40 GHz bands to have similar characteristics and we have assumed the same parameters for modelling base station active antenna systems in both these bands.

A6.14 We consider that understanding beamforming is important for coexistence analysis because beamforming allows a base station to focus its transmissions dynamically, extending its coverage in chosen directions for a time whilst reducing coverage in other directions.

A6.15 We have used the recommendation ITU-R M.2101[18] for generating the antenna patterns with an antenna element spacing to wavelength ratio (d/λ) of 0.5. We have applied a correction factor to the pattern generated such that a total integrated gain (TIG) of 0 dBi is achieved, in line with the approach agreed in TG5/1.[19] The total integrated gain is calculated using Equation A6.1:

Equation A6.1: Calculation of Total Integrated Gain

$$Total\ Integrated\ Gain = \frac{1}{4\pi}\int_{0}^{2\pi}\int_{0}^{\pi} A_A(\theta,\varphi)\sin(\theta)\,d\theta d\varphi$$

[17] Samsung, *5G for Fixed Wireless Access (Orange Romania Case study)*, September 2019, accessed May 2022.
[18] Generating antenna radiation patterns based on Table 4 in Recommendation ITU-R M.2101-0 (02/2017), Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies.
[19] We follow the notes on the correction factor for AAS in *Annex 1 to Task Group 5/1 Chairman's Report*, section 16, in this study.

A6.16 Where:

φ and θ represent the azimuth and elevation angles, respectively, with units in degrees,

$A_A(\theta,\varphi)$ is the composite antenna gain at angle (θ,φ) with linear units computed based on ITU-R M.2101.

A6.17 Since we are generating the beam pattern numerically using recommendation ITU-R M.2101 and are dealing with sampled rather than continuous values, the double integrals in Equation A6.1 can be replaced by summations and the TIG can be approximated as:

Equation A6.2: Calculation of Total Integrated Gain when using sampled data

$$TIG \approx \frac{\pi}{2N_\varphi N_\theta} \sum_{\varphi=0}^{N_\varphi-1} \sum_{\theta=0}^{N_\theta-1} A_A(\theta,\varphi)\sin(\theta)$$

where N_φ and N_θ are the number of samples in azimuth and elevation, respectively.

A6.18 The corrected pattern in linear units, $\hat{A}_A(\theta,\varphi)$, is then calculated using Equation A6.3,

Equation A6.3: Calculation of corrected antenna pattern

$$\hat{A}_A(\theta,\varphi) = \frac{A_A(\theta,\varphi)}{TIG}$$

A6.19 The horizontal and vertical cross-sections of the antenna pattern generated for an 8×8 array with no electrical steering ($\theta_{etilt} = 0°$ and $\varphi_{escan} = 0°$) using Equation A6.3 are shown in Figure A6.1. This antenna pattern is representative of a low power base station. We note that the maximum gain in the vertical cross-section appears at an elevation angle of 100°. This value accounts for the 10° mechanical downtilt used in the modelling. We show the cross-sections of a 16×16 antenna pattern ($\theta_{etilt} = 0°$ and $\varphi_{escan} = 0°$), representative of a medium power base station in Figure A6.2.

Figure A6.1: Vertical (left) and horizontal (right) cross-sections of the antenna gain pattern for an 8x8 array

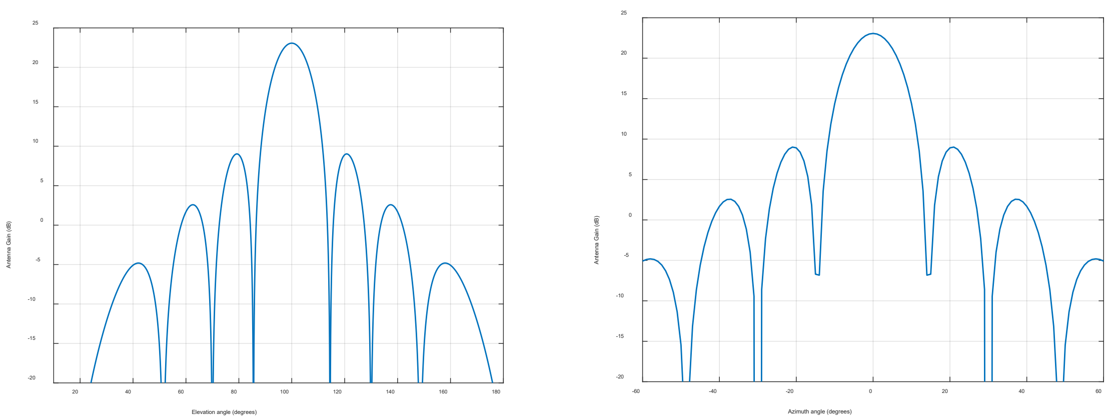
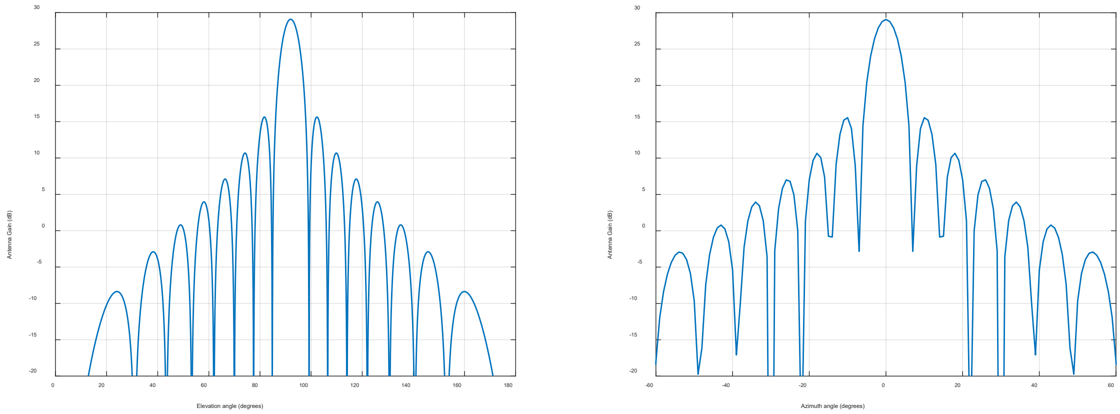


Figure A6.2: Vertical (left) and horizontal (right) cross-sections of the antenna gain pattern for a 16x16 array



Out-of-block emission parameters

A6.20 For 26 GHz, the out-of-block emissions limits for 5G base stations operating in the 26 GHz have been set out in the '**26 GHz Decision**'.[20] It is currently expected that CEPT will publish a report with proposed technical conditions for the 40 GHz band in 2022, which will form the basis of a harmonising Commission Decision in early 2023.[21] A draft ECC Decision[22] for 40 GHz is available while the technical conditions including the emission limits are being developed and harmonised in Europe and we consider this draft ECC Decision relevant for the purposes of our modelling work. In addition, for the purposes of our modelling, we have taken account of the relevant 3GPP[23] technical specifications document.[24]

A6.21 In line with Ofcom's Spectrum Strategy,[25] we have used what we believe to be more realistic values in our sharing studies. ECC Report 249[26] observes that typical operating parameters may be more appropriate for assessing coexistence with other systems than the regulatory limits. Due to being in the early stages of 26 GHz and 40 GHz base station deployment, we currently have limited information about the emission levels of real devices. However, on the basis of the above, we have defined what we believe are a

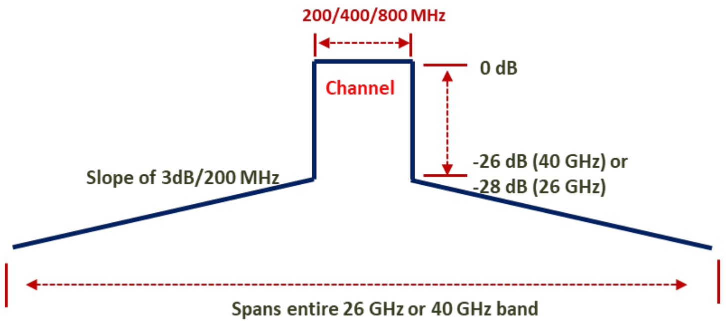
[20] Commission Implementing Decision (EU) 2019/784 of 14 May 2019 on harmonisation of the 24,25-27,5 GHz frequency band for terrestrial systems capable of providing wireless broadband electronic communications services in the Union. See consolidated text. This decision has been developed on the basis of studies conducted by CEPT in ECC Decision (18)06 on the harmonised technical conditions for Mobile/Fixed Communications Networks (MFCN) in the band 24.25-27.5 GHz, as amended on 20 November 2020.
[21] As set out in annex 5, for the avoidance of doubt, any such decision will not be part of UK law.
[22] Draft ECC Decision, *Harmonised technical conditions for Mobile/Fixed Communications Networks (MFCN) in the band 40.5-43.5 GHz*, accessed March 2022.
[23] The 3GPP is a global consortium of standards organisations which develop protocols for mobile telecommunications.
[24] 3GPP TS 38.104 v17.4.0 (2021-12), *Technical specification group radio access network, NR, base station radio transmission and reception (Release 17)*, accessed February 2022.
[25] Ofcom, *Supporting the UK's wireless future, our spectrum management strategy for the 2020s*, 19 July 2021.
[26] ECC Report 249, *Unwanted emissions of common radio systems: measurements and use in sharing/compatibility studies*, published 28 January 2022, accessed March 2022.

realistic set of out-of-block emission characteristics which involves a degree of regulatory judgement.

A6.22 Adjacent channel leakage ratios (ACLR) of 28 dB and 26 dB for base stations in the 26 GHz and 40 GHz ranges, respectively, have been defined in the 3GPP documents. In our sharing studies with fixed services, we have assumed that the emission levels will drop by the ACLR value at the edge of the 5G channel and further decrease at a rate of 3 dB for every 200 MHz separation from the edge of the channel. This is the same assumption we have made regarding the out-of-band emissions levels for 26 GHz 5G coexisting with passive services in the 23.6-24 GHz range. An illustration of the out-of-block emissions we have considered in shown in Figure A6.3.

A6.23 In our previous coexistence studies in sub-6 GHz, we only considered those in-band fixed links that are separated by less than two and half times the bandwidth of the 5G carrier from the 5G channel edge. Since we believe the out-of-block emissions from mmWave 5G devices may fall away more slowly as frequency separation increases than in other bands, we have considered the coexistence between 5G and fixed links across the entire 26 GHz and 40 GHz bands.

Figure A6.3: 5G emissions profile considered in the coexistence studies between mmWave 5G and fixed services



5G channel plan

A6.24 We have considered 5G channel bandwidths of 200 MHz, 400 MHz and 800 MHz in this analysis. Examples of the channelisation plans for 200 MHz channels in the 26 GHz and 40 GHz bands are shown in Figure A6.4 and Figure A6.5, respectively. Note that a different shading has been used for the bottom 850 MHz in the 26 GHz band (4 x 200 MHz channels) to differentiate between the spectrum we are proposing to authorise on a first come, first served and the spectrum we are proposing to authorise by auction in our proposed high density areas.

A6.25 Since we are considering 200 MHz channels in the example, there is 50 MHz of spectrum in the 26 GHz band that we have not considered here as shown in Figure A6.4.[27] We note

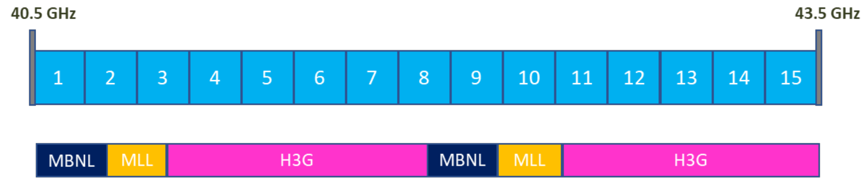
[27] There is 3.25 GHz of spectrum available in the 26 GHz band which can be divided into sixteen 200 MHz channels totally 3.2 GHz, leaving 50 MHz of spectrum which does not fit in the 200 MHz channelisation plan.

however that the entire 26 GHz spectrum could be authorised for new uses, for example, if a licensee request to use only 50 MHz.

A6.26 The channel plan for larger bandwidths is formed by aggregating smaller channels. For example, for channels of 400 MHz, the first 400 MHz channel is equivalent to channels 1 and 2 in the 200 MHz plan.

Figure A6.4: Illustration of a 200 MHz channel plan in the 26 GHz band

Figure A6.5: Illustration of a 200 MHz channel plan in the 40 GHz band



Modelling of fixed links in the 26 GHz and 40 GHz bands

A6.27 There are currently around 1,400 fixed links operating in the 26 GHz band which are coordinated by Ofcom. In the 40 GHz band, MBNL operate several thousand fixed links across the UK, around 4000, H3G operate less than one hundred, around 90 links, concentrated in a small number of cities, mainly in and around London, while MLL has no active deployment in the band.[28]

A6.28 The parameters we have used for modelling the fixed links in both bands are based on the parameters in the Recommendation ITU-R F.758[29] and listed in Table A6.2. We have not considered the effect of blocking in the analysis as we believe that the effect of out-of-block emissions from 5G base stations will dominate the coexistence analysis.

A6.29 We believe that blocking is unlikely to dominate the coexistence analysis because our analysis of the actual operating parameters of fixed links in the 26 GHz and 40 GHz bands showed that the typical EIRP spectral density[30] of the fixed links is high enough to be comparable with the proposed power levels of outdoor mmWave 5G base stations. For the 26 GHz links, the linear mean EIRP spectral density equals 50 dBm/MHz and the linear

[28] MLL has no current active deployments at 40 GHz, though we understand from pre-consultation engagement that it has deployed in the 32 GHz and 40 GHz bands in the past, including point-to-multi-point, small cells, and FWA uses. MLL has told us it continues to research develop and deploy capabilities in technologies such as FWA and Networked point-to-point Services.

[29] ITU-R document F.758-7, *System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference*, published November 2019, accessed May 2022.

[30] EIRP spectral density over 1 MHz is used for comparison between the power levels of fixed links and 5G base stations due to a large difference between the bandwidths of these systems.

median is calculated as 41 dBm/MHz. For the 40 GHz fixed links, the linear mean EIRP spectral density equals 35 dBm/MHz and the linear median is calculated as 29 dBm/MHz. For comparison, if we use the the worst case assumptions for 5G from Table A6.1 (i.e. 5G base station beam pointing slightly downtilted in elevation and towards the fixed link in azimuth and transmitting at the proposed regulatory power limit), then the in-block EIRP spectral density of a low power 5G base station would be equal to 24 dBm/MHz, and that of a medium power 5G base station – to 35 dBm/MHz. These 5G base station power levels are lower than or similar to those that the fixed links already have to cope with from other fixed links in the two bands, considering the linear mean and median EIRP spectral density values of the fixed links stated above. We also note that that the maximum EIRP spectral density of the real 26 GHz and 40 GHz fixed links is as high as 67 dBm/MHz and 47 dBm/MHz, respectively, and could theoretically be even higher for the 40 GHz band because the regulatory limit is 55 dBW EIRP in any measured bandwidth for that band.[31]

A6.30 We have considered the long-term protection criteria of the fixed links with an interference-to-noise ratio (I/N) of -10 dB in our assessment as we have done in our previous studies leading to WRC-19.[32] We have not investigated the impact of short-term propagation events because we think the risk of interference to fixed links will mainly be from relatively close 5G base stations (a few kilometers or less). Short-term propagation events only become relevant at much larger distances.

Table A6.2: Parameters used for fixed links

Parameter	Unit	Value	Comments
I/N	dB	-10	Section 4.13 in Rec. ITU-R F.758-7
Noise Figure (NF)	dB	6.5	Refer to Table 9 in ITU-R recommendation F.758-7
Bandwidth	MHz	7, 14, 28 or 56	Depends on individual fixed link
Antenna Pattern	NA	Parabolic	Recommendation ITU-R F.699[33]
Antenna Gain	dBi	Variable	Typical values range between 31 dBi and 48 dBi
Antenna Height	m	Variable	Values vary between about 4m and 100m above ground level

[31] Ofcom, *Auction of spectrum: 10 GHz, 28 GHz, 32 GHz and 40 GHz. Information memorandum*, 7 August 2007.
[32] Refer to Table C-3 in TG 5/1 studies, *Annex 03 Part 5 - Sharing and compatibility of the FS and IMT operating in the 24.25-27.5 GHz frequency range*, published September 2018, accessed September 2020.
[33] ITU-R document F.699-8, *Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz*, January 2018, accessed May 2022.

Modelling coexistence between outdoor mmWave 5G and fixed links

A6.31 As set out in section 5, we are required to give five years' notice before revoking fixed links licences for spectrum management reasons. Therefore, if we proceed with our proposals to revoke fixed links in and around high density areas, there could still be a period immediately after the auction during which new users would need to coexist with current licensees.

A6.32 Below, we explain our anslysis of how we expect coexistence between new uses and fixed links to affect spectrum availability in the 26 and 40 GHz bands. For this analysis, we have used the transmission characteristics of mmWave 5G base stations and the protection criteria for fixed links. We have studied real 26 and 40 GHz fixed links deployments in our proposed high density areas to assess how terrain and clutter might also affect coexistence with new mmWave base stations.

We used the interference-to-noise (I/N) ratio metric to assess the coexistence between new uses and fixed services

A6.33 Our studies to assess the coexistence issues between 5G and fixed services are based on the interference-to-noise ratio (I/N) protection criteria.

A6.34 The equation used for calculating the I/N metric is given in Equation A6.4:

Equation A6.4: Calculation of I/N from an interferer to a victim system

$$\frac{I}{N} = P_t + G_t + G_r - L_p - N + A_{MI} + A_{BW} + F_{WCR}$$

A6.35 Where:

$\frac{I}{N}$ is the interference-to-noise ratio at the victim receiver in dB
P_t is the transmit power of the interfering system in dBm / (BW in MHz)
G_t is the gain of the interfering system towards the victim receiver in dBi
G_r is the gain of the victim receiver towards the interfering system in dBi
L_p is the path loss between the interfering system and the victim receiver in dB
N is the victim receiver system noise in dBm / (BW in MHz), which is calculated as the sum of the thermal noise floor and noise figure of the receiver, i.e., $kT_0b + NF$, where k is the Boltzmann constant, T_0 is the temperature in Kelvin and b is the operating BW of the receiver
A_{BW} is the bandwidth adjustment factor in dB, given by the ratio $10\log_{10}\frac{overlapping\ BW}{interferer\ BW}$

$A_{MI} = 0$ dB for co-channel operation and $A_{MI} = -ACLR$ in dB for adjacent channel operation and $ACLR$ is the adjacent channel to interference ratio.
F_{WCR} is the worst case reduction factor in dB which we explain in more detail later in this annex.

A6.36 We do not consider building entry loss (L_{bel}) and loss due to body proximity (L_b) in Equation A6.4 as these are not applicable to the scenarios we are modelling. We also assumed a feeder loss of 0 dB, and so it was not included in the equation.

A6.37 We conducted the study using the HTZ Communications software, which enabled us to model real deployments of fixed links, and UK terrain. We have used the ITU-R P.452-16[34] propagation model and the clutter dataset developed for Ofcom by Siradel.[35] While the HTZ software is commonly used for determining the coverage around a transmitter, by applying the principle of reciprocity, we can calculate the proportion of the area in each high density area where 5G base stations would risk causing interference to fixed links. We refer to spectrum that cannot be used in these areas as the spectrum 'sterilised' by fixed links. This approach consists of modelling the fixed link receivers as transmitters with a nominal transmit power set to 1W (because using relative values allow us to analyse the impact of different thresholds) and generating the coverage around the station for a particular threshold. The coverage area generated corresponds to the area sterilised.

A6.38 The threshold value to use in HTZ Communications is derived from Equation A6.4 as:

Equation A6.5: Calculation of threshold value to use in determining the sterilisation zone

$$Threshold\ Value = -\left(P_t + G_t - N + A_{MI} + A_{BW} - \frac{I}{N} + F_{CR}\right) + 30\ dBm$$

A6.39 Note that the fixed link receiver antenna gain is already modelled within the HTZ Communications tool and so it is not included in Equation A6.5 in order to avoid double-counting.

A6.40 We have analysed the coverage plots from HTZ in Matlab to assess the spectrum availability in a given region. Further details are provided in the results section of this annex.

