Award of the 700 MHz and 3.6-3.8 GHz spectrum bands

Conclusions to further consultation on modelling and technical matters

STATEMENT:

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Annex

1. Overview

What we have decided – in brief

We are preparing to award spectrum in the 700 MHz and 3.6-3.8 GHz band. The spectrum will enable the industry to provide services with greater capacity and wider coverage, and to support new wireless technologies, including 5G – the latest generation of mobile services.

On 13 March 2020, following several consultations, we published a statement setting out our conclusions on the award of this spectrum by auction. We confirm those conclusions in this document, having taken account of the responses we received to a further consultation we published on 15 May 2020.

We will now proceed with our preparations to hold the auction as soon as it is reasonably practicable to do so in light of the Covid-19 pandemic. We will work with all interested bidders to ensure the auction can proceed in a secure and safe way. In light of the practical steps that we need to take in this regard, we are aiming for a formal start to the auction process in late November with a view to starting bidding in mid-January 2021.

1.1 We published a statement on 13 March 2020 (the "**13 March Statement**") setting out our conclusions on the award of the 700 MHz and 3.6-3.8 GHz spectrum bands by auction.[1] We published a further consultation on 15 May 2020 (the "**Further Consultation**"), after a stakeholder raised concerns that it had not had the opportunity to comment on our reference to a "single-user throughput" model (the "**SUT Model**") in the 13 March Statement.[2]

1.2 We referred to the SUT Model in the 13 March Statement in relation to our view that operators were likely in the longer term to be able to support a wide range of 5G services with less than 80-100 MHz of spectrum bandwidth in the 3.4-3.8 GHz band (whether contiguous or not). The Further Consultation invited comments on our use of the SUT Model for these purposes and its results, which were revised to correct certain errors which we had identified in the results we had published in the 13 March Statement.

1.3 The stakeholder had also raised a concern about our reference in the 13 March Statement to Dynamic Spectrum Sharing ("**DSS**"), a technology which enables the dynamic allocation of spectrum resources for 4G and 5G respectively based on demand for each service, using

[1] See *Award of the 700 MHz and 3.6-3.8 GHz spectrum bands*, Ofcom Statement, 13 March 2020, https://www.ofcom.org.uk/__data/assets/pdf_file/0020/192413/statement-award-700mhz-3.6-3.8ghz-spectrum.pdf

[2] See *Award of the 700 MHz and 3.6-3.8 GHz bands, Further consultation on modelling and technical matters*, Ofcom consultation, 15 May 2020, https://www.ofcom.org.uk/__data/assets/pdf_file/0023/195521/consultation-sut-modelling-700mhz-3.6-3.8ghz-spectrum.pdf

the same frequency carrier to carry both 4G and 5G traffic. The stakeholder highlighted the fact that a technical solution for DSS was not available in the 2.3 GHz band and suggested that this raised concerns about our reference to the use of DSS to facilitate re-farming of 4G spectrum. We therefore also invited comment on this matter in the Further Consultation.

1.4 Following our review of stakeholders' responses to the Further Consultation, our assessment is that the results of the SUT Model, as revised, support our view that it is likely to be technically feasible for MNOs to support a wide range of 5G services with channel bandwidths in their current holdings smaller than 80 MHz, including 40 MHz.

1.5 Taking this together with the other parts of our competition assessment set out in the 13 March Statement, our overall conclusion remains that there is a low risk of competition concerns related to 3.4-3.8 GHz spectrum from any auction outcome.

1.6 Moreover, following the Further Consultation, our view remains that DSS could facilitate re-farming of most spectrum currently used for 4G to 5G. DSS is currently available for frequency division duplex (FDD) bands, which include 800 MHz, 900 MHz, 1800 MHz, 2.1 GHz bands and part of the 2.6 GHz band, and so is likely to be an option for operators to consider.

1.7 In their responses to the Further Consultation, stakeholders made submissions on the following additional matters, on which we had not sought further comments:

a) O2 was concerned about limitations of capacity in its spectrum portfolio;[3]

b) Vodafone[4] was concerned about H3G's incentives to trade to defragment holdings in the 3.4-3.8 GHz band and the impact of potential Government policy on the use of equipment from high-risk vendors, particularly Huawei; it also repeated its proposal that the auction should be replaced by a managed allocation of spectrum in the current circumstances;

c) BT[5] argued for the application of a cap of 140 MHz on spectrum holdings in the 3.4-3.8 GHz band;

d) an MNO [✂REDACTED] requested that we revisit the design of the assignment stage of 700 MHz FDD frequencies;[6]

e) An individual respondent was concerned about the effects of 5G on health and the environment.