A6.41 We list the steps we followed for the analysis in Table A6.3.

[34] ITU-R recommendation P.452-16, *Prediction procedure for the evaluation of interference between stations on the surface of the Earth at frequencies above 0.1 GHz*, published September 2015, accessed May 2022.
[35] https://www.siradel.com/ - All right, title and interest in the Siradel dataset are owned by Siradel. Land usage classification has been developed as per Ofcom's requirements for radio wave propagation studies in 2015.

Table A6.3: Steps for determining fixed links sterilisation and channel availability for new uses

- Choose the city/high density area for the analysis.
- Select fixed links within 50 km from the centre of the selected area or within 100 km if analysing the London area. We believe that a radius of 50 km/100 km is adequate to capture all fixed links that may impact 5G deployment and import to HTZ Communications.
- Load clutter and digital elevation data in HTZ Communications
- Set the nominal power of each fixed links to 1W
- Under Network Calculation, select Tx/Rx FS coverage.
  - Set the heights of the Rx antennas to 6 m for low power or 15 m for medium power deployments
  - Set the simulation distances to 50 km or 100 km for London
  - Select the P.425-16 model under the Model options
  - Load the additional clutter losses for this model developed by Siradel for Ofcom.
  - Run the simulations
- Once the simulation is complete, export the site-by-site coverage plot in ASCII.

Spectrum availability analysis in Matlab

- Set the 5G channel bandwidth e.g., 200/400/800 MHz
- Create an array representing the high density region under investigation; each entry in the array represents a 100 m-by-100 m pixel
- For each 5G channel, identify which fixed link operate in co or adjacent channel
- Define the BEM for the 5G stations
- For each fixed link station, load the corresponding ASCII file
  - For each entry of the high density array, determine which of the 5G channel is useable, based on the BEM and threshold value calculated in Equation 4
- Plot a 'heat-map' illustrating the availability of 5G channels and extract corresponding statistics.

Increasing realism in our modelling

A6.42 The results of this analysis are dependent on the threshold value in Equation 5 and the input parameters of our modelling such as the transmit power, antenna gains, I/N threshold and out-of-block emissions characteristics from the 5G base station. Under the worst case assumptions, P_t and G_t would be set to the maximum TRP and beamforming gains. This would occur if the base station antenna panel is directly facing the fixed link receiver and transmitting a single beam at maximum power towards the fixed link receiver. We believe that these conditions do not represent typical operating conditions.

A6.43 We believe that a reduction of at least 12 dB in our modelling relative to the worst case is reasonable, due to one or a combination of the following:

- **Time averaged beam pattern of beamsteered antennas** – The beam pointing direction will change over time as the base station serves terminals in different locations and which will not always align with the victim fixed link receiver.

- **Multiple concurrent beams** – It is likely that there will be multiple concurrent beams from a base station pointing in possibly different directions. It is also expected that subsets of the antenna elements would be used for generating each beam which will lead to a corresponding decrease in the transmit gain. Each doubling of the number of beams could result in around 6 dB decrease in EIRP level from the single beam case. For example in a two-beam scenario, the antenna elements may be divided into two subpanels, each with half the total number of antenna elements and supplied by half the total available power. This would lead to a 3 dB lower peak beamforming gain per beam and 3 dB lower power per beam for a total reduction in peak EIRP of 6 dB.
- **How often the base station is transmitting** – Base stations will not be active on a continuous basis (i.e. a 100% duty cycle). We believe it is likely that base stations will be listening for uplink transmissions for at least 20% of time. Base stations also transmit less when the full data capacity of the base station is not needed and loading will typically vary depending on the time of the day and the number of active user terminals. The risk of interference therefore increases when both the 5G network and fixed link network are heavily loaded at the same time, but the risk of interference reduces when they are not heavily loaded at the same time. We acknowledge that the traffic of some fixed links and 5G base stations could be high at the same time, for example, when the fixed link is used for mobile backhaul.

A6.44 In addition to these factors, we believe that typical fixed link receivers using forward error correction (FEC) and adaptive modulation and coding are likely to be resilient to interference. We are undertaking experiments with real fixed link devices to assess this resilience. Furthermore, 5G base stations may operate at lower transmit power by using downlink power control, but the extent this improves coexistence may vary by how mobile equipment vendors implement power control.

A6.45 Given that there are several factors that could mitigate the risk of interference from 5G to fixed links, we have tried to estimate the combined effect of those mitigations. We have chosen a 12 dB reduction from the worst case and we have used this as the central case as part of our sensitivity studies. 12 dB reduction from the worst case could be representative of a heavily loaded base station using four traffic beams from a base station panel divided into four sub-arrays. Our sensitivity analysis has also considered a more conservative scenario with a 6 dB reduction from the worst case. For example, the 6 dB case could be representative of a lightly loaded base station having one beam with a long dwell period pointing towards a fixed link receiver. We have also considered a less conservative scenario with 18 dB reduction from the worst case which could represent a multiple beam 5G base station that is lightly loaded.

A6.46 Below, we explain our analysis of the extent to which each of the above mitigations might reduce potential interference from new uses to fixed links in more detail.

Time averaged beam pattern of beamsteered antennas

A6.47 Beamsteering from active antenna systems including in mmWave 5G could help to improve coexistence with fixed services because the 5G base station will move its beams to serve users across its coverage area.

A6.48 We have considered the time average effect of the antenna pattern in this study. For a single-beam base station serving terminals distributed across a sector, we have calculated that the mean antenna gain towards the horizon is approximately 12 dB lower than the maximum gain for both low and medium power deployments (see Table A6.4).

A6.49 The next subsections explain how we calculated the time averaged antenna pattern. First, we model the user equipment distributions around low and medium power base stations. The time average gain was computed by generating 10,000 random UE positions around the base station and taking the linear average of the patterns generated using Equation 3 and only considering azimuth angles within $\pm 60°$.

Table A6.4: Comparison of maximum and average base station gains towards the horizon

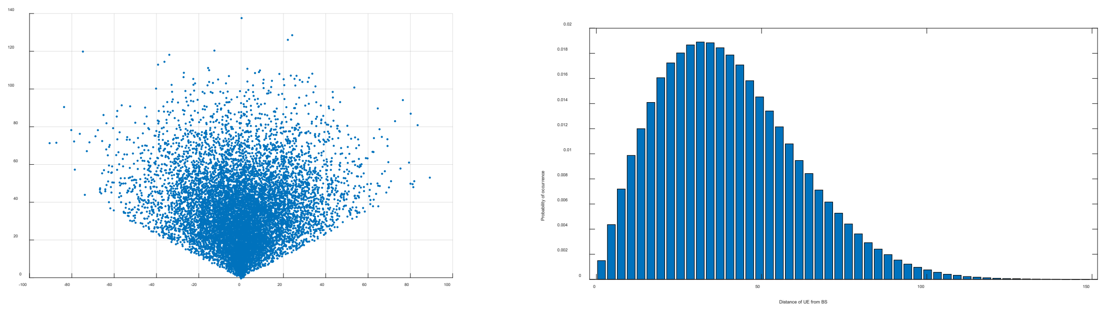
	Maximum gain towards horizon	Average gain towards horizon
Low power	22 dBi	10 dBi
Medium power	28 dBi	16 dBi

Low power deployments

A6.50 As in our previous work,[10] we have modelled the low power base station with an active antenna array size of 8x8 (i.e. 64 transmitting antenna elements) at 6 m above ground, serving mobile terminals or user equipment (UE) at 1.5m above ground. We base our simulations on the agreement reached in TG 5/1 for UE distribution around hotspots.[36] The UEs are assumed to follow a Gaussian distribution over $\pm 60^{\circ}$ in azimuth coverage angle and a Rayleigh distribution with $\sigma = 32$ m on the distance between the BS and the UE. This results in most of the UEs being within 100 m from its serving base station. A graphical representation of the UE spread around an urban/suburban hotspot is shown in Figure A6.6.

[36] For UE distribution around hotspots, refer to Section 12 of TG 5/1 studies, Annex 1, *System parameters and propagation models to be used in sharing and compatibility studies*, version May 2017, accessed August 2020.

Figure A6.6: Representative UE distribution around low power base station in busy hubs (distances in metres)



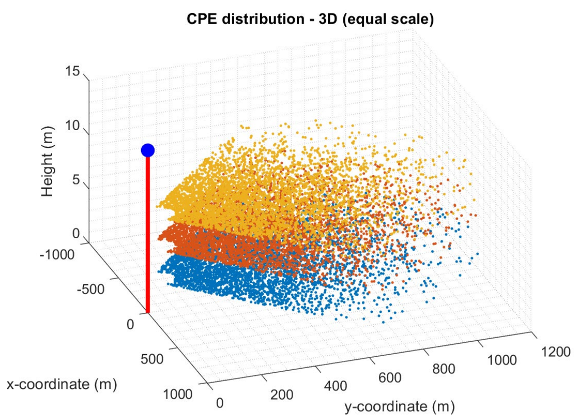
Medium power deployments

A6.51 Medium power base stations, which can potentially provide wider coverage, have more directional antennas with higher peak gains and located higher than low power base stations.

A6.52 To model the user equipment (UE) including CPE distribution, we made the following assumptions:

- The distance between the UE and the base station is Rayleigh distributed with parameter $\sigma = 400$ m, with the minimum distance being 100m and maximum distance to be 1.2 km;
- UEs are uniformly distributed at heights of 3 m, 6 m and 9 m. The reason for distributing the UEs at different heights is to model deployment across several floors in a building.
- UEs are uniformly distributed in azimuth between $\pm 60°$ from the base station boresight. As opposed to the UE distribution around low power base stations, we do not anticipate that UEs in medium power geometries to be concentrated mainly around busy locations. Instead, these would be deployed on consumer premises which are better represented by a uniform distribution. An illustration of the user terminals' distribution around a base station is given in Figure A6.7.

Figure A6.7: Illustration of terminals' distribution around a medium power base station



Multiple concurrent beams

A6.53 We believe that mmWave base stations are likely to support multiple beams concurrently. For example, we note that the 5G NR base station from Ericsson can generate between one and three beams per polarisation.[37] In the case of more than one beam being generated, the antenna elements are divided into subarray, with each of the subarray generating one beam.

A6.54 In the case of multiple beams generated by subsets of the antenna array, the movement of individual beam is likely to be less dynamic and less directional than if the whole array was used to generate a single beam at full power. For example, an antenna panel with 16x16 elements might generate either one beam with a gain of 29 dBi or two beams of 26 dBi or four beams of 23 dBi. The base station would also need to divide its power between each beam, so each doubling in the number of beams results in a four times (6 dB) reduction in the peak boresight radiated power. Assuming a TRP of 30 dBm (refer to Table A6.1) it would be possible to have one beam of 59 dBm / 200 MHz EIRP or two beams of 53 dBm / 200 MHz EIRP or four beams of 47 dBm / 200 MHz EIRP.

A6.55 We have only considered base stations generating a single beam in our coexistence studies but we consider the possibility of them generating multiple beams as an important part of the possible coexistence mitigations in our sensitivity analysis.

How often the base station is transmitting

A6.56 We do not expect a base station to be continuously transmitting. We have modelled the TDD DL/UL ratio to be 4:1 which means that the base station could transmit at most 80% of the time which we think could be reasonable for an outdoor mobile network.[38] We believe that this ratio DL/UL ratio can also be applied to mmWave services and note that an 80% DL traffic could reduce the interference by about 1 dB assuming the fixed link receiver has error correction which means that the effect of interference can be time-averaged.

A6.57 Considering the lean carrier design of modern mobile systems, including 5G, which can decrease the amount of control traffic and that all sites will not be fully loaded especially in the early roll-out stages, base stations might not be transmitting continuously during the downlink period.

A6.58 In this study, we have assumed that the base stations are always active but we believe that the downlink traffic factor could improve coexistence between 5G and fixed services and this has been considered as part of our sensitivity analysis.

[37] Ericsson, *EMF test report: Ericsson AIR 5322 B258/B258A*, date of report: June 2021, accessed March 2022.

[38] See section 5.1.4 in 5G smart, Evaluation of radio network deployment options, version 1.0, published on 21 December 2021, accessed March 2022.

Fixed links receiver resilience

A6.59 Factors such as FEC, adaptive modulation and coding and automatic repeat requests can improve the performance of fixed link receivers against interference from 5G.

A6.60 We are currently planning a measurement campaign to look at how dynamic interference will impact the performance of a fixed link and identify the conditions which will result in a link failure. We aim to run the experiment with equipment from different vendors as these may have varying resilience to interference.

A6.61 We will use the outcome of this measurement campaign to review and update our coexistence studies.

Spectrum availability results

A6.62 We have investigated how well fixed links and new uses would be able to coexist in six representative high density areas: Greater London, Greater Manchester, Tyne and Wear, Greater Birmingham, Edinburgh, and Greater Glasgow.

A6.63 The results below are shown as heatmaps indicating the number of 5G channels that could be used in any 100 m x 100 m square within each high density area if a base station was deployed in that square, taking into account fixed link use in each pixel. We also present bar plots showing the proportion of each high density area for which individual 5G channels can be used.

26 GHz results

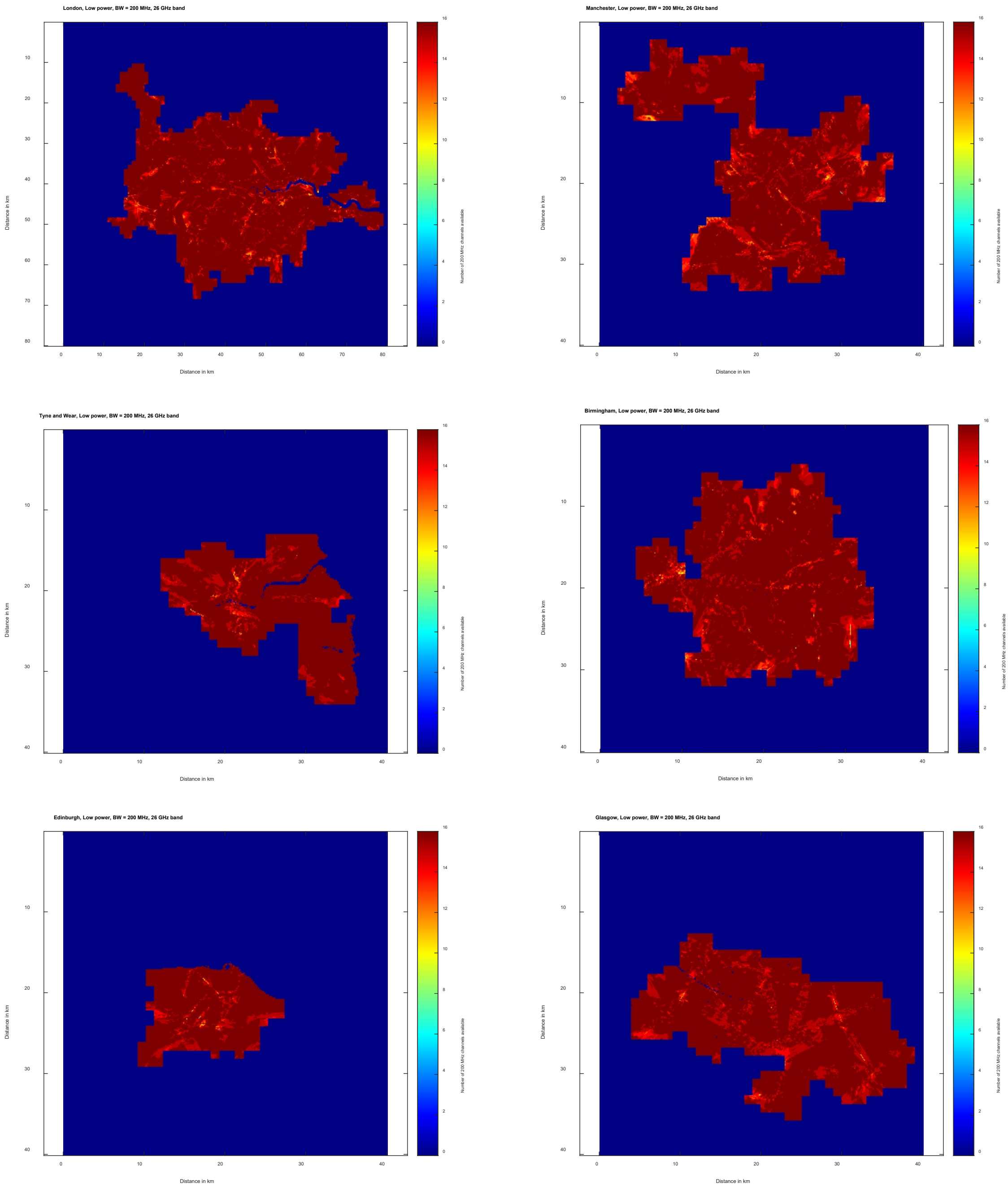
A6.64 We have analysed the extent to which existing fixed links would constrain new deployments in the 26 GHz band, and how this constraint would differ depending (i) on whether the new uses are operating at low or medium power, and (ii) whether they are operating in a 200 MHz, 400 MHz or 800 MHz channel size.

200 MHz channels

Low power

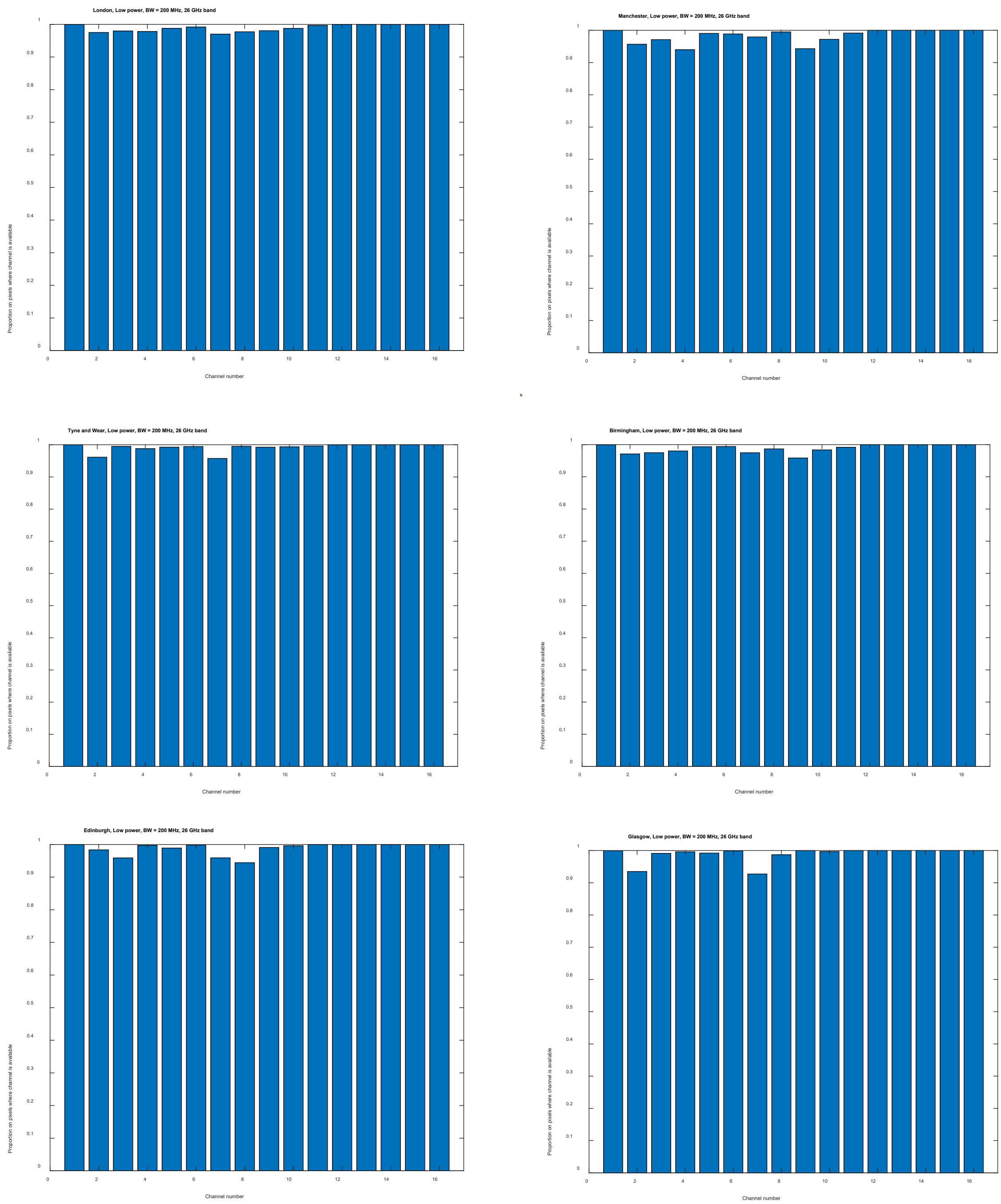
A6.65 The results of our analysis of the availability of 200 MHz channels for low power deployments are shown in Figure A6.8 and Figure A6.9. We note that in all the cities considered, there is greater than 97% location availability for low power services in frequencies which are co-channel with fixed links and greater than 99% location availability in frequencies not co-channel with fixed links. This can be attributed to the low power transmissions and the modelling of the base stations at 6 m height which is likely to mean they are transmitting through clutter (such as trees and buildings). The shielding from the clutter would reduce the risk of interference to the fixed services.

Figure A6.8: Heatmap showing the availability of 200 MHz channels for low power deployments in the 26 GHz band, the different colours indicate the number of channels available in each pixel of the high density area



A6.66 For example, the heatmap on the top left shows that in London, in all the grid squares which are shaded in dark red squares, all 16 channels are available for new uses. However, in the yellow squares, only 10 channels are available for new uses.

Figure A6.9: Bar plots showing the proportion of each high density area where each 200 MHz 5G channel is available for low power deployment



A6.67 For example, the chart at the top left shows that in London, existing fixed links would be able to coexist with new low power deployments with miminal risk of interference in channels 1 and 12-16, and would be able to coexist with minimal risk of interference in more than 97% of locations in the remaining channels.

A6.68 We observe in Figure A6.9 that in all the areas we considered, the spectrum sterlisation is slightly greater in 5G channels 2 to 11 than channels 1 and 12 to 16. This is because fixed links are deployed in 24.5-26.5 GHz which is a subset of the mobile band, 24.25-27.5 GHz, which means that 5G channels 2 to 11 are co-channel with incumbent fixed links and 5G channels 1 and 12 to 16 are not co-channel with incumbent fixed links.

Medium power

A6.69 The results of our analysis of the availability of 200 MHz channels for for medium power deployments are shown in Figure A6.10 and Figure A6.11. Here we observe that fixed links sterilise a significantly greater proportion of spectrum for medium power base stations than for low power base stations. Again, we note that 5G channels that are not co-channel with the fixed links, channel 1 and the channels 12 to 16 (c.f., Figure A6.4), are available over a greater area of the high density areas than 5G channels which are co-channel with fixed links. We also note that the availability of channels 12 to 16 gradually increases with greater frequency separation from the edge of the fixed link band which is an effect of the sloping out-of-block emissions characteristics considered in the analysis (c.f., Figure A6.3).

Figure A6.10: Heatmap showing the availability of 200 MHz channels for medium power deployments in the 26 GHz band, the different colours indicate the number of channels available in each pixel of the high density area

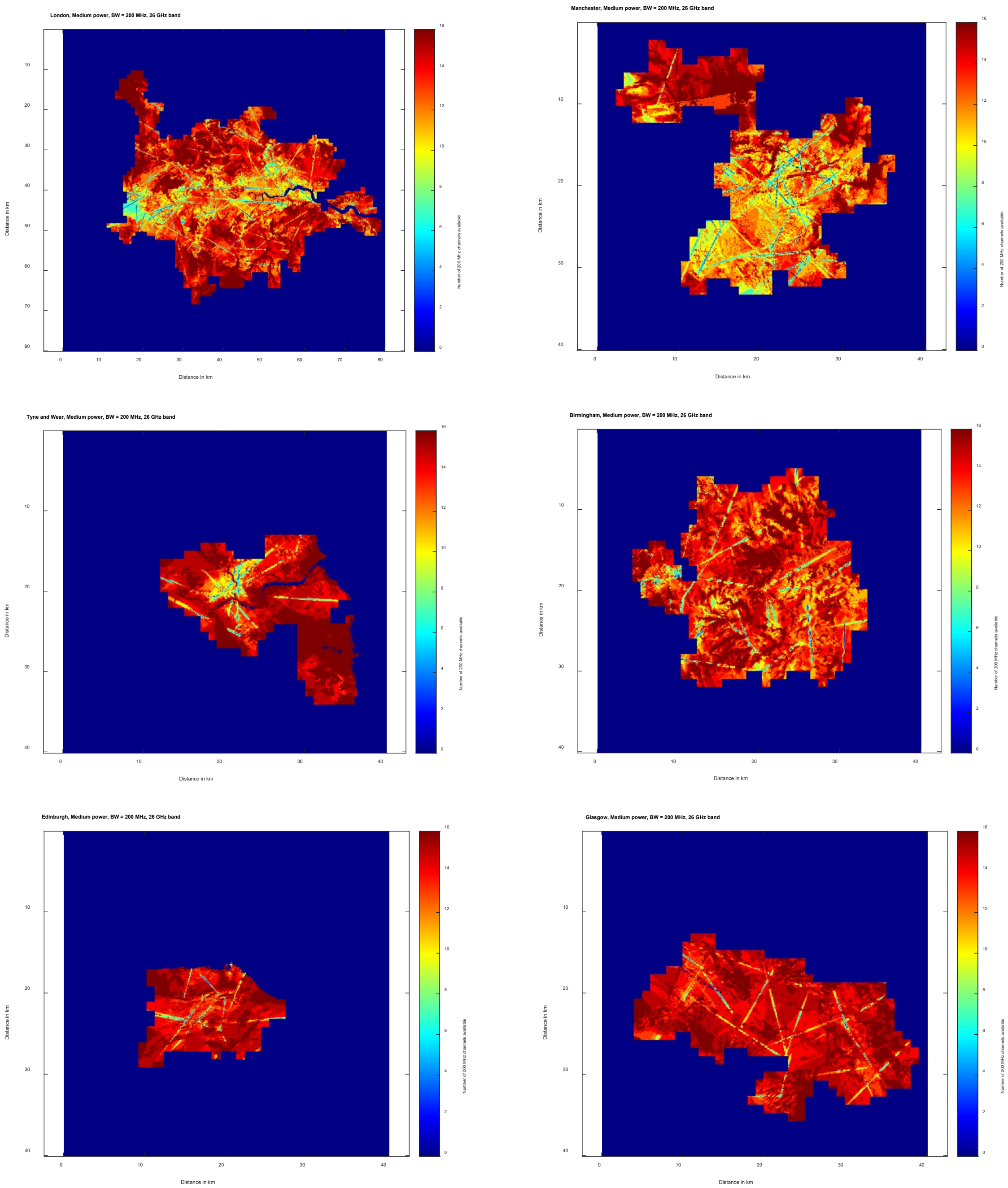
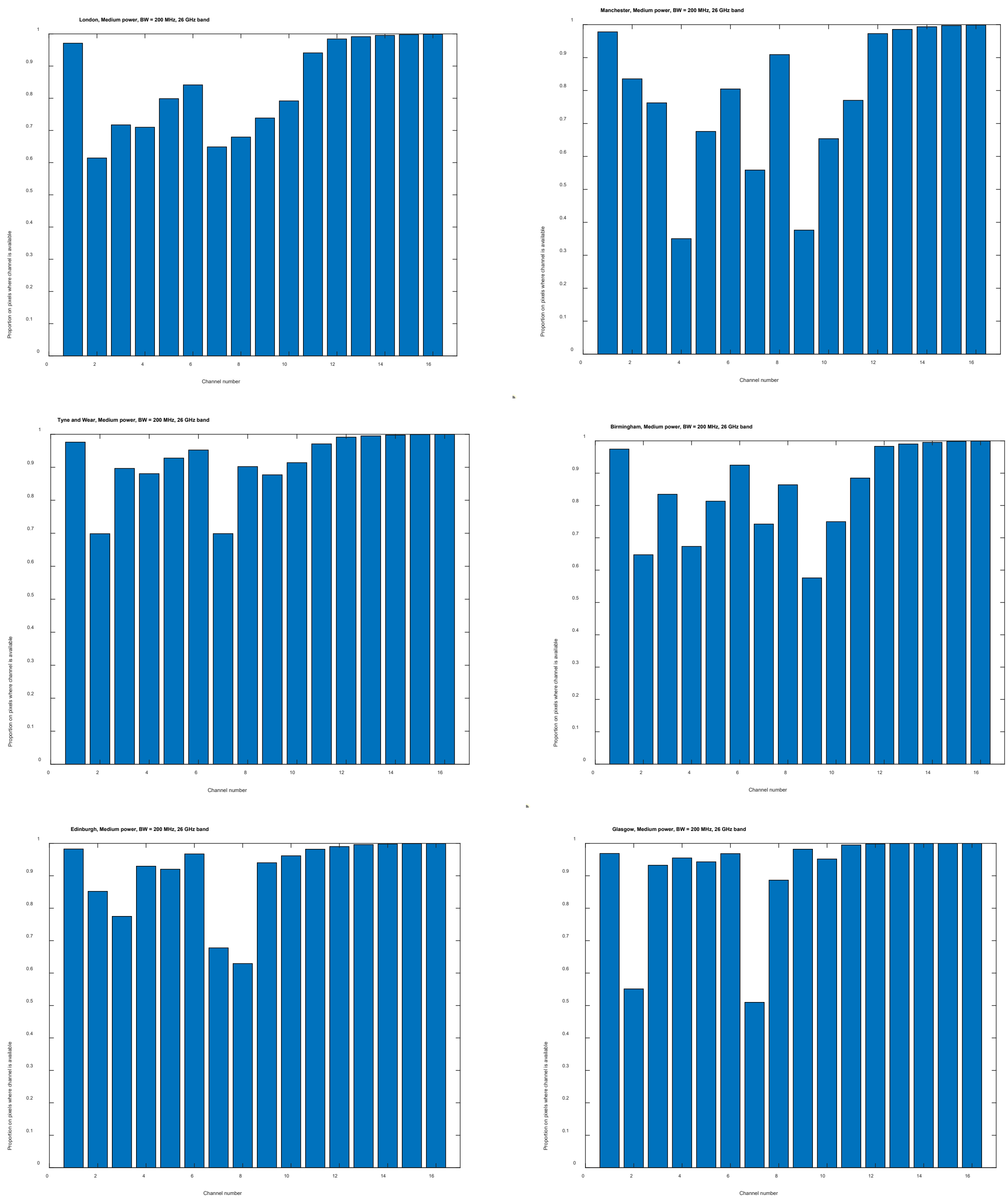


Figure A6.11: Bar plots showing proportion of each high density area where each 200 MHz 5G channel is available for medium power deployment



400 MHz and 800 MHz channel

A6.70 We have also analysed the availability of wider 5G channels of 400 MHz and 800 MHz. The results are provided in Figure A6.12 and Figure A6.13 for low and medium power deployments, respectively, in Manchester. Similar trends can be observed for the remaining cities and we have therefore not included them in this annex.

A6.71 As the 5G channel bandwidth increases the proportion of 5G channels which overlap with one or more more fixed link channels increases leading to a proportionately lower channel availability for wider channels than for narrower channels. Nevertheless, channel availability for low power deployments remains high for all of the 5G bandwidths studied. The availability for medium power deployments is significantly lower than for low power deployments in the channels which are co-channel with fixed links (channels 1 to 6 for 400 MHz channels and channels 1 to 3 for 800 MHz channels).

A6.72 For the 400 MHz channel plan, we have combined channels 1 and 2 from the 200 MHz raster[39] to form the first 400 MHz channel. Similarly we have combined channels 1 and 2 from the 400 MHz channel plan to create the first 800 MHz channel.

Figure A6.12: Channel availability in Manchester for low power deployments in the 26 GHz band for 400 MHz and 800 MHz channels

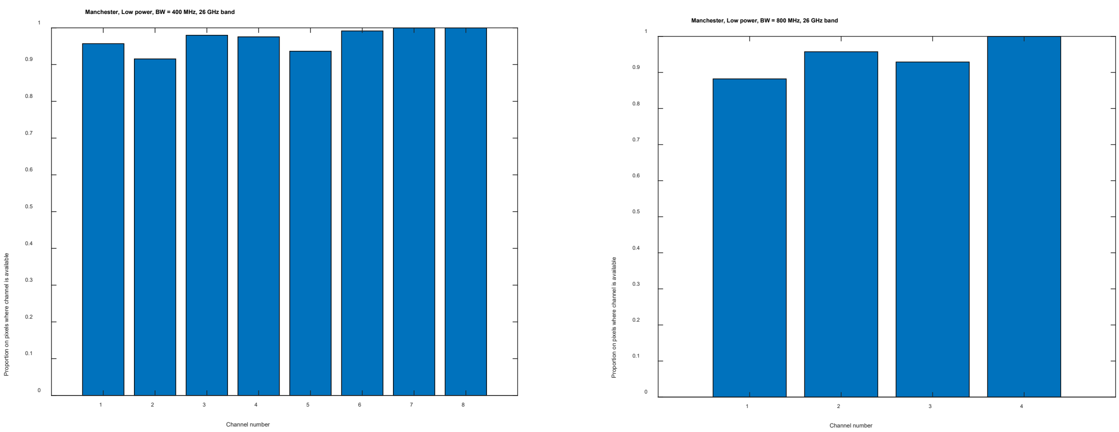
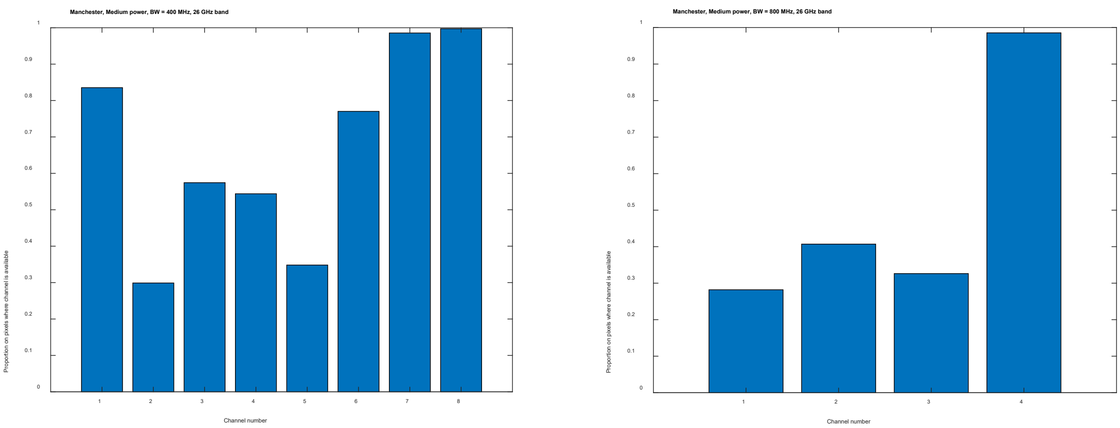


Figure A6.13: Channel availability in Manchester for medium power deployments in the 26 GHz band for 400 MHz and 800 MHz channels



[39] A raster refers to the increments in which the channels are assigned.

40 GHz results

A6.73 We have considered the extent to which existing fixed links would constrain new deployments in the 40 GHz band in three scenarios:

- Sterilisation caused by MBNL's fixed links only;
- Sterilisation caused by H3G's fixed links only; and
- Sterilisation caused by both MBNL and H3G's fixed links together.

A6.74 In each scenario, we have considered how the level of constraint would differ depending on whether new users are opering at low or medium power, and whether they are using 200, 400 or 800 MHz channels.

A6.75 We have not considered the impact of MLL's deployments because they do not currently have any active deployment in the 40 GHz band.

Sterilisation caused by MBNL's fixed links only

Low power

A6.76 MBNL operates the largest number of links in the 40 GHz band. The results of our spectrum availability analysis new for low power, 200 MHz bandwidth deployments are shown in Figure A6.14 and Figure A6.15.

A6.77 For low power deployments, we note good availability in the channels which are co-channel with MBNL's fixed links and almost total availability in the channels which are not co-channel with MBNL's fixed links.

Figure A6.14: Heatmap showing the availability of 200 MHz channels for low power deployments in the 40 GHz band, the different colours indicate the number of channels available in each pixel of the high density area