[3] O2 non-confidential response to the Further Consultation, pages 3-4.

[4] Vodafone non-confidential response to the Further Consultation, page 2.

[5] BT non-confidential response to the Further Consultation, paragraph 5.

[6] [✂REDACTED] letter to Ofcom of 12 June 2020.

1.8 We have examined these submissions and conclude that, to the extent they contain any new evidence, they do not give us cause to change the conclusions we set out in the 13 March Statement.

1.9 As we explained in March, a significant part of this spectrum could be used now to provide services. We think it is important for consumers and for competition that the spectrum be used as soon as is reasonably practicable without unnecessary delay. Stakeholders have had multiple opportunities to make representations to us in relation to the auction, and we intend to proceed to hold it as soon as the current circumstances allow, with a target of mid-January for the start of bidding.

1.10 Any claim for judicial review would inevitably further delay the auction, and the use of this important spectrum. We therefore remain of the view that any claim for judicial review should be brought promptly, with a request that the courts expedite the matter. We therefore request that if any stakeholder intends to bring a claim for judicial review that they should do so by the end of August, having indicated such intention to us and any interested parties within two weeks of the date of this document.

The overview section in this document is a simplified high-level summary only. Our reasoning and the conclusions we have reached are set out in the full document.

2. Introduction

2.1 In December 2018, we published a consultation document setting out our proposals for the award of 80 MHz in the 700 MHz band and 120 MHz in the 3.6-3.8 GHz band (the "**December 2018 consultation**").[7] One of the issues that we considered as part of our competition assessment was whether an operator needed 80-100 MHz of spectrum in the 3.4-3.8 GHz band in the longer term to compete in 5G services. We reached the provisional view that this was not necessary. We reached the conclusion that this was not necessary in the 13 March Statement, following two further consultations on the auction design.[8]

2.2 On 9 April 2020, a stakeholder raised with us a concern that Ofcom had not given stakeholders an opportunity to comment on the use of the SUT Model in supporting Ofcom's position, set out in the 13 March Statement. It also raised a concern about our reference to the availability of dynamic spectrum sharing to facilitate re-farming of 4G spectrum for 5G.

2.3 We published the Further Consultation on 15 May 2020 to ensure that all stakeholders had an opportunity to make any observations they wished to make on these matters.

2.4 We received responses from the four mobile network operators (MNOs) and a confidential response from an individual.[9] The MNOs addressed the questions on which we consulted, and raised certain wider points, some of which they had variously put to us previously.

2.5 In the rest of this document, we summarise the position consulted on in the Further Consultation, summarise and consider the responses, and set out our final conclusions.

[7] See *Award of the 700 MHz and 3.6-3.8 GHz spectrum bands*, Ofcom consultation, 18 December 2018, https://www.ofcom.org.uk/__data/assets/pdf_file/0019/130726/Award-of-the-700-MHz-and-3.6-3.8-GHz-spectrum-bands.pdf

[8] See *Defragmentation of spectrum holdings in the 3.4-3.8 GHz band*, Ofcom consultation, 11 June 2019, https://www.ofcom.org.uk/__data/assets/pdf_file/0011/152102/consultation-defragmentation-spectrum-holdings.pdf, and *Award of the 700 MHz and 3.6-3.8 GHz spectrum bands - Revised proposals on auction design*, Ofcom consultation, 28 October 2019, https://www.ofcom.org.uk/__data/assets/pdf_file/0028/172648/revised-proposal-auction-design.pdf

[9] The individual is concerned about the effects of 5G on health and the environment.

3. Matters on which we consulted

3.1 In this section we review and consider stakeholders' responses to the two matters which we set out in the Further Consultation, namely:

a) our use of the SUT Model, as revised, in supporting our position in the 13 March Statement; and

b) our reference to the availability of dynamic spectrum sharing to facilitate re-farming of 4G spectrum to 5G.