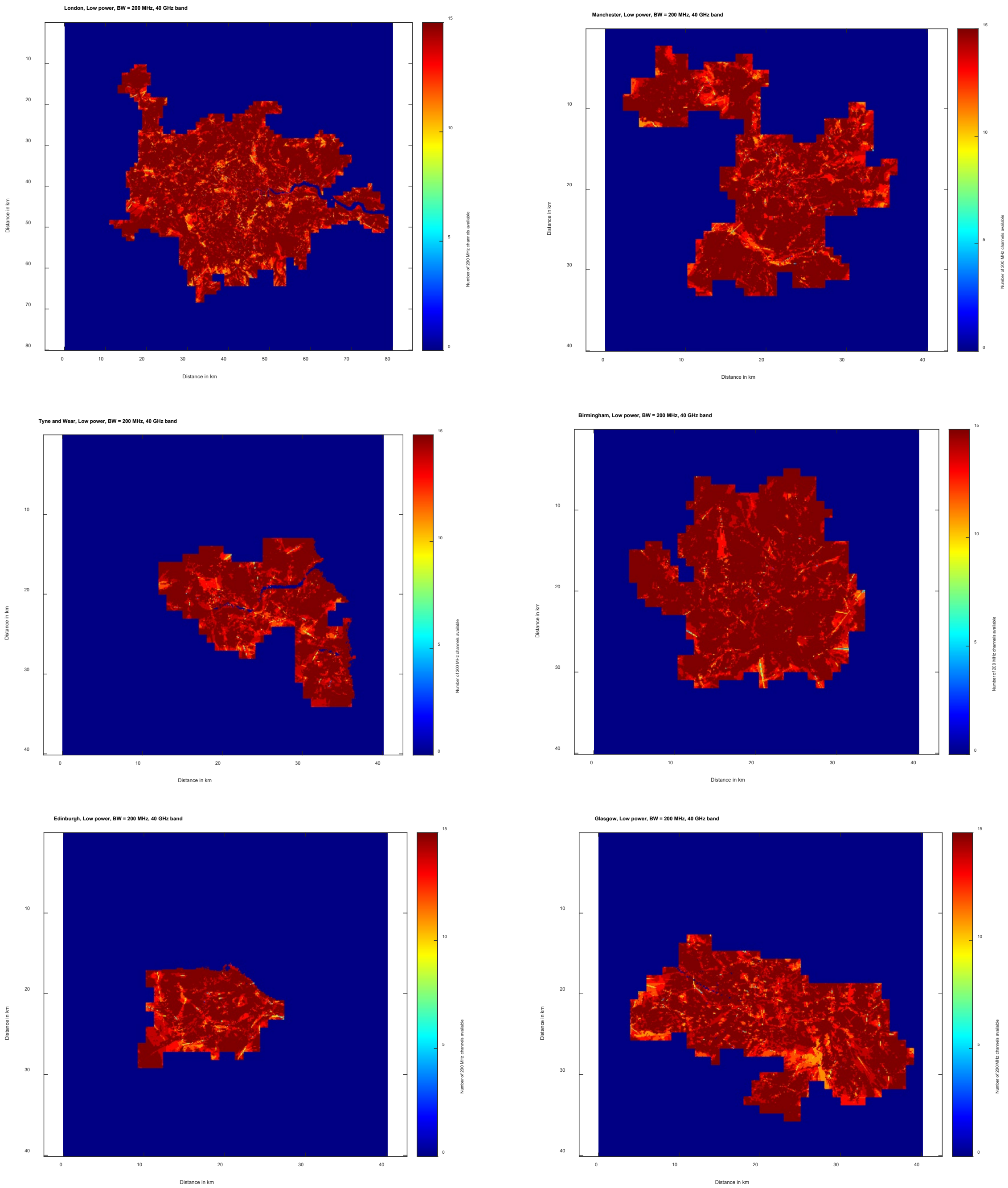
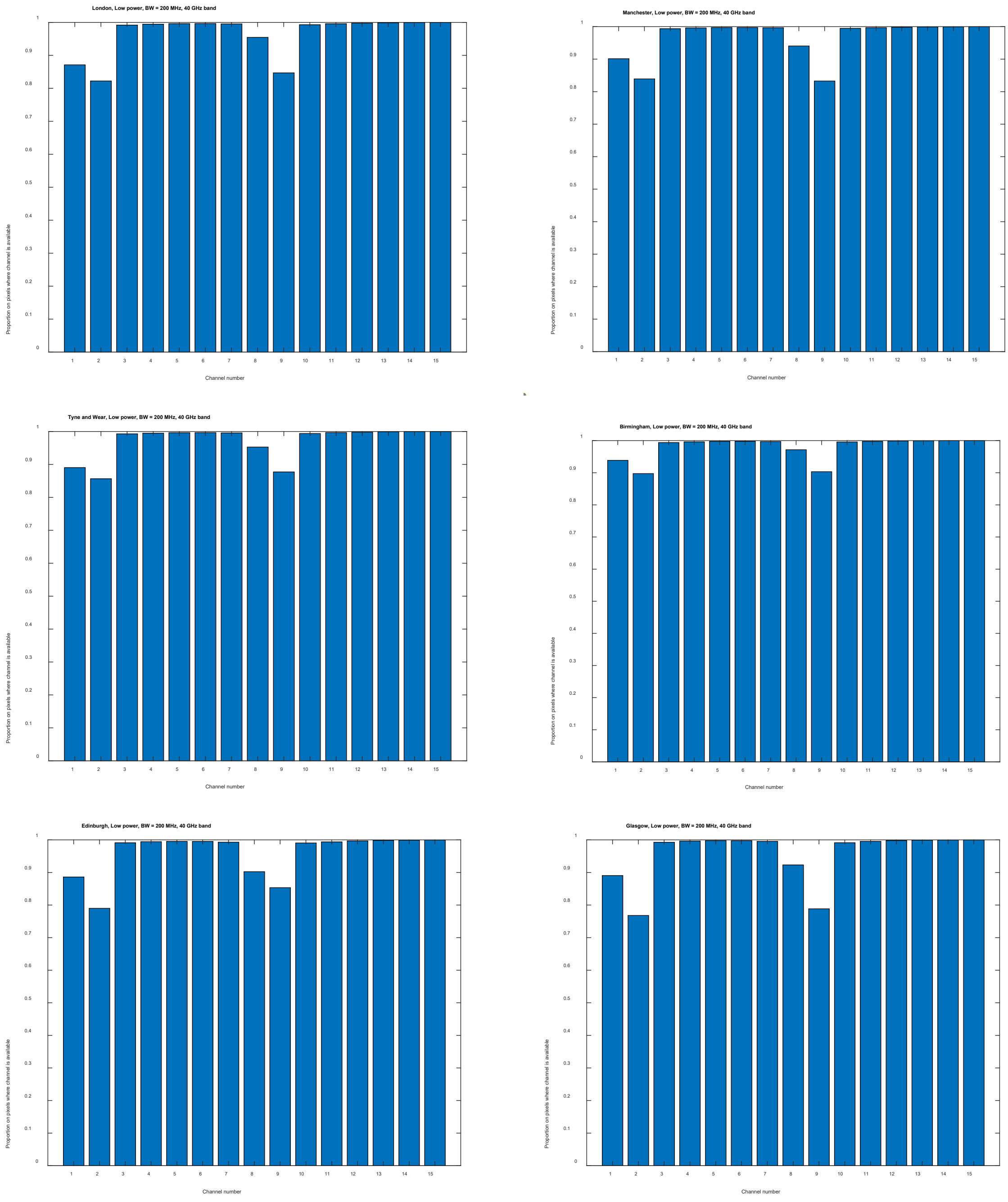
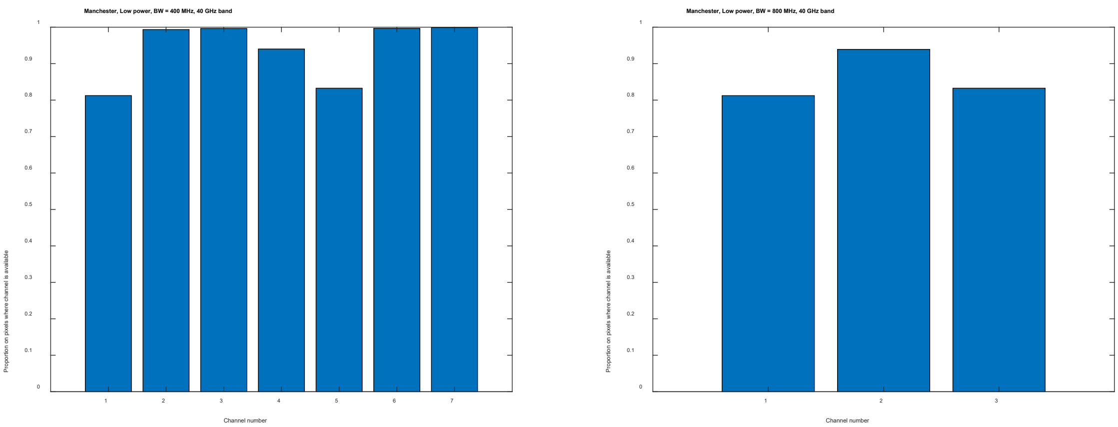


Figure A6.15: Bar plots showing proportion of each high density area where each 200 MHz 5G channel is available for low power deployment



A6.78 The availability plots for low power 400 MHz and 800 MHz channels are shown in Figure A6.16.

Figure A6.16: Channel availability for low power deployments in the 40 GHz band for 400 MHz and 800 MHz channels



Medium power

A6.79 Figure A6.17 and Figure A6.18 show the availability for medium power deployments in the 40 GHz band considering only MBNL's fixed links.

A6.80 In the medium power deployment scenario we note that there is significantly lower availability in the channels which are co-channel with MBNL's fixed links and good availability in the channels which are not co-channel with MBNL's fixed links.

A6.81 We also note that as there is a much larger density of fixed links in the 40 GHz band than the 26 GHz band and the impact of the sloping out-of-block emission levels on adjacent channel availability for medium power deployments can be more clearly seen here. Some form of coordination between the fixed links and new uses in adjacent blocks might therefore be necessary.

A6.82 We show the availability for medium power 400 MHz and 800 MHz channels in Figure A6.19. We note from Figure A6.16 and Figure A6.19 that for the 800 MHz channel plan, channels 1 and 3 have lower availability. This is an artefact of the channel raster that we have used and we recognise that in practice better availability could be achieved by alternate channelisation plans, e.g., by combining 400 MHz channels 2 and 3 to make first 800 MHz channel.

Figure A6.17: Heatmap showing the availability of 200 MHz channels for medium power deployments in the 40 GHz band, the different colours indicate the number of channels available in each pixel of the high density area

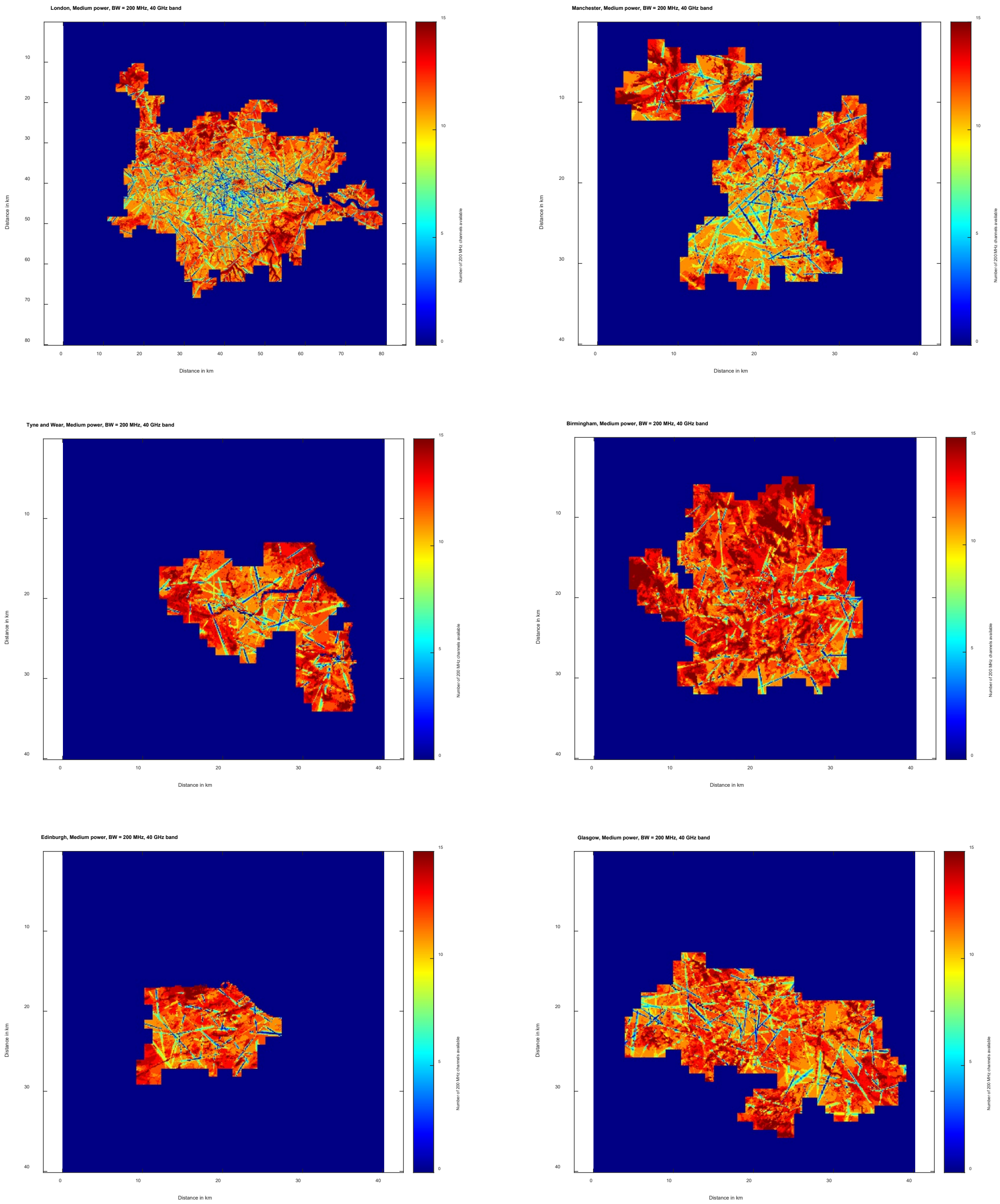


Figure A6.18: Bar plots showing proportion of high density areas where each individual 200 MHz 5G channel is available for medium power deployment

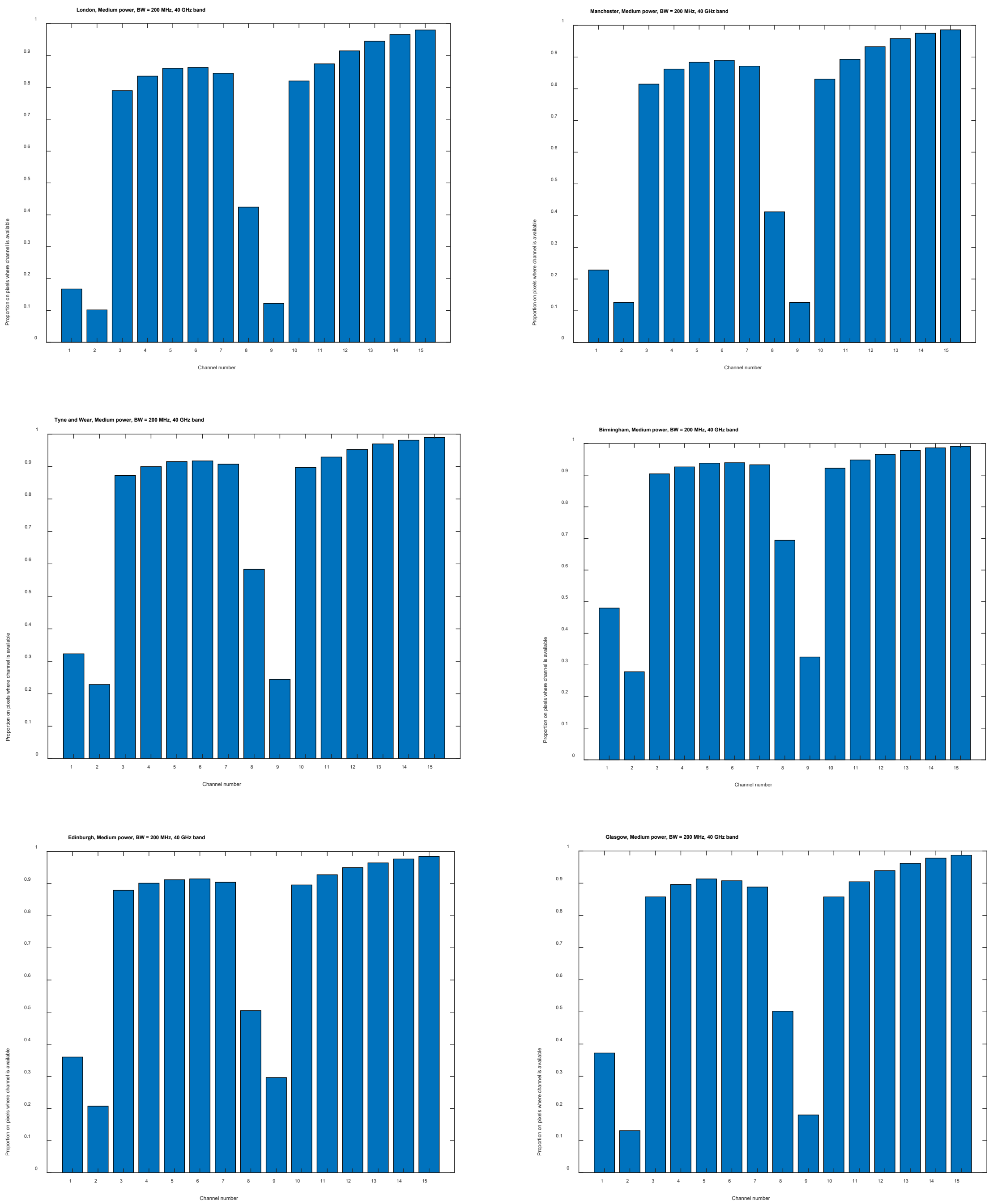
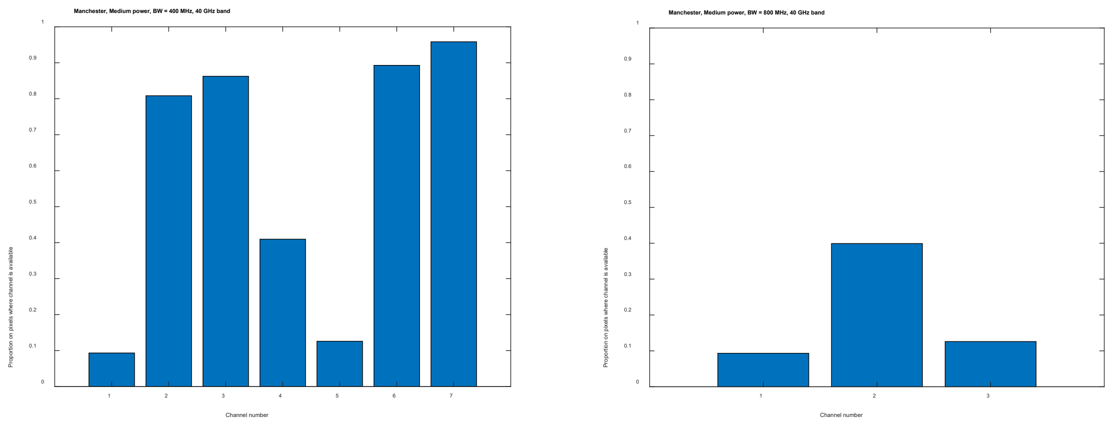


Figure A6.19: Channel availability for medium power deployments in the 40 GHz band for 400 MHz and 800 MHz channels



Sterilisation caused by H3G's fixed links only and sterlisation caused caused by both MBNL and H3G's fixed links together

A6.83 H3G has a small number of fixed links operating in the 40 GHz band located mainly around central London. Considering only these links, the availability of 5G channels for low and medium power services are shown in Figure A6.20 and Figure A6.21, respectively.

A6.84 We note that low power deployments in London would only risk causing interference to H3G's fixed links in a small number of locations. Medium power deployments will however pose a risk of interference to H3G's links over a wider area.

A6.85 For comparison, we also present the availability plots considering both MBNL's and H3G's fixed links in London in Figure A6.22 and Figure A6.23 for low and medium power deployments, respectively. Overall, we note little change in spectrum availability in London for low power deployments but about 10% reduction in availability for the medium power deployment compared to the results which only considered MBNL's links.

Figure A6.20: Availability of 200 MHz 5G channels for low power deployment in the 40 GHz band considering only H3G's fixed links

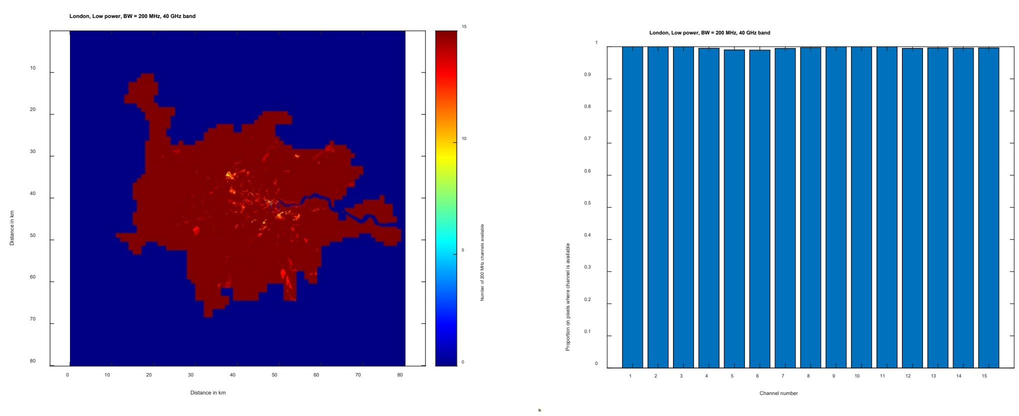


Figure A6.21: Availability of 200 MHz 5G channels for medium power deployment in the 40 GHz band considering only H3G's fixed links

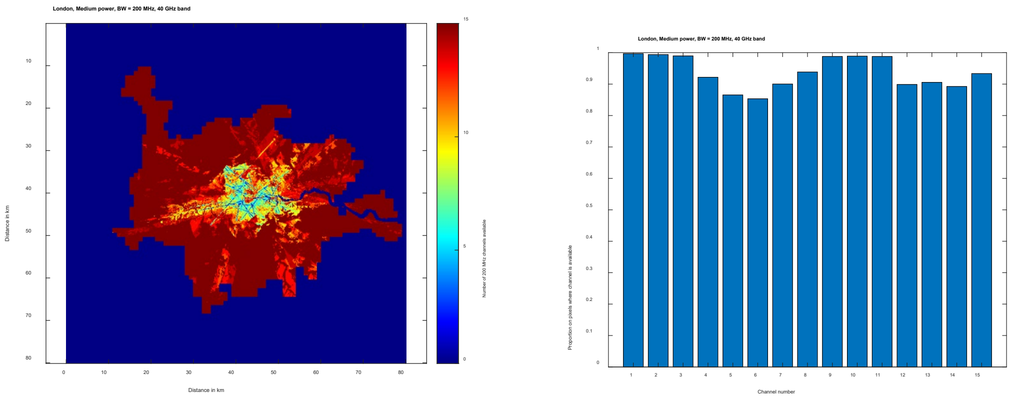


Figure A6.22: Availability of 200 MHz 5G channels for low power deployment in the 40 GHz band considering both H3G's and MBNL's fixed links

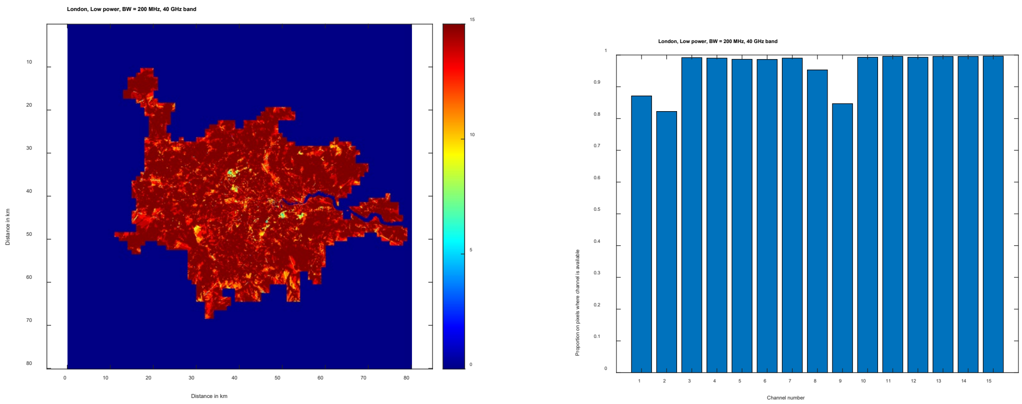
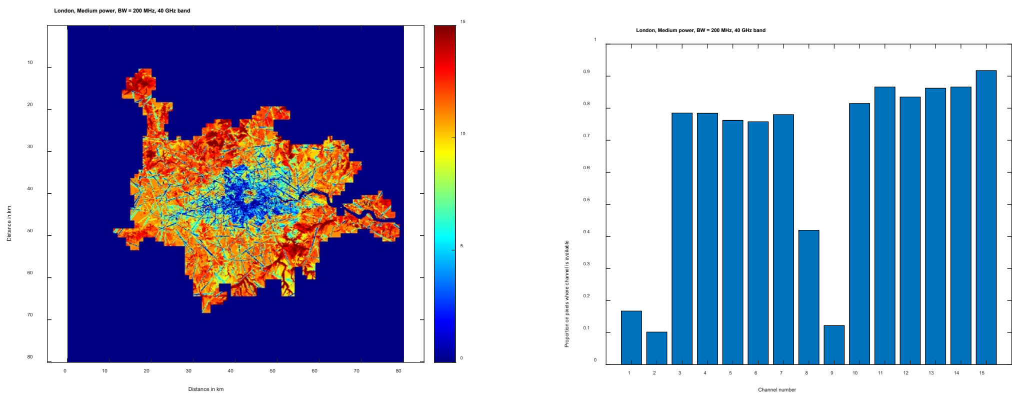


Figure A6.23: Availability of 200 MHz 5G channels for medium power deployment in the 40 GHz band considering both H3G's and MBNL's fixed links



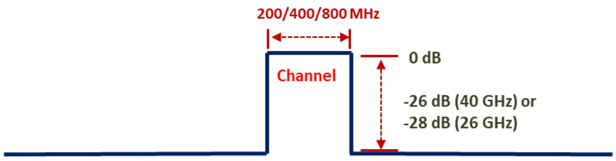
Sensitivity analysis to assess the impact of the modelling assumptions

A6.86 We believe that our modelling of the mmWave 5G to be representative of the devices in practice and the results presented in the previous sections to be a realistic study of coexistence between mmWave 5G and fixed links, however, we acknowledge that there remain some uncertainties over how signals from mmWave 5G, which could be more dynamic and time varying than signals from fixed links, will affect coexistence with fixed links. For this reason, we have conducted a sensitivity analysis to assess the impact of using different modelling assumptions than the ones we have used.

A6.87 Specifically, we have considered the following changes to our modelling assumptions:

- **Varying the worst case reduction factor (F_{WCR})**. In the case which we have already presented we considered that reducing conservatism by 12 dB from the worst case could be appropriate. In this sensitivity analysis we examine a case where conservatism is reduced by 6 dB only and another case where conservatism is reduced by 18 dB.
- **A 'flat' out-of-block emissions profile** which follows the block edge mask from the 3GPP standards with no decay from the edge of the block. An illustration of the flat out-of-block emissions profile is given in Figure A6.24.

Figure A6.24: Flat out-of-block emissions profile considered in the sensitivity analysis



A6.88 We have taken high density area in and around Manchester as an example. Results for the low power and medium power deployments in 26 GHz are shown in Figure A6.25 and Figure A6.26, respectively. The top-left plot represents the case where F_{WCR} is 6 dB and assuming a flat block edge mask while the middle-right plot represents our central case.

A6.89 The analysis demonstrates that the spectrum availability results for low power deployments do not significantly change under different modelling assumptions. The analysis shows that under the assumption of $F_{WCR} = 6\ dB$ and flat block edge mask, the adjacent channel availability for medium power deployment may be around 70%.

A6.90 The results for the 40 GHz band considering only MBNL's fixed links are shown in Figure A6.27 and Figure A6.28 for low and medium power, respectively.

A6.91 We note that the results for medium power deployments are more sensitive to the assumption on the BEM than the results for the low power deployments when considering the availability of spectrum for 5G outside of MBNL's holdings. The risk of interference will depend on the out-of-block performance of real equipment and whether medium power base stations are deployed near fixed links.

Figure A6.25: Comparison of 200 MHz channel availability for low power deployments in Manchester in the 26 GHz band under different modelling assumptions

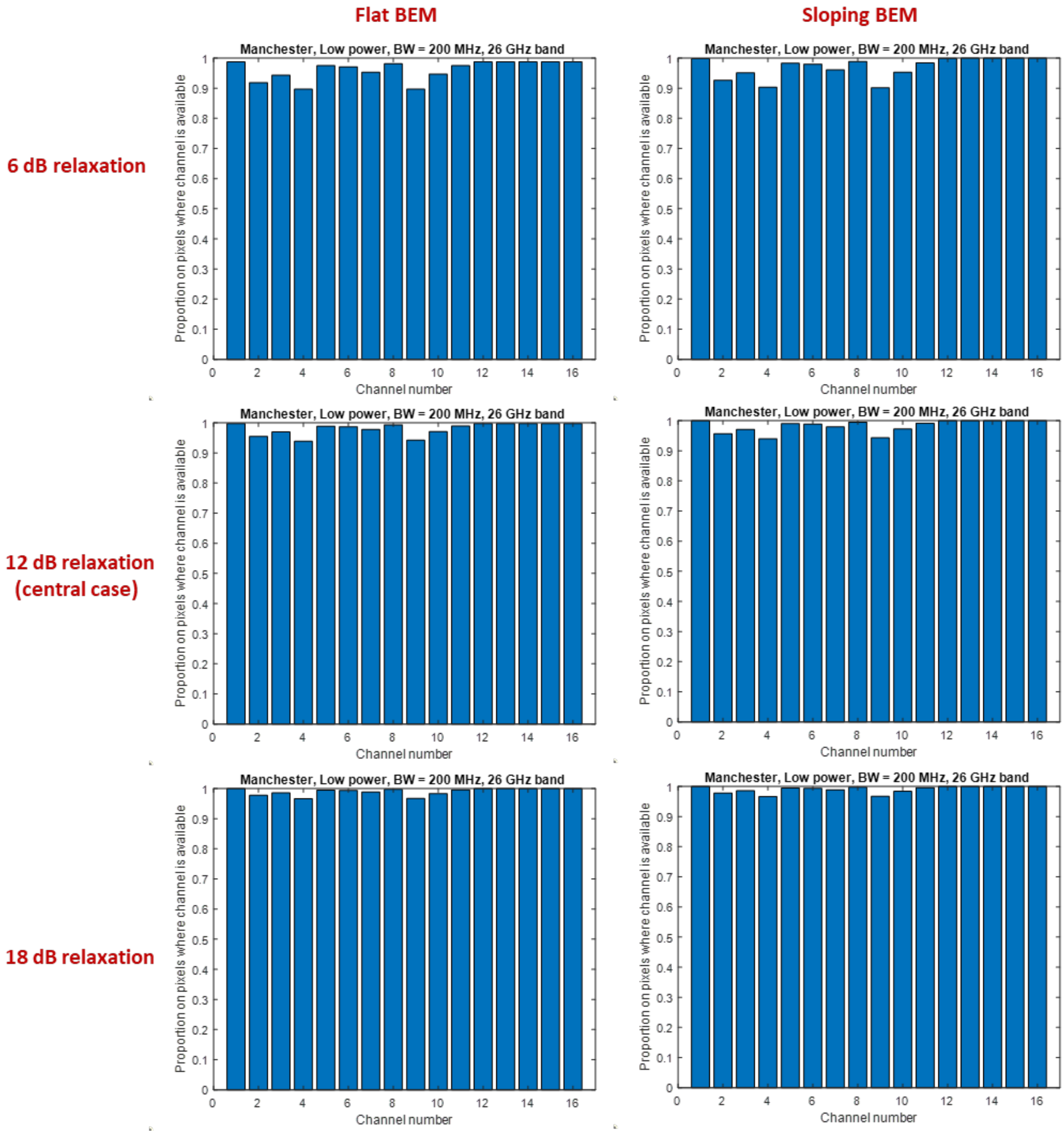


Figure A6.26: Comparison of 200 MHz channel availability for medium power deployments in Manchester in the 26 GHz band under different modelling assumptions

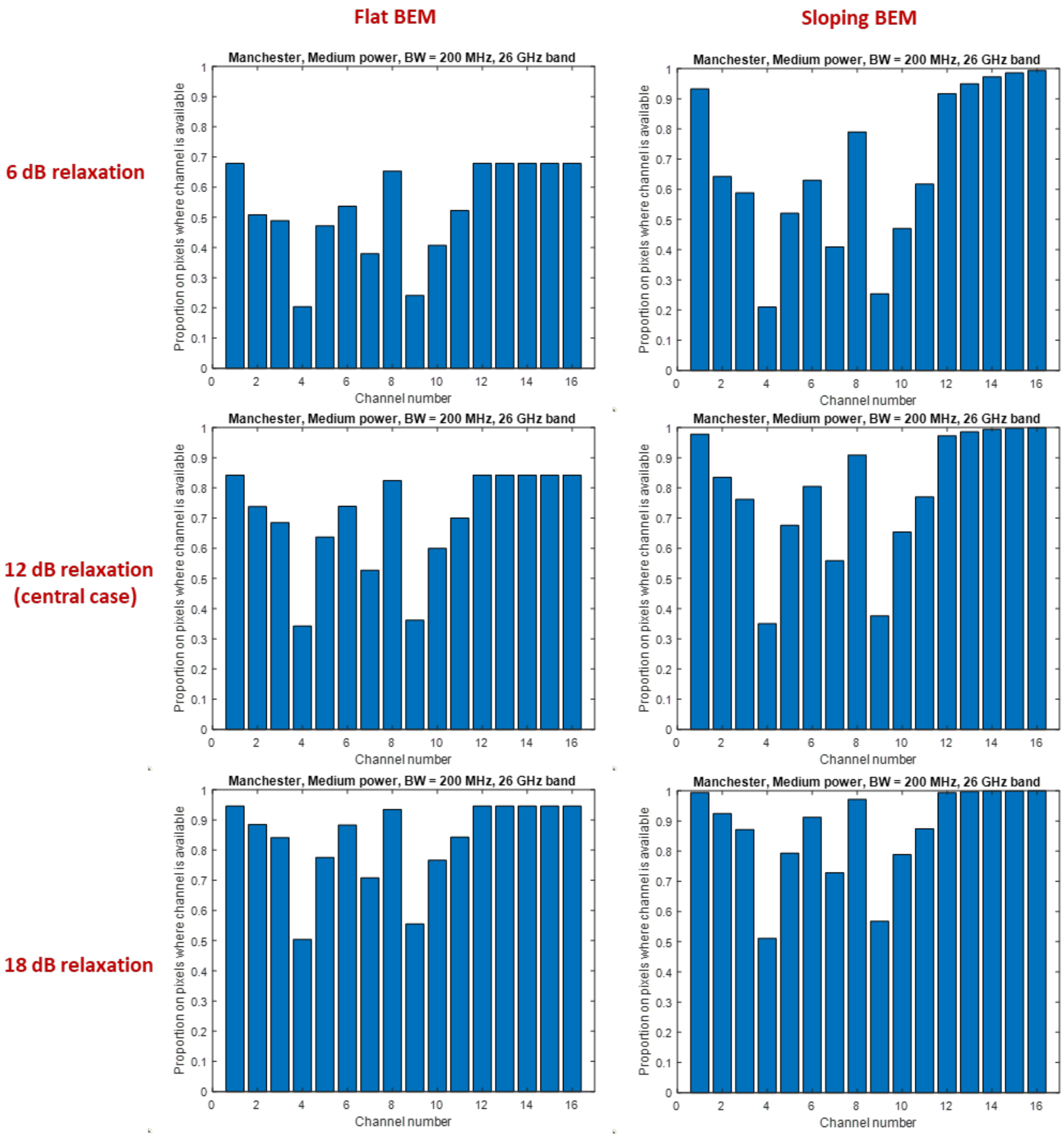


Figure A6.27: Comparison of 200 MHz channel availability for low power deployments in Manchester in the 40 GHz band under different modelling assumptions

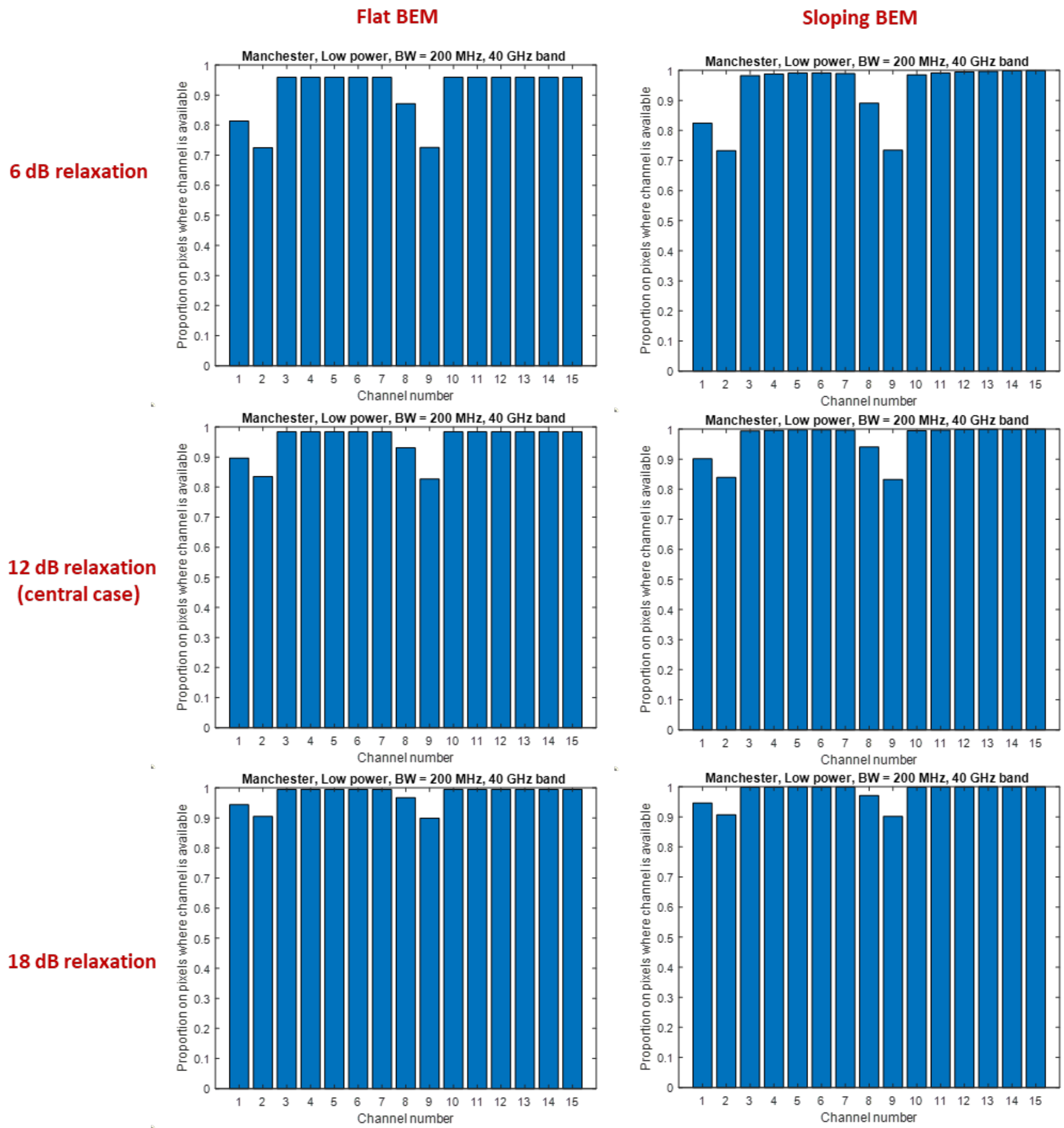
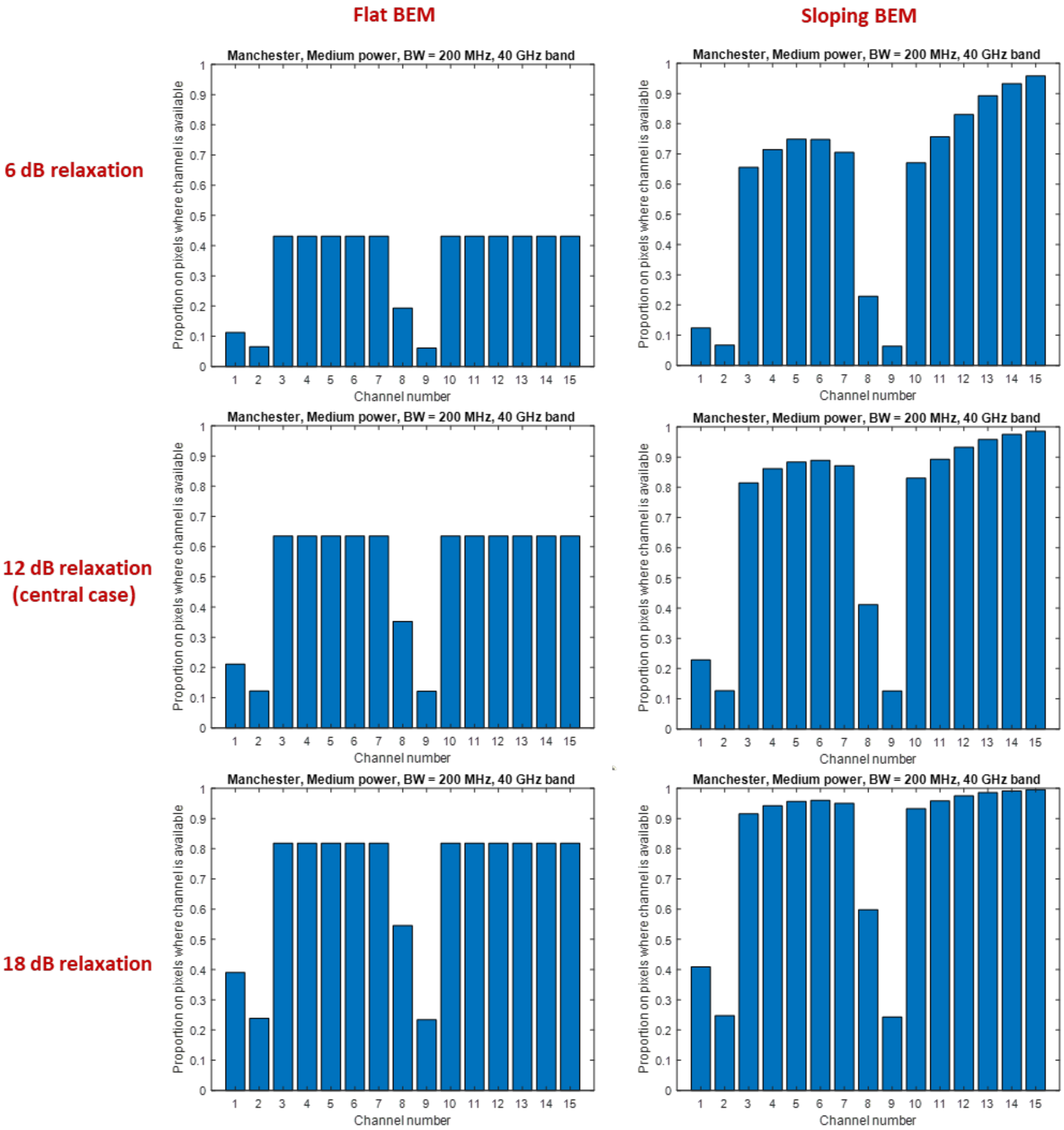


Figure A6.28: Comparison of 200 MHz channel availability for medium power deployments in Manchester in the 40 GHz band under different modelling assumptions



Conclusion

A6.92 We carried out coexistence analysis between mmWave 5G services and fixed links and investigated the amount of spectrum available for mobile operators to deploy base stations in high density areas. Our modelling assumes that there are mitigating factors which could combine to reduce the risk of interference by 12 dB when compared with the worst case scenario, and that 5G out-of-block emissions are likely to decrease as frequency separation grows.