The SUT Model

Consultation position on the SUT Model

3.2 In this section we summarise what we said about the SUT Model in the Further Consultation.

Reference to the SUT Model in the 13 March Statement

3.3 In the 13 March Statement, having conducted a competition assessment, we decided to include a cap of 416 MHz on the total amount of mobile spectrum any single operator may hold as a result of the award, and to include measures in the assignment stage of the auction to facilitate defragmentation of the MNOs' holdings in that band. We decided not to include a further sub-cap on holdings in the wider 3.4-3.8 GHz band.

3.4 We referred to the SUT Model in the 13 March Statement in relation to one of several elements of reasoning in our competition assessment, in which we considered various potential competition concerns which might arise as a result of different outcomes of the auction.

3.5 We identified two main potential competition concerns which could arise as a result of asymmetry of MNOs' ultimate holdings in the 3.4-3.8 GHz band:[10]

a) first, there could be an asymmetry in the relative scale of holdings if H3G won a large share of the remaining 120 MHz available in the 3.4-3.8 GHz band; and

b) second, fragmented holdings in the band could prevent one or more MNOs from realising the benefits of contiguity or proximity.

3.6 We considered two time periods in our assessment[11]:

a) the short term lasting until around 2021, in which the 3.4-3.8 GHz band would be the main spectrum useable for 5G; and

[10] 13 March statement, paragraph 4.219.

[11] 13 March Statement, paragraphs 4.205 and 4.225-4.226.

b) the longer term from around 2022, when Ofcom considered that technological developments would be likely to enable other bands to be used for 5G.

3.7 Having considered both the short and longer term, we concluded that there was a low risk of competition concerns related to 3.4-3.8 GHz spectrum arising from any auction outcome.[12] With respect to the longer term, we reached this conclusion for three main reasons:[13]

a) In the longer term, spectrum in other bands in which Vodafone, O2 and BT/EE have holdings would be available for 5G, which the operators could re-farm for 5G use;

b) If MNOs really needed more spectrum in the 3.4-3.8 GHz band to compete, they would be likely to be able to acquire some 3.6-3.8 GHz spectrum in this auction; and

c) Having regard to the uncertainty about which future 5G services were likely to be important for consumers, and what the technical requirements for those services might be, we had not seen clear evidence suggesting there were likely to be future 5G services which would be of significant commercial importance and which would require 80-100 MHz of contiguous spectrum.

3.8 With respect to (c), we considered:

a) which would be the key 5G services for competition (and when they would become important), and

b) whether operators were likely to require 80-100 MHz of 3.4-3.8 GHz bandwidth, contiguous or otherwise, to provide those services.

3.9 We concluded that there was very little certainty over which 5G services would be important and when.[14]

3.10 We recognised that, in principle, large bandwidths could assist in delivering some hypothetical use cases (such as augmented/virtual reality, or very high-resolution professional quality video streaming).[15]

3.11 However, we noted that stakeholders had not provided clear evidence of use cases which were likely to require 80-100 MHz of 3.4-3.8 GHz bandwidth (contiguous or otherwise) and which were likely to be of significant commercial and competitive importance.[16] We noted that, at this stage, any assessment of the commercial and competitive importance of hypothetical services would be inherently speculative.

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[12] 13 March Statement, paragraph 4.203.

[13] 13 March Statement, paragraphs 4.208-4.211.

[14] 13 March Statement, paragraphs 4.257, A.7.6 and A.7.19.

[15] 13 March Statement, paragraph 4.258.

[16] 13 March Statement, paragraphs 4.211, 4.258, 4.290(b) and A7.39.

3.12 Finally, we noted that if some new and important service that required 80 MHz did emerge, then in our view there was a low risk that the necessary performance could not be achieved by alternative means – including dual connectivity, carrier aggregation, Wi-Fi/Wi-Fi offload, or mmWave spectrum – without too great a loss in quality of service.

3.13 As part of our overall assessment, we checked whether our own modelling – using the SUT Model – suggested that 80-100 MHz bandwidth in the 3.4-3.8 GHz band would be necessary to support a range of potential future 5G services.

3.14 In addition, and separately from the SUT Model, we explained that MNOs would have access to increasingly large capacity over time due to re-farming existing spectrum for 5G, deployment of equipment supporting massive MIMO and beamforming. LTE networks would also continue to contribute to meeting capacity needs. We did not identify any points at which capacity demands driven by 5G would diverge significantly from MNOs' ability to provide the required capacity.[17]

The SUT Model

3.15 The SUT Model calculates an approximate theoretical maximum data throughput which a radio link in a cell of a 5G mobile network could support, given an assumed bandwidth of the radio carrier and an assumed received signal quality, expressed as signal to interference and noise ratio (the "**SINR**").[18] Data throughput is the rate at which data can be successfully transmitted in a cell of a network and, as such, is one measure of the performance of a network.

3.16 The data throughput calculated by the SUT Model can be thought of as the maximum data throughput which a single user could experience at a location at which a given SINR applies, if all the data-carrying resources of the radio carrier were dedicated to that user, i.e. if there were no other active users on that carrier in the cell. We can use the SUT Model to explore the technical feasibility of delivering the minimum throughput required to support a particular service by comparing that throughput to the maximum throughput which the radio carrier of a given bandwidth can deliver at various SINR levels achieved in a real network.

3.17 We recognised in the 13 March Statement that the SUT Model was a simplified theoretical model and that, in an actual deployment, many users would share the resources of a carrier. Nonetheless, we considered that its results could give us some indication of what services carriers of different bandwidths might technically be capable of supporting.

[17] 13 March Statement, paragraph 4.259.

[18] Although there are other considerations that also affect signal quality, since the SUT Model focuses on the aspect related to SINR, we refer to SINR and signal quality interchangeably for ease of discussion in this document.

Results of the SUT Model

3.18 The results we set out in the 13 March Statement suggested that MNOs were likely to be able to support a wide range of 5G services with their current holdings (i.e. with channel bandwidths smaller than 80 MHz, including 40 MHz), in combination with massive MIMO (mMIMO).[19] That is to say, the results suggested that it would be technically feasible for operators to support a wide range of 5G services with smaller bandwidths than 80 MHz. We drew no conclusions as to the associated commercial incentives or the competitive significance of future hypothetical services.

3.19 After we published the 13 March Statement, we identified and corrected certain errors in the original SUT modelling. We set out the revised results of the SUT Model in the Further Consultation. We noted in the Further Consultation that the differences were due to some adjustments to the modelled spectrum scenarios and to corrections of the errors identified.[20] In consequence, paragraphs A.7.56 to A7.65 of Annex 7 to the 13 March Statement are no longer valid and should be ignored. The correct description of the SUT Model as revised is set out in the Further Consultation. In the Further Consultation, we also modelled two different downlink-to-uplink Time-Division Duplex ("**TDD**") ratios.[21]

3.20 We used 3GPP document TR 22.891 as the primary source of information about potential future 5G services.[22] Document TR 22.891 sets out 74 potential use cases (i.e. services) but does not specify the type of spectrum expected to carry the services. We considered that in a number of cases it was likely that use of a large bandwidth of mmWave spectrum was anticipated rather than spectrum in the 3.4-3.8 GHz band. A number of the services are also specific to indoor or hot spot usage.[23]

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[19] mMIMO is a new antenna technology which MNOs are likely to deploy in many 5G base stations. Two of the key benefits of mMIMO are improved capacity by utilizing multi-user MIMO (MU-MIMO) and improved coverage by utilizing beamforming, which, for example, allows coverage from a network using 3.x GHz spectrum to approximately match that of a network using 1800 MHz. Note that we did not include mMIMO in the SUT modelling. This is because we would expect mMIMO to be used in addition to the single-user MIMO (SU-MIMO) configurations that we did include, as it is unlikely that an operator would deploy mMIMO across all the cells in its network. Also, we have modelled SUT which assumes that there is only one user in a cell and that user receives all the carrier resources.

[20] For a description of the changes made to the model please see paragraph A1.54 in Annex A1 of the Further Consultation.

[21] We additionally presented uplink results using a downlink to uplink ratio of 1:1 as this may be more representative of some indoor scenarios. See paragraphs 1.21-1.22, A1.41 and A1.54(a) of the Further Consultation.

[22] The 3GPP is a global consortium of standards organisations which develop protocols for mobile telecommunications.

[23] See Annex A1 of the Further Consultation, paragraphs A1.17 to A1.33 for a discussion of all the services in TR 22.891.