A6.93 Our results indicate that low power base stations could operate co-channel with fixed services in a large proportion of locations in high density areas with little risk of interference in the 26 GHz band. In the 40 GHz band the number of locations where low power base stations could operate without a risk of interference to fixed links is slightly reduced because of the higher number of fixed links in the high density areas in the 40 GHz band than in the 26 GHz band. We also note that there is a risk of interference from medium power base stations to co-channel fixed services in a considerable proportion of locations in high density areas in both the 26 GHz and 40 GHz bands.

A6.94 Our results show that low power base stations could operate in adjacent frequency ranges to the fixed services in both the 26 GHz and 40 GHz bands with minimal risk of interference. However, there remains a risk of interference from 40 GHz medium power base stations to the fixed services in adjacent frequency ranges in a significant proportion of locations in high density areas. The extent of this risk depends on the modelling assumptions used and the management of this risk is likely to require further investigation.

A6.95 We summarise the outcomes of the studies in Table A6.5. We calculated the values in the table by taking the linear average of the spectrum location availability in each of the six high density areas that we studied. Some cities had higher or lower spectrum location availability than others and so we have used a range of values to reflect the differences we observed between cities. This analysis considers 200 MHz channels for new uses and we would expect the availability for wider channels (e.g. 400 or 800 MHz) to be lower than that shown in Table A6.5, because wider 5G channels are more likely to be co-channel with one or more fixed links than narrower 5G channels.

Table A6.5: Summary of 200 MHz channel availability for new wireless systems including 5G; the percentages are the percent of locations in high density areas where those frequencies are available

	26 GHz		40 GHz	
New wireless system power level	Co-channel with fixed links **2 GHz BW** 24.5 – 26.5 GHz	Not co-channel with fixed links **1.25 GHz BW** 24.25 – 24.5 GHz; 26.5 – 27.5 GHz	Co-channel with MBNL **2 × 0.250 GHz BW** 40.5 – 40.75 GHz; 42.0 – 42.25 GHz	Not co-channel with MBNL **2 × 1.25 GHz BW** 40.75 – 42.0 GHz; 42.25 – 43.5 GHz
Low power	> 97%	> 99%	85-90%	> 99%
Medium power	65-90%	> 99%	< 50%	85-95%

A6.96 To understand how sensitive our modelling is should real world deployments turn out to have different characteristics to those we have modelled, we also carried out a sensitivity analysis to understand how our results might change if we considered:

a) a worst case reduction factor of 6 dB instead of 12 dB;

b) a worst case reduction factor of 18 dB; and

c) a case where out-of-block emissions do not fall with greater frequency separation.

A6.97 In the case of interference to fixed links from medium power 5G base stations operating in adjacent frequency ranges, we found that the results were sensitive to our modelling assumptions, and about how 5G out-of-block emissions decrease with increasing frequency separation from the block edge.

A6.98 We will update our analysis in light of feedback from stakeholders. In addition, we are also carrying out measurements of fixed link receiver resilience and will use the results to further inform this analysis.

A7. Further details on methodology for defining high density areas

Introduction

A7.1 In this annex we provide additional details on the methodology we used to define high density areas, as described in section 4.

Other options for defining town and city boundaries

A7.2 As outlined in paragraph 4.6, we considered a range of different methods for identifying, and determining the boundaries of, the largest UK towns and cities.

A7.3 While we consider that the definitions of towns and cities used by the UK's statistics agencies (i.e. the Office of National Statistics (ONS), National Records of Scotland (NRS) and the Northern Ireland Statistics and Research Agency (NISRA)), and in particular the ONS' 'Major Towns and Cities' (MTaC) dataset, are likely to be the most suitable approach for defining high density areas, we also considered using grid squares, local authority boundaries, and postcodes.

A7.4 Below, we outline our assessment of these alternative options (i.e. grid squares, local authority boundaries, and postcodes).

Grid squares based on mobile traffic data

A7.5 We considered using grid squares to define the boundaries of high density areas, where the grid squares selected are based on the areas with the highest mobile traffic. An example of how this could conceptually work is the 5 km grid squares in Figure 4.1 in section 4.

A7.6 However, the exact boundaries created by this option would depend significantly on the size of the grid square chosen, and the alignment of the grid square system may mean that many towns are not neatly captured by this approach. In other words, while in some cases the grid squares may be neatly centred on a city, in others grid squares could split up a city across multiple squares. If only some of those squares have high data traffic, this would cause only parts of city to be identified as high density areas, which would reduce the likelihood of investment and rollout across the city. In addition, we would have to choose a suitable resolution for the grid squares we use, which would be a difficult judgment call as on one hand larger squares would pick up more rural areas outside of cities, whereas smaller squares may miss key locations in cities.[40]

[40] Identifying too few areas runs the risk of reducing citywide operators' economies of scale and incentives to invest in areas. However, identifying areas where deployments are likely to be fewer in number as high density areas would risk underutilisation of spectrum.

A7.7 As a result, we do not think that grid squares are appropriate for identifying high density areas, particularly for the risk of poor accuracy outlined above.

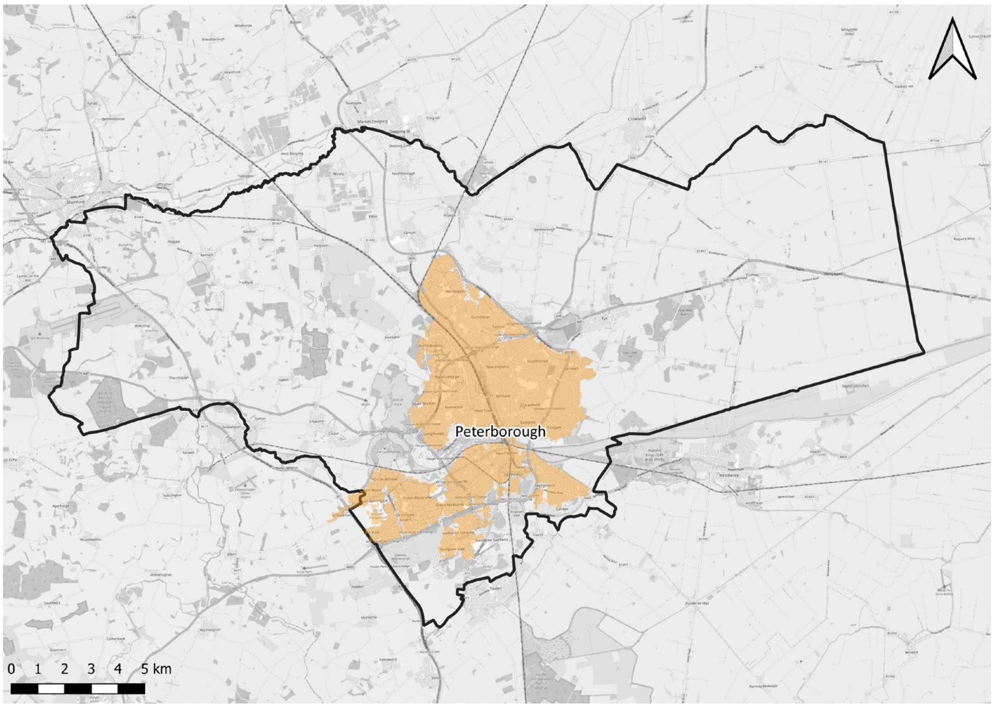
Local authority boundaries

A7.8 We also considered local authority boundaries, as these areas are likely to be easily recognisable to users, and are large enough to support investment and network deployment.

A7.9 However, we found that local authority boundaries, even for individual towns or cities, often cover large amounts of countryside as well as the towns and cities we are aiming to capture. This problem is identified in analysis by the ONS, which notes that "Local authority data are not suitable for investigating the topic of towns, as many local authorities include a number of different towns as well as encompassing rural areas and sometimes large urban conurbations."[41] An example of this can be seen in Figure A7.1 below, which shows the built-up area of the city of Peterborough along with the boundaries for Peterborough City Council.

A7.10 In conclusion, we do not think local authority boundaries are appropriate for identifying high density areas as they do not accurately match the pattern of mmWave deployment that we expect to see.

Figure A7.1: Map showing Peterborough City Council boundary (black outline) and Peterborough built-up area (orange)



Source: Ofcom; Office for National Statistics licensed under the Open Government Licence v.3.0; base map © OpenStreetMap contributors

[41] ONS, 'Understanding towns in England & Wales: an introduction', 9 July 2019.

Postcodes

A7.11 We also explored the use of different postcode area options to define boundaries, such as postcode districts (e.g. CF10). We found, however, that postcode districts vary substantially in size and, as with local authority boundaries, do not accurately capture the areas in which we are expecting to see the highest levels of mmWave deployment. Ofcom would also have to define which individual postcode areas were combined to form a high density area, on an individual city-by-city basis, which would introduce additional complexity. We also note that changes to postcode areas over time could cause confusion.

A7.12 As a result, we do not consider postcodes to be appropriate for identifying high density areas.

Addition of cities and towns in Scotland and Northern Ireland

A7.13 As explained in paragraph 4.9, the MTaC data from the ONS covers England and Wales, and includes the following 112 towns and cities:

Table A7.1: Towns and cities included in ONS' Major Towns and Cities dataset

Barnsley	Cheltenham	High Wycombe	Oxford	Stockport
Basildon	Chester	Huddersfield	Peterborough	Stockton-on-Tees
Basingstoke	Chesterfield	Ipswich	Plymouth	Stoke-on-Trent
Bath	Colchester	Kingston upon Hull	Poole	Sunderland
Bedford	Coventry	Leeds	Portsmouth	Sutton Coldfield
Birkenhead	Crawley	Leicester	Preston	Swansea
Birmingham	Darlington	Lincoln	Reading	Swindon
Blackburn	Derby	Liverpool	Redditch	Telford
Blackpool	Doncaster	London	Rochdale	Wakefield
Bolton	Dudley	Luton	Rotherham	Walsall
Bournemouth	Eastbourne	Maidstone	Salford	Warrington
Bracknell	Exeter	Manchester	Scunthorpe	Watford
Bradford	Gateshead	Mansfield	Sheffield	West Bromwich
Brighton and Hove	Gillingham	Middlesbrough	Shrewsbury	Weston-Super-Mare
Bristol	Gloucester	Milton Keynes	Slough	Wigan
Burnley	Grimsby	Newcastle upon Tyne	Solihull	Woking

Burton upon Trent	Guildford	Newcastle-under-Lyme	South Shields	Wolverhampton
Bury	Halifax	Newport	Southampton	Worcester
Cambridge	Harlow	Northampton	Southend-on-Sea	Worthing
Cardiff	Harrogate	Norwich	Southport	York
Carlisle	Hartlepool	Nottingham	St Albans	
Chatham	Hastings	Nuneaton	St Helens	
Chelmsford	Hemel Hempstead	Oldham	Stevenage	

Source: ONS Major Towns and Cities statistical geography.

A7.14 As the MTaC dataset from the ONS only relates to England and Wales, we have replicated the approach to include Scotland and Northern Ireland, to generate a dataset which covers the whole of the UK. To do this, we included all towns and cities in Scotland and Northern Ireland with a population of 75,000 or more, the same threshold used by the ONS to create the MTaC dataset.[42]

A7.15 When adding these towns and cities, we have used boundaries defined by National Records Scotland (NRS) and the Northern Ireland Statistics and Research Agency (NISRA). In the case of Scotland, we have used the boundaries for **Localities**, as used in NRS' Mid-2020 Population Estimates for Settlements and Localities in Scotland.[43] In the case of Northern Ireland, we have used NISRA's 2015 Settlement Development Limits (**SDLs**).[44]

A7.16 Using this method, we have added the following areas:

Table A7.2: Towns and cities in Scotland and Northern Ireland with population over 75,000

Scotland	Northern Ireland
Glasgow	Belfast
Edinburgh	Derry/Londonderry
Aberdeen	
Dundee	
Paisley	
East Kilbride	

Source: Ofcom; population data UK Census 2011; Locality boundaries from NRS; SDL boundaries from NISRA

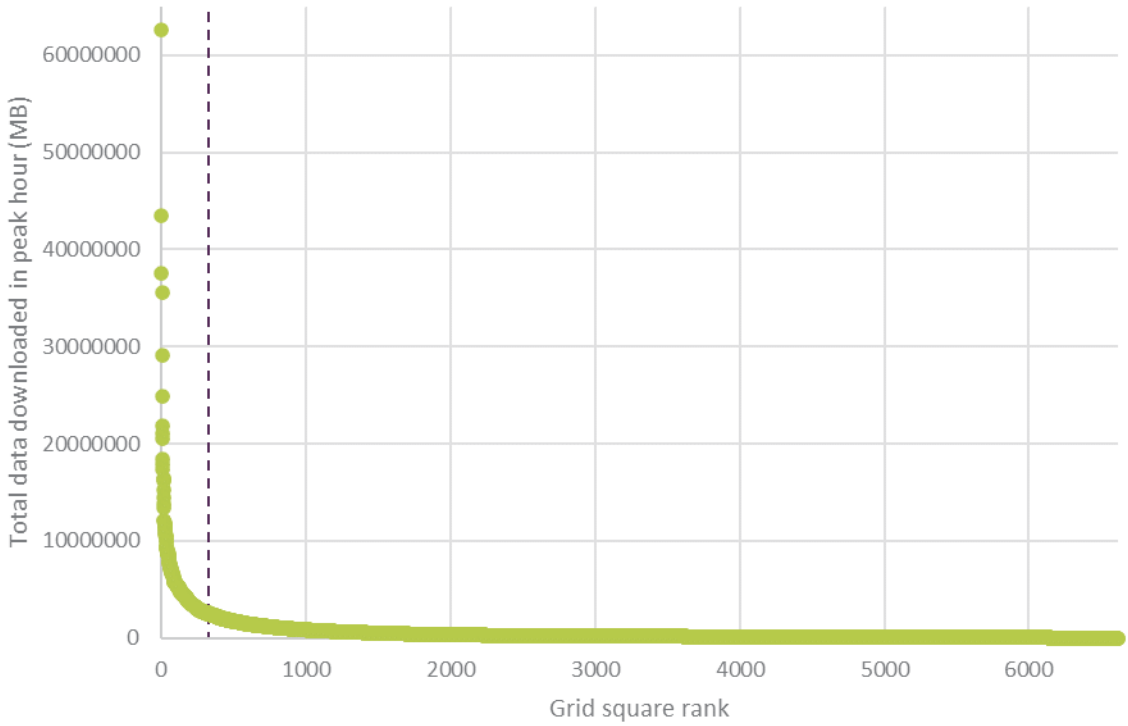
[42] The original MTaC threshold is set at 75,000 residential or workday population, in order to cover towns which the ONS deemed serve as significant local centres. As we were unable to determine the workday population of settlements in Scotland and Northern Ireland, we have used residential population in these cases.
[43] NRS, Mid-2020 Population Estimates for Settlements and Localities in Scotland; file used was *Localities2020_MHW.shp*
[44] NISRA, Settlement Development Limits (2015).

Inclusion of additional towns with high data traffic

A7.17 As outlined in paragraph 4.11, we consider that the amount of mobile data used in a town at peak times is also an important indicator of whether that town should be classified as a high density area. We have therefore identified which areas of the UK have the highest data traffic (using data obtained through Ofcom's Connected Nations report).

A7.18 In carrying out this analysis, we assessed the total peak hour data traffic across the UK based on 5 km grid squares.[45] When these results are plotted on a graph in descending order, as can be seen in Figure A7.2 below, there is a sharp decline in the peak hour data traffic immediately. We consider that there is a reasonable breakpoint in the curve at 5%, where the peak hour data traffic has reduced considerably compared to the highest data squares. We have then used the top 5% of 5 km squares to add additional towns with high data traffic.

Figure A7.2: Total peak hour data downloaded in 6,613 5 km grid squares in the UK, showing vertical line at 5% (331st ranked grid square)



Source: Ofcom

A7.19 As outlined in paragraph 4.13, while most of the locations with high data throughput we had identified in this way were already included in the list of towns and cities, a small number of locations were not represented. For those additional locations, we identified which city or town the relevant grid square covered and added these to our list.

[45] We only included 5 km grid squares where there was at least one base station with data traffic.

A7.20 We have done this using boundaries from the same datasets which already formed our list of towns and cities with populations of 75,000 or higher:

a) **England & Wales**: we used either Built-up Areas (BUAs)[46] or Built-Up Area Sub Divisions (BUASDs),[47] which are both set out by the ONS based on 2011 Census data. These BUAs and BUASDs are used in the creation of the MTaC dataset, so we consider that it is consistent for us to use these for additional settlements in England & Wales.

b) **Scotland**: we used Localities, as outlined in paragraph A7.15.

c) **Northern Ireland**: we would have used SDLs, as outlined in paragraph A7.15, however there were no additional areas in Northern Ireland added through this stage.

A7.21 In some instances, it was easy to determine which town or city was associated with a high data grid square, as the boundaries outlined above only indicated one BUA, BUASD or Locality within a 5 km grid square. However, in other cases the boundaries indicated that it was possible that the high data usage being generated in an area could be attributed to several different areas. This was more prevalent with suburbs of major cities. In these cases, we have not sought to include every single BUA, BUASD or Locality which overlaps with a given 5 km grid square, but have tried to capture the areas where we think it is most likely the high data traffic is associated with. In doing this, the criteria we use to assess whether or not to include a BUA, BUASD or Locality are:

a) **Population**: we have prioritised areas with higher populations over those with lower populations.

b) **Placement in relation to grid square**: an area which has only a small portion of it overlap with the high data grid square would be less likely to be included than an area fully within the grid square.

c) **Local features**: we have considered features on the ground in the relevant areas which could drive high data traffic, such as high streets, shopping centres, transport hubs and other sites which could have high enough footfall to account for high mobile data usage.

A7.22 Through this method, we added the following 57 additional locations into our list:

[46] ONS, Built-up Areas (December 2011) Boundaries V2.
[47] ONS, Built-up Area Sub Divisions (December 201) Boundaries.

Table A7.3: Additional high-data locations

England and Wales (BUAs and BUASDs)		
Aldershot BUASD	Frimley BUASD	Redhill (Reigate and Banstead) BUA
Altrincham BUASD	Gosport BUASD	Rochester BUASD
Ashford (Ashford) BUASD	Gravesend BUASD	Runcorn BUASD
Ashton-under-Lyne BUASD	Grays BUA	Sale BUASD
Aylesbury BUASD	Hatfield BUASD	Scarborough BUA
Bexley BUASD	Hebburn BUASD	Stafford BUASD
Bluewater Retail Park	Hindley BUASD	Staines BUASD
Bootle BUASD	Ince-in-Makerfield BUASD	Stalybridge BUASD
Camberley BUASD	Jarrow BUASD	Stoke Mandeville BUASD
Clacton-on-Sea BUA	Kettering BUASD	Swanscombe BUASD
Crosby BUASD	Litherland BUASD	Tamworth BUA
Dewsbury BUASD	Loughborough BUA	Thanet BUA
Dukinfield BUASD	Maidenhead BUASD	Tynemouth BUASD
Epsom BUASD	New Addington BUA	Wallsend BUASD
Ewell BUASD	Newbury BUASD	Waltham Abbey BUASD
Farnborough BUASD	Northfleet BUASD	Waltham Cross BUASD
Filton BUASD	Platt Bridge BUASD	Weybridge BUASD
Scotland (Localities)		
Bellshill	Carfin	Carfin
Blantyre	Coatbridge	Rutherglen
Bothwell	Hamilton	Uddingston

Source: Ofcom; BUA and BUASD boundaries from ONS; Locality boundaries from NRS

Full ranked list of 107 discrete potential high density areas

A7.23 As outlined in paragraphs 4.15-4.19, we have used a 1 km grid square overlay to determine the boundaries of the high density areas. In doing so, towns and cities that share boundaries or are near each other are merged together, giving a total of 107 discrete areas. These discrete areas form our list of potential high density areas.

A7.24 From paragraph 4.21 onwards we explain how we have ranked all these 107 potential areas using data on peak hour mobile data, and base station density.

A7.25 Table A7.4 below gives a ranked list of all 107 potential high density areas, and outlines which constituent areas have been combined together to form each of the 107 areas. These constituent areas will all be one of the following:

a) An ONS Major Town or City (**MTaC**);

b) An ONS Built-up Area (**BUA**);

c) An ONS Built-up Area Sub Division (**BUASD**);

d) An NRS Locality in Scotland (**Locality**); or

e) A Northern Irish settlement defined by NISRA's Settlement Development Limits (**SDL**).

A7.26 Figure A7.3 shows all these areas on a map. To access the shapefiles defining the proposed top 20, top 40 and top 80 high density areas, please see the landing page for this consultation on Ofcom's website.

Table A7.4: All 107 potential high density areas, ranked

Rank	Location	Comprised of
1	Greater London	MTaC: Hemel Hempstead, London, Watford; BUAs: Grays, New Addington; BUASDs: Bexley, Bluewater Retail Park, Epsom, Ewell, Gravesend, Northfleet, Staines, Swanscombe, Waltham Abbey, Waltham Cross
2	Greater Manchester	MTaC: Bolton, Bury, Manchester, Oldham, Salford, Stockport; BUASDs: Altrincham, Ashton-under-Lyne, Dukinfield, Sale, Stalybridge
3	Greater Glasgow	Localities: Bellshill, Blantyre, Bothwell, Cambuslang, Carfin, Coatbridge, East Kilbride, Glasgow, Hamilton, Motherwell, New Stevenston, Paisley, Rutherglen, Uddingston, Viewpark
4	Greater Birmingham	MTaC: Birmingham, Dudley, Solihull, Sutton Coldfield, Walsall, West Bromwich
5	Cardiff	Cardiff MTaC
6	Tyne & Wear	MTaC: Gateshead, Newcastle upon Tyne, South Shields, Sunderland; BUASDs: Hebburn, Jarrow, Tynemouth, Wallsend
7	Bristol	Bristol MTaC; Filton BUASD
8	Liverpool	MTaC: Liverpool, Birkenhead; BUASDs: Bootle, Crosby, Litherland
9	Edinburgh	Edinburgh Locality
10	Leeds & Bradford Area	MTaC: Bradford, Halifax, Leeds, Wakefield

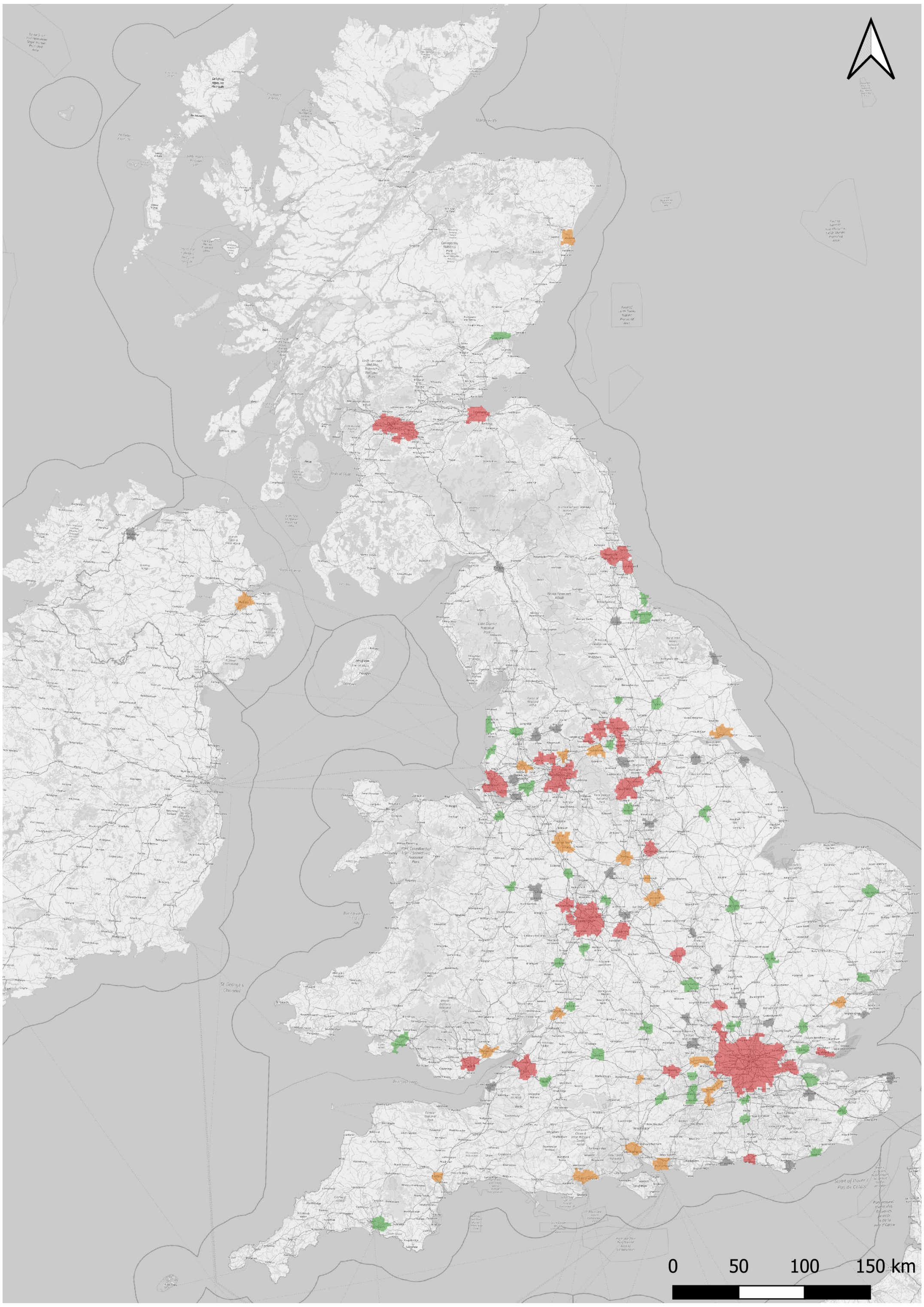
Rank	Location	Comprised of
11	Sheffield	MTaC: Rotherham, Sheffield
12	Reading	Reading MTaC
13	Nottingham	Nottingham MTaC
14	Wolverhampton	Wolverhampton MTaC
15	Northampton	Northampton MTaC
16	Southend	Southend-on-Sea MTaC
17	Brighton	Brighton and Hove MTaC
18	Doncaster	Doncaster MTaC
19	Luton	Luton MTaC
20	Coventry	Coventry MTaC
21	Belfast	BELFAST CITY SDL
22	Aberdeen	Aberdeen Locality
23	Stoke-on-Trent	MTaC: Newcastle-under-Lyme, Stoke-on-Trent
24	Leicester	Leicester MTaC
25	Huddersfield	Huddersfield MTaC
26	Guildford, Woking & Weybridge	MTaC: Guildford, Woking; Weybridge BUASD
27	Southampton	Southampton MTaC
28	Colchester	Colchester MTaC
29	Exeter	Exeter MTaC
30	Hull	Kingston upon Hull MTaC
31	Bournemouth & Poole	MTaC: Bournemouth, Poole
32	Rochdale	Rochdale MTaC
33	Newport	Newport MTaC
34	Derby	Derby MTaC
35	Wigan	Wigan MTaC; BUASD: Hindley, Ince-in-Makerfield, Platt Bridge
36	Loughborough	Loughborough BUA
37	Portsmouth & Gosport	Portsmouth MTaC; Gosport BUASD
38	Gloucester	Gloucester MTaC

Rank	Location	Comprised of
39	Slough & Maidenhead	Slough MTaC; Maidenhead BUASD
40	Newbury	Newbury BUASD
41	Plymouth	Plymouth MTaC
42	Chester	Chester MTaC
43	York	York MTaC
44	Oxford	Oxford MTaC
45	St Albans & Hatfield	St Albands MTaC; Hatfield BUASD
46	Peterborough	Peterborough MTaC
47	Shrewsbury	Shrewsbury MTaC
48	Cambridge	Cambridge MTaC
49	Ashford	Ashford (Ashford) BUASD
50	Norwich	Norwich MTaC
51	Milton Keynes	Milton Keynes MTaC
52	Crawley	Crawley MTaC
53	Redhill & Reigate	Redhill (Reigate and Banstead) BUA
54	Medway Towns	MTaC: Chatham, Gillingham; Rochester BUASD
55	Stafford	Stafford BUASD
56	Chelmsford	Chelmsford MTaC
57	Hartlepool	Hartlepool MTaC
58	Preston	Preston MTaC
59	Middlesbrough	MTaC: Middlesbrough, Stockton-on-Tees
60	Swansea	Swansea MTaC
61	Blackpool	Blackpool MTaC
62	Bath	Bath MTaC
63	Dundee	Dundee Locality
64	Basildon	Basildon MTaC
65	Farnborough & Aldershot	BUASDs: Aldershot, Camberley, Farnborough, Frimley
66	Tamworth	Tamworth BUA
67	Dewsbury	Dewsbury BUASD

Rank	Location	Comprised of
68	Swindon	Swindon MTaC
69	Lincoln	Lincoln MTaC
70	Chesterfield	Chesterfield MTaC
71	Southport	Southport MTaC
72	Ipswich	Ipswich MTaC
73	Harrogate	Harrogate MTaC
74	Cheltenham	Cheltenham MTaC
75	Bracknell	Bracknell MTaC
76	Basingstoke	Basingstoke MTaC
77	Warrington	Warrington MTaC
78	Redditch	Redditch MTaC
79	Worcester	Worcester MTaC
80	Hastings	Hastings MTaC
81	St Helens	St Helens MTaC
82	Stevenage	Stevenage MTaC
83	Mansfield	Mansfield MTaC
84	Blackburn	Blackburn MTaC
85	Harlow	Harlow MTaC
86	Thanet	Thanet BUA
87	Darlington	Darlington MTaC
88	Bedford	Bedford MTaC
89	Barnsley	Barnsley MTaC
90	Aylesbury	BUASDs: Aylesbury, Stoke Mandeville
91	Grimsby	Grimsby MTaC
92	Maidstone	Maidstone MTaC
93	Scarborough	Scarborough BUA
94	Kettering	Kettering BUASD
95	Burnley	Burnley MTaC
96	Carlisle	Carlisle MTaC

Rank	Location	Comprised of
97	High Wycombe	High Wycombe MTaC
98	Runcorn	Runcorn BUASD
99	Derry/Londonderry	DERRY CITY SDL
100	Nuneaton	Nuneaton MTaC
101	Clacton-on-Sea	Clacton-on-Sea BUA
102	Weston-super-Mare	Weston-Super-Mare MTaC
103	Telford	Telford MTaC
104	Worthing	Worthing MTaC
105	Burton upon Trent	Burton upon Trent MTaC
106	Eastbourne	Eastbourne MTaC
107	Scunthorpe	Scunthorpe MTaC

Figure A7.3: Map showing all 107 potential high density areas, including top 20 (red), top 40 (red and amber), top 80 (red, amber and green), and 27 areas not ranked within top 80 (dark grey)



Source: Ofcom, base map © OpenStreetMap contributors; N.B. Orkney and Shetland not shown as no areas there are potential high density areas

A8. Fixed links cost model

A8.1 We have modelled the potential costs of clearing fixed links in the 26 GHz and 40 GHz bands.

A8.2 The results from this modelling exercise are used to inform our assessment of the proportionality of clearing existing fixed links from the 26 GHz band in section 5 and 40 GHz band in section 7.

A8.3 This annex explains the methodology and results of our modelling.

Overall approach

A8.4 The objective of our modelling exercise is to estimate the incremental costs to existing fixed link users to maintain their current service through other means, if we were to revoke some of their licences to use the 26 and 40 GHz bands. We investigate incremental costs because the relevant costs for our assessment are the additional costs that would not have also been incurred if the user had kept the existing fixed link in the existing band.[48]

A8.5 The key steps in our modelling were:

a) First, at a high level, we identified the most cost-effective migration alternatives for existing fixed link users. This involved considering the options available to users, such as migrating to an alternative spectrum band or to leased lines. The higher expected costs of leased lines meant we focused our subsequent modelling on migrating to alternative spectrum bands.

b) Second, we estimated the incremental costs that could arise when migrating a fixed link to a new spectrum band. This involved forecasting the incremental operating and capital costs and applying an appropriate discount rate.

c) Third, we developed a baseline scenario which assumes that users can move all existing links into a new spectrum band, without having to incur any higher costs on an ongoing basis,[49] and then we aggregated the estimated one-off costs of moving bands under the different clearance options set out in section 5.[50] [51]

[48] For example, users of fixed links incur maintenance costs in their existing band and would expect to also incur maintenance costs for any new fixed link in a new band. However, we would only include maintenance costs if we expected the new maintenance costs to be higher (or lower) than the old maintenance costs, and if that was the case the costs would be calculated from the difference between the expected new maintenance costs and the old maintenance costs.

[49] We consider that in most circumstances operating a fixed link in an alternative spectrum band is likely to involve similar equipment, maintenance and site rental charges to operating a fixed link in the 26 GHz and 40 GHz bands. We therefore assume that users of fixed links are unlikely to incur higher costs on an ongoing basis.

[50] The options set out were to clear the 26 GHz and 40 GHz bands in the top 20, top 40, or top 80 high density areas, or to clear all fixed links in the band on a nationwide basis.

[51] We are only considering the cost of revoking existing fixed links in and around high density areas. In all cost scenarios we have used the maximum number of potential links in and around high density areas as described in section 5.

d) Fourth, we developed sensitivities for our analysis to test our modelling assumptions in the baseline scenario. The first sensitivity is a 'higher ongoing costs' scenario to illustrate how the aggregated costs in the baseline scenario could change under alternative modelling assumption. For the higher ongoing costs scenario, we adapted the baseline scenario so that only a higher cost migration option was available to certain links. In the second sensitivities, we apply a longer useful lifetime for existing fixed link equipment to the baseline and higher ongoing cost scenario – in our baseline scenario, we assume that useful equipment life is seven years but in the sensitivities we assume 15 years.

A8.6 This gives us a total of four scenarios: our baseline scenario; the higher ongoing costs scenario; the baseline scenario but assuming a useful equipment life is 15 years; and the higher ongoing costs scenario but assuming a useful equipment life is 15 years.

A8.7 Our modelling approach estimates the average cost of clearance for a fixed link, but we recognise that this may not fully capture the range of costs incurred by different users. Individual users in specific locations and circumstances could face higher or lower costs when moving a fixed link. The assumptions we use are therefore intended to capture the costs of a typical user of a fixed link, which we consider is appropriate in considering the proportionality of clearing the band.

A8.8 Below, we describe each of the steps and our assumptions in the modelling and a summary of our results across all scenarios. Table A8.1 provides the estimated aggregated costs for links in the 26 GHz band, while Table A8.2 and Table A8.3 provide costs for MBNL and H3G links in the 40 GHz band. We have separated out the costs of MBNL's links and H3G's links in the cost modelling to allow an easier assessment of the options proposed for the 40 GHz band in section 7.

Table A8.1: Summary of the cost estimates for clearing the 26 GHz band under different scenarios

Number of high density areas	Baseline scenario (£m)	Higher ongoing costs scenario (£m)	Baseline, 15 year useful equipment lifetime (£m)	Higher ongoing costs, 15 year useful equipment lifetime (£m)
20	0.7	3.0	2.1	4.2
40	0.8	3.5	2.4	4.9
80	1.0	4.1	2.9	5.9
All UK	1.3	5.7	4.0	8.1

Source: Ofcom

Table A8.2: Summary of the cost estimates for clearing MBNL fixed links in the 40 GHz band under different scenarios

Number of high density areas	Baseline scenario (£m)	Higher ongoing costs scenario (£m)	Baseline scenario, 15 year useful equipment lifetime (£m)	Higher ongoing costs scenario, 15 year useful equipment lifetime (£m)
20	2.9	12.5	8.8	17.8
40	3.4	14.6	10.3	20.7
80	4.0	16.9	11.9	23.9
All UK	4.4	18.9	13.3	26.7

Source: Ofcom

Table A8.3: Summary of the cost estimates for clearing H3G fixed links in the 40 GHz band under different scenarios[52]

Number of high density areas	Baseline scenario (£m)	Higher ongoing costs scenario (£m)	Baseline scenario, 15 year useful equipment lifetime (£m)	Higher ongoing costs scenario, 15 year useful equipment lifetime (£m)
20	0.05	0.2	0.1	0.3
40	0.05	0.2	0.1	0.3
80	0.06	0.3	0.2	0.4
All UK	0.06	0.3	0.2	0.4

Source: Ofcom

A8.9 We seek views from stakeholders on the costs that we have considered as part of this modelling exercise, as well as the results.

Migration alternatives for incumbent fixed link users

A8.10 We identified two potential migration options for incumbent fixed links if the 26 GHz and/or 40 GHz bands are cleared. These are:

[52] Under all options that involve revocation of 40 GHz licences (options 2, 3 and 4), H3G would need to move all its fixed links in high density areas. This is due to the duplex nature of its fixed links and is explained in more detail at paragraphs 7.69-7.72.

a) Existing users relocate to a different spectrum frequency.[53]

b) Existing users move to a wired fibre connection (i.e. a leased line product).

A8.11 The indicative costs of an operator using leased lines provided by Openreach are outlined in previous Ofcom market reviews. In cases where there is no need for excess construction charges the costs are likely to be around £3,000-£4,000 for a 5 km 1Gbit/s leased line.[54] However, existing fixed link sites are not necessarily going to be situated close to the existing Openreach leased line network. Therefore, if a leased line is used to replace an existing fixed link, then a network extension would likely be required, with associated excess construction charges. Indicative costs of laying a new connection are about £86,000 per 1 km of line.[55] However, we recognise this may be an overestimate for some fixed links if users can make use of existing ducts that may be available.

A8.12 Later in this annex we outline our estimate of the costs of moving to a new spectrum frequency. In general, these costs are significantly lower than our expectation for the charges for leased lines. As a result, we consider it appropriate to estimate the cost of clearing fixed links in both the 26 GHz and 40 GHz bands by assuming that all existing fixed links would migrate to a different spectrum band.

A8.13 In doing so, we note that there may be individual fixed links that could be replaced more cost effectively using a wired leased line connection, either provided by Openreach or by another telecoms provider. If this were the case, then we would expect the overall estimate of costs to decrease. However, we believe that leased lines are likely to be relevant for only a small number of fixed links, and we therefore expect any effect on overall costs to be minimal.

Estimating costs for existing users that need to migrate to a different spectrum band

A8.14 We have estimated the cost of clearing the 26 GHz and 40 GHz spectrum bands by determining the incremental costs associated with moving those fixed links to a different band.

A8.15 When a user moves a fixed link to a new spectrum band it is likely to face two types of costs:

a) The first type would be **one-off transition costs**. For example, this could include replacement of equipment earlier than normal or having to incur additional installation costs from setting up a new link.

[53] We expect users would be able to move their links to a new spectrum band. Based on preliminary analysis, we expect that a combination of the 18, 23 and 38 GHz bands would be the most likely destinations for migrating 26 GHz fixed links. 40 GHz users may also be able to move to other bands in which they have block assigned licences. As part of any migration, they may need to buy new equipment (e.g., transmitter) to be able to operate in the new frequency.