3.21 Our analysis of the use cases and modelling results set out in the Further Consultation indicated that it was likely to be technically feasible to deliver the majority of those use cases with a network using 40 MHz of spectrum.

3.22 The revised SUT Model results, when compared to the corresponding results we presented in the 13 March Statement, showed lower throughputs in the downlink and significantly lower throughputs in the uplink in all bandwidth scenarios. This led us to consider whether the revised results suggested that we should draw different conclusions from those we reached in the 13 March Statement.

3.23 In considering the revised results, we examined in more detail the nature of some of the services for which we modelled results (those for which the minimum necessary SINR values looked more demanding). We also considered their plausible network deployment patterns, to further understand the nature of the technical feasibility challenge in providing those services using different bandwidths in the 3.4-3.8 GHz band.

3.24 This analysis suggested to us that the higher SINR values likely to be needed in three use cases we identified looked challenging for deployment on a macro cell network at 3.4-3.8 GHz (whether with 40, 80 or even 100 MHz of bandwidth). The minimum throughput requirement could reasonably be achieved with alternative network deployment patterns – such as small cell deployment at a hot spot for mobile broadband live video, or deployment indoors with a symmetrical uplink/downlink ratio[24] for industrial control. We explained that we might expect operators to deploy such alternatives if these services proved to be commercially important.

3.25 We reached a provisional conclusion that the results of the modelling remained consistent with our view as set out in the 13 March Statement that it is likely to be technically feasible for MNOs to support a wide range of 5G services with channel bandwidths in their current holdings smaller than 80 MHz, including 40 MHz.

Stakeholders' responses on the SUT Model

3.26 A detailed review of the stakeholders' responses on the SUT Model is set out at Annex A1.

3.27 Although respondents were either content with, or had independently verified, the accuracy of the results of the revised SUT Model, all MNOs said that there were a number of omissions, simplifications and invalid assumptions in our modelling. Their criticisms took issue with:

i) our choice of 5G use cases;

ii) certain inputs we chose for the SUT Model and certain assumptions we made in it;[25] and

[24] We modelled a 1:1 uplink/downlink ratio as a symmetrical assignment of uplink and downlink symbols.

[25] These included downlink-to-uplink ratio indoors, special multiplexing order at low SINR, capacity penalty of using fragmented spectrum and spectrum scenarios modelled.

iii) the fact that we did not extend the SUT Model further.

3.28 They also suggested how we might have extended our model, primarily with the goal of modelling capacity, to include multiple users in a cell; and cell and network densification. They further suggested that we could have modelled SINR distribution across a cell.

3.29 O2, BT and Vodafone considered that aspects of our modelling led to our results being overly optimistic. O2[26] provided a consultant's report as part of its response, which criticised a number of features: our use of a 1:1 downlink-to-uplink ratio for the industrial control use case; our lack of discussion of how likely the SINR values, which we said were necessary, are to be realised, especially in the uplink; our assumption that small cells could be deployed to resolve issues whenever needed; and our simplification of the role of 4x4 SU-MIMO antennas.

3.30 Vodafone[27] said that it did not see anything in Ofcom's SUT Model analysis with which it would fundamentally disagree, but described our choice of use cases as arbitrary. It said that a major use case [✂ REDACTED] which it claimed that our analysis showed to be problematic.[28] It also said that Ofcom had focused too narrowly on consumer use cases to the detriment of the industrial applications that are just as important to the UK economy.[29]

3.31 BT[30] said we should have used a different 3GPP document as the source for our 5G use cases and that we should have included services requiring 1 Gbps in our analysis.

3.32 H3G[31] agreed with our modelling and extended it to consider both the impact of multiple users in a cell and also to what extent operators would need to densify their networks to match the throughput of an 80 MHz carrier on a sparser network with the throughput of a 40 MHz carrier on a denser network. H3G reported that its extended modelling still supported our conclusions.

3.33 BT,[32] O2[33] and Vodafone[34] argued that we should not have confined ourselves to the SUT Model, which represents a simplification of realistic scenarios. They argued that we should

[26] Professor William Webb's report submitted on behalf of O2 in response to the Further Consultation, paragraph 28.

[27] Vodafone non-confidential response to the Further Consultation, page 9.

[28] Vodafone confidential response to the Further Consultation, page 10.