[54] The 2021-2026 Wholesale Fixed Telecoms Market Review (WFTMR) estimated the cost of a 5 km EAD leased line provided by Openreach with no excess construction charges to be between £3,000-4,000. Graph A9.1.

[55] The 2019 Business Connectivity Market Review (BCMR) estimated that a 1 km network extension that requires a new duct would cost about £86,000. Paragraph 6.56.

b) The second would be **higher ongoing costs** that might arise due to a difference between ongoing costs from operating a fixed link in a new spectrum band compared to the costs of operating in the 26 or 40 GHz band. There could be different reasons why the new band may require higher ongoing costs. For example, more expensive/larger equipment,[56] or needing to use an additional hop with new equipment to maintain the quality of transmission across the fixed link.

Methodology to estimate one-off transition costs

A8.16 We have estimated one-off transition costs by estimating capital costs for equipment that a user may need to write off, if its licence for a fixed link is revoked and it needs to transition to a different spectrum band. Capital costs will have been already incurred by a user and they will have an expected timeframe (or lifetime) over which they expect to use the equipment before replacing or retiring it. If the revocation of a 26 GHz or 40 GHz licence means that equipment needs to be retired or replaced earlier than expected, then this will result in an incremental cost to the user that would not be incurred if they had been able to stay in the existing band.

A8.17 We have estimated the extent of these costs by looking at the difference between a user being able to replace their own equipment according to their normal timeline, and the user having to replace their equipment earlier than scheduled due to their licence being revoked. We assume in this calculation that all telecommunications equipment would need to be replaced when transferring to a new band.

A8.18 To calculate the one-off transition costs we have:

a) Estimated the average current value of fixed link telecommunications equipment using an estimate for the original capex cost and the average current age of the equipment.

b) Determined the annual cost of existing equipment for each year for the remainder of the equipment's lifetime based on the expected depreciation and cost of capital.[57]

c) Considered that existing users could use the five-year revocation notice period[58] to manage the transition to a new spectrum band. We assume that operators can reduce the need to write off capital equipment by moving an individual link to a new band when it reaches the end of its lifetime. This could be at different points over the course of the five-year revocation period. Given this, we have estimated costs on the basis that:

[56] Larger equipment is likely to require greater space on a tower and therefore higher ongoing rental costs. More expensive equipment will also lead to higher ongoing costs as it will need to be replaced at a higher cost each time the equipment reaches the end of its lifetime. We assume the lifetime of equipment is seven years and so it will need to be replaced two times over the 20 year period over which we are assessing costs.

[57] We use a WACC of 5.7% based on the most recent estimate of WACC used for MNOs in the 2021-2026 Wholesale Voice Markets Review. We consider this appropriate as an estimate for fixed link users given the use of fixed links to provide mobile communication services.

[58] As set out in section 5, if we were to revoke their licence for spectrum management reasons, we would give affected users a five years' notice.

i) capital costs will only be written off for equipment that has a remaining lifetime at the start of the revocation period that is greater than five years; and

ii) the capital costs written off for this equipment are based on the value at the end of the five-year revocation period.

d) Determined the present value of these costs by discounting the costs to a present value using the social time preference rate.[59]

A8.19 Assumptions we use in the calculation of one-off transition costs are shown in Table A8.4.

Table A8.4: Assumptions used as part of the one-off cost calculation

Assumption	Value
Capex of equipment	£7,000[60]
Installation cost	50% of capex[61]
Lifetime of telecommunications equipment	7 years[62]
WACC of fixed link operator	5.7%[63]
Social time preference rate	3.5%[64]

Source: See footnotes in table

A8.20 As well as the assumptions in Table A8.4, we have also (a) applied straight line depreciation based on the expected lifetime of assets, and (b) assumed the age of existing assets is equally distributed across all the fixed links in the 26 GHz and 40 GHz bands. We do not have any evidence which suggests the latter assumption is unreasonable.

A8.21 Using these assumptions, we have estimated the value of the capital costs associated with a single fixed link at the end of the five-year revocation period. This value depends on the age of equipment at the start of the revocation period from which its remaining lifetime can be calculated.[65]

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[59] We determine the present value of costs by using a social time preference rate of 3.5% as suggested by the Treasury Green Book. We apply a STPR to be consistent because we have used the Spackman approach to determine the present value of costs. This is appropriate because we are assessing the costs and benefits from clearing spectrum for public benefit as outlined in a Statement by the Joint Regulators Group.

[60] Our equipment capex cost is sourced estimate from a 2015 Plum report for Ofcom produced for the Fixed Wireless Strategy and we assume that the nominal value from the 2015 report remains appropriate. We consider this is appropriate as the cost trends for telecoms equipment used in the mobile call termination (MCT) model used in the 2021-2026 Ofcom Wholesale Voice Markets Review suggest that cost deflation in equipment in real terms (e.g. due to efficiencies) has been of a similar magnitude to the overall rise in general inflation.

[61] 2015 Plum report, page 114.

[62] 2015 Plum report, page 15.

[63] 2021-2026 Wholesale Voice Markets Review, page 55.

[64] Treasury Green Book, page 46.

[65] E.g., a new piece of equipment will have a remaining lifetime of seven years, a one-year-old piece of equipment will have a remaining lifetime of six years, etc.

A8.22 The second column of Table A8.5 shows the value of equipment at the end of the revocation period, based on its remaining lifetime and which will be the cost that needs to be written off.

Table A8.5: Cost of writing off fixed link equipment when moving to a new band

Remaining life of equipment at the start of the revocation period	Value to be written off if revocation period is 5 years
7 years	£2,606
6 years	£1,290
5 years	£0
4 years	£0
3 years	£0
2 years	£0
1 year	£0
Average	**£556**

Source: Ofcom

A8.23 Our methodology suggests that the average cost of writing off equipment when applying a five-year revocation period would be £556.

A8.24 However, we consider this value could potentially be an underestimate of the average one-off costs for moving fixed links for two main reasons:

a) There may be additional planning and administrative costs when moving to a new spectrum band over and above the normal planning and administrative costs which relate to equipment renewal.[66]

b) We assume the operator can fully utilise the revocation period to manage the transfer to a new spectrum band. However, there may be additional constraints as part of the transfer process. For example, the moving process could potentially be more efficient when moving several links together. Therefore, some links which are not fully depreciated may be moved at the same time as links that have reached the end of their usable life earlier than the end of the revocation period, this could result in a higher cost than if no migration was required.

A8.25 However, we recognise that there could also be reasons why the cost could be lower than we have suggested. For example, some equipment could be potentially re-used in the new spectrum band.

[66] This could potentially include any incremental costs associated with applying and paying for a new spectrum licence in the new band over and above costs that would have been incurred if the user had continued to operate the fixed link in its existing band.

A8.26 For the reasons outlined above, we think a reasonable baseline assumption for the one-off transition costs of a single existing links slightly higher than the £556 calculated. We have therefore increased our assumption to a cost of **£1,000 per link** to reflect these additional factors and the uncertainty in our estimates.

We have developed a baseline scenario for total costs for existing users

A8.27 We have determined overall costs for clearing the 26 GHz and 40 GHz bands by developing a baseline scenario that assumes that users are able to move all existing links into a different spectrum band, without having to incur any higher costs on an ongoing basis. Therefore, the only costs incurred in this scenario are the one-off transition costs estimated above for moving a single fixed link into a different band.[67]

A8.28 We consider this baseline is an appropriate best estimate of costs based on users being able to move their fixed links to Ofcom managed bands, such as the 18, 23 and 38 GHz bands.[68]

A8.29 To estimate the total costs of revoking fixed links in the 26 GHz and 40 GHz bands we have multiplied our estimate of the one-off transition costs of a user moving one fixed link by the number of links that need to be revoked.

A8.30 The number of links that needs to be revoked depends on:

a) the number and location of high density areas; and

b) the extent to which existing fixed links in (and close to) each high density area need to be revoked.

A8.31 The exact number of links that need to be revoked for each area will depend on the technical characteristics of the individual deployments. Some fixed links outside of a high density area may cause interference to new users in a high density area. We have therefore assumed that all fixed links in a high density area and fixed links that have at least one part of the link within 25 km of a high density area need to be revoked. We expect that some, but not all, links in this category will need to be revoked, therefore the figure given by this method should be regarded as on the high side.

A8.32 Table A8.6 shows our cost estimates for revocation in the baseline scenario for the 26 GHz band for each of the high density area options and if there was a UK-wide clearance of the

[67] Alternative, higher cost scenarios were also developed to test assumptions about our cost estimates, including the potential for users to incur higher ongoing costs once they have moved a fixed link into a new band.
[68] The licence fees would change, for existing licence holders in the 40 GHz band, if fixed links were moved to alternative Ofcom-managed fixed links bands. However, as described in section 7, we cannot say at this point whether there is likely to be a material difference between the fees that would apply in an Ofcom-managed band and the annual licence fees in 40 GHz that may be set after 21 February 2023.

band. These are the options outlined in section 4. Table A8.7 and Table A8.8 provide the same estimates for MBNL's and H3G's links in the 40 GHz band.[69]

Table A8.6: Cost of revocation in the 26 GHz band in the baseline scenario

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation (£m)
20	698	0.7
40	815	0.8
80	969	1.0
UK-wide	1334	1.3

Source: Ofcom; 26 GHz fixed link statistics taken from Ofcom licensing data

Table A8.7: Cost of revocation in the 40 GHz band for MBNL under the baseline scenario

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation (£m)
20	2936	2.9
40	3426	3.4
80	3956	4.0
UK-wide	4417	4.4

Source: Ofcom; MBNL fixed link statistics taken from data provided by MBNL

Table A8.8: Cost of revocation in the 40 GHz band for H3G under the baseline scenario

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation (£m)
20	45	0.05
40	48	0.05
80	63	0.06
UK-wide	63	0.06

Source: Ofcom; H3G fixed link statistics taken from data provided by H3G

Sensitivity analysis

A8.33 We recognise that there is some uncertainty about the exact level of additional costs users of fixed links could incur due to revocation. To help understand the potential magnitude of

[69] We have not considered the impact of MLL's deployments because they do not currently have any active deployment in the 40 GHz band.

higher costs, we have also developed additional higher cost scenarios to assess how costs could develop in certain circumstances.

A8.34 We have tested two of the assumptions outlined above for the higher cost scenarios:

a) Our assumption that all users of fixed links will be able to move their links into a new spectrum band without additional ongoing costs.

b) Our assumption that fixed link equipment has a useful lifetime of seven years.

A8.35 We have tested the first assumption by estimating the potential for higher ongoing costs for some fixed link users ('higher ongoing costs scenario').

A8.36 We have tested the second assumption by re-estimating the costs of the baseline scenario when assuming a longer economic lifetime of fixed link telecoms equipment ('longer equipment lifetime scenarios').

A8.37 The approach we have taken to develop each of these higher cost scenarios is outlined below.

Methodology to estimate ongoing costs for the higher ongoing costs scenario

A8.38 The higher ongoing costs scenario tests the potential for fixed links users to incur higher ongoing costs once they have moved to a new band. We consider these additional costs could take different forms. For example, they could require more expensive equipment that needs to be replaced on an ongoing basis, more space on towers, or in some circumstances an additional hop if radio waves in the new band do not propagate as far as those in the existing band.[70]

A8.39 We are defining ongoing costs here as the additional costs to users from using a new frequency, not the total costs that they will incur when operating in a new band. For example, a user of an existing fixed link has costs related to towers or ongoing maintenance, that we would expect to continue for any new link. Therefore, we only need to include these costs if they are *higher* for the fixed link in the new spectrum band than they are for the existing fixed link and in that case we would only include *incremental costs* that arise from moving the links.

A8.40 As outlined above, we also do not think these costs are particularly likely or material for most users that would move their links to a new band. We expect almost all would face similar ongoing costs in a new spectrum band as they did previously. However, we have constructed the higher ongoing costs scenario based on what we consider is an unlikely but still plausible scenario.

A8.41 We do not have a clear upper end estimate of what the costs could be. By way of sensitivity testing, we have therefore modelled an illustrative example that reflects what

[70] Replacing a fixed link with an additional 'hop' is where a fixed link is replaced with two fixed links instead of just one. For example, a fixed link could be in locations X and Y. This fixed link could be replaced by two new fixed links, such that one of the new fixed links would connect X and Z, and the other would connect Z and Y. This ensures that X and Y are still connected, but by two fixed links instead of just one.

we consider is the top end of plausible costs, noting that costs are likely to be lower in practice.

A8.42 Our illustrative example assumes that 2% of existing links would be subject to the higher costs that arise because they require an additional hop, with the remaining 98% of links not subject to any higher ongoing costs. We have chosen the costs of installing a new hop as we consider it would be the most expensive situation, which reflects that this is the upper end estimate and that other modifications would be cheaper.

A8.43 To calculate the cost of building a new hop we used the following approach:

a) Estimated the annual equivalent cost for both a new site from the capex and opex assumptions listed in Table A8.9 below and assumed all costs were recovered over a 20-year period.[71]

b) Determined an annual equivalent cost for telecommunications equipment that would be needed on that site over a 20-year period.[72]

c) Determined the present value of all of these costs by discounting to a present value using the social time preference rate.[73] [74]

A8.44 The list of assumptions we use in the higher ongoing costs cost calculation are shown in Table A8.9 below.

Table A8.9: Assumptions used as part of the higher ongoing cost calculation

Assumption	Value[75]
Capital costs of rural site	£113,399
Operating costs of rural site	£378
Capital costs of urban site	£11,340
Operating costs of urban site	£5,670
Lifetime of urban and rural sites	20 years

[71] We assumed a 50/50 split between rural and urban sites across all our high density area to get an average site cost. We expect new sites could be in rural locations (e.g., around the edge of our cities) which may require the construction of a tower, or within cities, where a new site may be on an existing building. We have used a 20-year period to determine costs consistent with the approach for cost estimates set out in the Plum report.
[72] We assume a seven-year lifetime for equipment so we would expect it to be replaced twice over the period of 20 years.
[73] We determine the present value of costs by using a social time preference rate of 3.5% as suggested by the Treasury Green Book. We apply a STPR to be consistent because we have used the Spackman approach to determine the present value of costs. This is appropriate because we are assessing the costs and benefits from clearing spectrum for public benefit as outlined in a Statement by the Joint Regulators Group.
[74] To be conservative, we have discounted the additional ongoing costs to a present value based on those costs being incurred at the start of the revocation period. However, we note that cost related to a new site would not necessarily take place at that time (e.g., costs may be incurred towards the end of the revocation period or at any period during it). This could reduce costs in present value terms compared to our assumption.
[75] The capex and opex site costs are sourced from a 2015 Plum report for Ofcom produced for the Fixed Wireless Strategy. However, we have increased the nominal cost estimates outlined in the report by 13%. This ensures consistency with the MCT model, which assumes a 2% real increase in site opex and capex costs over the period from 2015 to 2022, and the increase in CPI over the same period.

Assumption	Value[75]
Capex of equipment (for additional hop)	£7,000
Installation of equipment cost	50% of capex
Other operating costs for equipment (infrastructure)	50% of annualised capex costs
Other operating costs for equipment (maintenance)	12% of capex per annum
Lifetime of telecommunication equipment	7 years
WACC of fixed link operator	5.7%
Social time preference rate	3.5%

A8.45 Using this methodology, we have estimated potential ongoing costs for a fixed link that requires a new hop to be £163,447 in present value terms over a 20-year period.

A8.46 Also, in addition to the higher ongoing costs incurred by 2% of fixed links in high density areas, we assume all of links in these areas incur the one-off costs outlined in the baseline scenario. This means we assumed the total cost per link in the higher ongoing cost scenario is **£164,447**.

A8.47 We have estimated the total costs under the higher ongoing cost scenario by multiplying our estimate of costs for a fixed link that would require a new hop by 2% of the number of fixed links and that number to the total costs outlined in the baseline scenario.

A8.48 Table A8.10, Table A8.11 and Table A8.12 outline the total costs in this scenario for both the 26 GHz and 40 GHz bands depending on the number of high density areas.

Table A8.10: Cost of revocation in the 26 GHz band in the higher ongoing cost scenario

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation (£m)
20	698	3.0
40	815	3.5
80	969	4.1
UK wide	1334	5.7

Source: Ofcom; 26 GHz fixed link statistics taken from Ofcom licensing data

Table A8.11: Cost of revocation in the 40 GHz band for MBNL in the higher ongoing cost scenario

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation (£m)
20	2936	12.5
40	3426	14.6
80	3956	16.9
UK wide	4417	18.9

Source: Ofcom; MBNL fixed link statistics taken from data provided by MBNL

Table A8.12: Cost of revocation in the 40 GHz band for H3G in the higher ongoing cost scenario

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation (£m)
20	45	0.2
40	48	0.2
80	63	0.3
UK wide	63	0.3

Source: Ofcom; H3G fixed link statistics taken from data provided by H3G

Methodology to estimate ongoing costs for the longer equipment lifetime scenarios

A8.49 Finally, we also tested our assumption that the expected lifetime of telecommunications equipment is seven years. Using an equipment lifetime of seven years means that when there is a five-year notice period prior to revocation, most equipment can be replaced as normal at the end of its lifetime and so the costs of revocation are relatively low.

A8.50 We have tested this assumption as we consider that there is the potential for equipment to be replaced over a longer period, dependent on different factors including the level of technical change of the equipment. If telecommunications equipment is expected to be used for a longer period, then the costs of migrating to a new band and needing to buy new equipment could materially increase.

A8.51 We consider that it is plausible for fixed link equipment to have an expected useful lifetime longer than seven years. Therefore, we have undertaken an additional modelling scenario where the equipment lifetime is assumed to be 15 years. All other assumptions and the methodology are the same as the baseline scenario and higher ongoing costs scenario.

A8.52 Under the baseline scenario with longer equipment lifetime, our methodology suggests that the average cost of writing off equipment when applying a five-year revocation period would be £2,332. We have increased this to **£3,000** for the same reasons given in paragraphs A8.23-A8.26, as we consider the potential for costs to be higher than our estimate will be of a similar magnitude to the costs when our lifetime assumption is seven years.

A8.53 Under the higher ongoing costs scenario with longer equipment lifetime, we estimate the average of cost of users that are required to build a new hop to be **£155,295**.[76] As outlined previously, we assume in this scenario that this cost will apply to only 2% of the number of fixed links.

A8.54 We have used these estimates together with the number of fixed links we propose to revoke to estimate the total costs in the longer equipment lifetime scenarios as shown in Table A8.13 for 26 GHz, and Table A8.14 and A8.15 for 40 GHz.

Table A8.13: Cost of revocation in the 26 GHz band in the longer equipment lifetime scenarios

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation – baseline scenario (longer equipment lifetime) (£m)	Estimated cost of revocation – higher ongoing costs scenario (longer equipment lifetime) (£m)
20	698	2.1	4.2
40	815	2.4	4.9
80	969	2.9	5.9
UK wide	1334	4.0	8.1

Source: Ofcom; 26 GHz fixed link statistics taken from Ofcom licensing data

Table A8.14: Cost of revocation in the 40 GHz band for MBNL in the Longer Equipment Lifetime scenarios

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation – modified baseline scenario (£m)	Estimated cost of revocation – modified higher ongoing costs scenario (£m)
20	2936	8.8	17.8
40	3426	10.3	20.7
80	3956	11.9	23.9
UK wide	4417	13.3	26.7

Source: Ofcom; MBNL fixed link statistics taken from data provided by MBNL

[76] In this scenario we assume that all users also face a cost of £3000 to cover equipment that needed to be replaced earlier than expected.

Table A8.15: Cost of revocation in the 40 GHz band for H3G in the Longer Equipment Lifetime scenarios

Number of high density areas	Number of fixed links revoked	Estimated cost of revocation – modified baseline scenario (£m)	Estimated cost of revocation – modified higher ongoing costs scenario (£m)
20	45	0.1	0.3
40	48	0.1	0.3
80	63	0.2	0.4
UK wide	63	0.2	0.4

Source: Ofcom; H3G fixed link statistics taken from data provided by H3G