[29] Vodafone non-confidential response to the Further Consultation, pages 10-11.

[30] BT non-confidential response to the Further Consultation, page 5.

[31] H3G non-confidential response to the Further Consultation, paragraphs 9.4 and 12.16.

[32] BT non-confidential response to the Further Consultation, paragraph 2.

[33] O2 non-confidential response to the Further Consultation, paragraph 2, and Professor William Webb's report submitted on behalf of O2 in response to the Further Consultation, paragraphs 4-5.

[34] Vodafone non-confidential response to the Further Consultation, pages 2, 11 and 14.

go further and model the effect of holdings smaller than 80 MHz on traffic-carrying capacity in a realistic deployment with many simultaneous users.

3.34 The consultant's report submitted by O2[35] said that a simplified and illustrative capacity model he had put together suggested to him that there were plausible scenarios where 40 MHz was not enough bandwidth to deliver 5G services to the number of simultaneous users likely to demand them. He concluded that with only 40 MHz there might be insufficient spectrum to meet the rapidly growing demands of subscribers with the result that services would need to be curtailed, and many subscribers might not be able to receive the 5G service that they would like.

Our conclusions in light of stakeholders' comments on the SUT Model

3.35 Stakeholders' comments on the SUT Model fell into two broad categories:

i) comments on the SUT Model and the use we made of it in the 13 March Statement and Further Consultation for minimum throughput requirements of 5G services (not capacity to support the traffic of multiple users); and

ii) comments on capacity requirements for carrying the traffic of multiple simultaneous users.

3.36 In Annex A1 we provide a detailed summary of the points made in stakeholders' responses and our conclusions in light of these.

3.37 Below we provide a high level summary of our conclusions.

Category (i) comments: the SUT Model

3.38 Stakeholders did not disagree with the conclusions we drew from our SUT Model regarding the technical feasibility of a wide range of future 5G services with the MNOs' current holdings of less than 80 MHz.

3.39 Taking into account respondents' criticisms, we remain of the view that the SUT Model, though a simplified theoretical model, is appropriate for our purposes and that it is reasonable for us to conclude that it is likely to be technically feasible for MNOs to support a wide range of 5G services with channel bandwidths in their current holdings smaller than 80 MHz, including 40 MHz.

3.40 We do not agree that we should have modelled the SINR distribution across a cell or considered in more detail how likely the SINR values which we said were necessary are to be realized. We do not consider this would add significant additional insight - any SINR distribution we calculated would, in any case, be specific to a certain environment and propagation model.

[35] Professor William Webb's report submitted on behalf of O2 in response to the Further Consultation, paragraphs 62 and 64.

3.41 In the Further Consultation, we used 3GPP document TR 22.891 as the primary source of information about potential future 5G services. As noted above, there are 74 use cases set out in TR 22.891 and we selected a sample of the most demanding use cases listed to test technical feasibility, including with 40 MHz of spectrum. There are of course other sources of information about potential future 5G services, but we do not believe that the alternative sources mentioned by stakeholders provide any better understanding of the spectrum bandwidth needed for future 5G services.

3.42 In the Further Consultation, we considered one industrial scenario, namely industrial control applications which require high reliability and very low latency (~1ms). Having considered alternative industrial use cases put forward by stakeholders in their consultation responses, we believe that the scenario we modelled is sufficiently representative of a wide range of industrial use cases.

3.43 In the Further Consultation, we identified two categories of services which may require speeds of "up to 1 Gbps": wireless local loop (fixed wireless access); and mobile broadband for indoor and hotspot scenarios. Figure 1 in the Further Consultation shows that very favourable signal conditions (i.e. very high SINRs) would be needed to enable 80 MHz and 100 MHz carriers to deliver 1 Gbps in the downlink. We therefore consider our assessment that operators would likely need to deploy mmWave spectrum and/or small cells to deliver these services remains valid.

3.44 We have assessed stakeholders' criticisms of various modelling inputs and assumptions and do not agree that they make our results overly optimistic. For instance, whilst we accept that an MNO would need to ensure co-existence between its indoor industrial control deployments (using a 1:1 downlink-to-uplink ratio) and its outdoor macro network (using a 3:1 ratio) in the same geographic area, this would be under the control of the MNO, which could use additional mitigations such as careful installation of indoor base stations and site shielding in those areas where it is necessary to do so.

Category (ii) comments: capacity

3.45 We do not agree that we should extend our modelling of traffic-carrying capacity (see stakeholder comments in paragraphs 3.33-3.34 above) in order to sustain the conclusions that we arrived at in the 13 March Statement. It is self-evident that more spectrum would (all other things equal) support proportionally greater traffic-carrying capacity for use by multiple simultaneous users. We considered the likely evolution of 5G capacity requirements and MNOs' ability to support them over time in the competition assessment we set out in the 13 March Statement, and see no new information in the responses that would cause us to change any of that assessment.[36]

3.46 In the 13 March Statement, we also considered the other main ways of increasing traffic-carrying capacity in addition to more spectrum, namely network densification and

[36] See 13 March Statement paragraphs 4.255 and 4.259.

increased spectral efficiency. We do not consider that the SUT Model, extensions of it or other modelling would usefully add to our analysis of these considerations.

Dynamic spectrum sharing

3.47 Dynamic spectrum sharing is a technology which enables an MNO to allocate spectrum resources dynamically between 4G and 5G handsets, based on instantaneous demand, using the same frequency carrier to carry both types of traffic.

Consultation position on dynamic spectrum sharing

3.48 In the 13 March Statement, at paragraph A7.36 of Annex 7, we said that we understood that DSS could facilitate re-farming of bands used for 4G to 5G. We added that, although we understood that DSS might reduce capacity by 7-10% when compared with a 4G-only carrier, its benefits might improve the overall spectrum efficiency of the network when compared with assigning static 4G and 5G carriers. We noted that DSS was already being used by some operators in other jurisdictions (such as AT&T and Swisscom).

3.49 A stakeholder raised a concern about our reference to the use of DSS to facilitate re-farming of 4G spectrum. In particular, it highlighted that a technical solution for DSS was not available in the 2.3 GHz band (which is licensed for use with time-division duplex technology).

3.50 We explained in the Further Consultation that we had not suggested in the 13 March Statement that DSS was necessarily available in all bands currently used for 4G. We said that it was our position, however, that it is likely to be available in a number of current 4G frequency-division duplex ("**FDD**") bands including 800 MHz, 900 MHz, 1800 MHz, 2.1 GHz and 2.6 GHz. We said that our view remained that DSS could facilitate re-farming of most bands currently used for 4G to 5G, and so was likely to be an option for operators to consider.

Stakeholders' responses on dynamic spectrum sharing

3.51 O2 said that DSS was not currently available in the 2.3 GHz band, in which it holds 40 MHz, and that this band is "*critical*" for O2's current 4G capacity.[37] It argued that O2's ability to re-farm 4G spectrum is far more limited than we assumed in the 13 March Statement[38] and that this would increase the challenges it faced in meeting ever growing capacity requirements over time for 4G and 5G services.[39]

[37] O2 non-confidential response to the Further Consultation, paragraphs 7-8.

[38] O2 non-confidential response to the Further Consultation, paragraph 13.

[39] O2 confidential response to the Further Consultation, paragraphs 14-15. Specifically, O2 made the following comments: [✂REDACTED] *(…) Therefore, whilst 5G usage will increase in the next few years, 4G usage will*

3.52 O2 further said that, while we estimated that DSS might reduce capacity by 7 to 10% when compared with a 4G-only carrier, this reduction is greater (being potentially around [✂REDACTED]), when compared to a 5G-only carrier.[40]

3.53 Vodafone[41] said that its vendor research indicates that the loss in throughput of 5G in a DSS carrier is more than [✂REDACTED] [42] when compared to a discrete 5G band.

3.54 Vodafone[43] also said that deploying DSS will be problematic where the existing 4G spectrum is already heavily loaded, and that such locations are inherently likely to be where an operator would be seeking to deploy 5G technologies.

3.55 Further, Vodafone[44] said that there were other technical deployment and device compatibility issues with DSS and that we might for this reason have overstated its benefits.

3.56 BT[45] did not disagree with our assessment of the capacity lost to DSS when compared with a 4G-only carrier, but observed that the inefficiency rose to 10-20% when compared with using a static 5G carrier.

Our position on dynamic spectrum sharing

3.57 While we acknowledge that DSS is not currently available in TDD bands, including the 2.3 GHz band, this does not change or otherwise invalidate our view that DSS could facilitate re-farming of most bands currently used for 4G to 5G – including 800 MHz, 900 MHz, 1.8 GHz, 2.1 GHz and the 2.6 GHz FDD bands.

3.58 We acknowledge that the capacity loss of DSS, when compared to 5G, may be greater than the capacity loss compared to a 4G carrier, being potentially of the order of [✂REDACTED], as suggested by O2. However, our comparison (7-10%) was with a 4G carrier. This is the relevant comparison as during a transition period where a 4G band is being re-farmed to 5G, it is the impact on 4G capacity that is relevant. Where a MNO enables DSS, it may choose to use some spectrum it uses for 4G to support some 5G traffic, but where its 4G capacity is constrained, it could prefer instead to prioritise maintaining 4G capacity to support users with 4G-only devices. For example, O2[46] told us that it turned off

continue to grow in parallel and will still account for the majority of demand in this period. (…)" (O2 non-confidential response to the Further Consultation, paragraph 15).

[40] O2 confidential response to the Further Consultation, paragraph 5.

[41] Vodafone non-confidential response to the Further Consultation, page 13.

[42] Vodafone confidential response to the Further Consultation, page 13.

[43] Vodafone non-confidential response to the Further Consultation, page 13.

[44] Vodafone non-confidential response to the Further Consultation, pages 13-14 and Vodafone confidential response to the Further Consultation, page 14.

[45] BT non-confidential response to the Further Consultation, page 7.

[46] O2 non-confidential response to the Further Consultation, paragraph 42.

another network feature, carrier aggregation, on some capacity-constrained base station sites because of the impact that carrier aggregation has on capacity.

3.59 DSS is one tool MNOs may use to facilitate re-farming. In enabling spectrum in a given band to be shared dynamically between 4G and 5G, DSS may allow MNOs to improve the overall spectrum efficiency of the network when compared with assigning 4G and 5G carriers in the same band statically.[47] There are pros and cons involved in any approach to re-farming and the MNOs are best placed to decide the optimal approach for them. As Vodafone[48] acknowledged in its response, DSS is an interesting technology, and [✂REDACTED][49].

3.60 We comment in the next section on O2's wider concern about its ability to support growing capacity demands, including its concern that we have overestimated its ability to re-farm 4G spectrum.

[47] See paragraph A7.36 in the 13 March Statement.

[48] Vodafone non-confidential response to the Further Consultation, page 13.

[49] Vodafone confidential response to the Further Consultation, page 13.

4. Further matters raised in responses

4.1 In addition to responding to the matters which we included in the Further Consultation, stakeholders made submissions on a number of other matters which we had examined in previous consultations and on which we had not sought further comments. We have nevertheless considered these submissions and whether, to the extent that they contained new evidence, we should revise our conclusions in the light of them.

Capacity limitations in spectrum portfolios

Stakeholders' submissions

4.2 In its submission on DSS, O2[50] said that our 13 March Statement required a far-reaching reconsideration. O2 said that "*Ofcom's error in respect of DSS*" exemplified a wider inadequacy in our analysis of the impact of our decisions on MNOs' ability to meet demand, and O2's in particular. In O2's view, this inadequacy undermined Ofcom's competition analysis and approach to defragmentation.

4.3 O2 said that in Annex 7 of the 13 March Statement, "*Ofcom rejected [O2's] explanation that 'operators with modest capacity spectrum holdings will not have the flexibility to refarm from 4G to 5G', stating that DSS could facilitate such refarming*"[51] and that "*As [O2] pointed out (..), this is incorrect. Ofcom's mistake has far reaching consequences for its analysis. As a result, it has failed to take into account the real limitations affecting [O2's] ability to provide a competitive 5G offering and the competition risks posed by the proposed auction rules*".[52]

4.4 In summary, O2[53] claimed in its submission that its ability to re-farm its spectrum bands from 4G to 5G is more limited than we had assumed in the 13 March Statement. It identified the current non-availability of DSS for the 2.3 GHz band as a material limiting factor in this respect, which it considered that we had overlooked.

4.5 O2 said that it currently used its 40 MHz of spectrum in the 2.3 GHz band to provide 4G services and that [✂REDACTED].[54] [✂REDACTED][55]

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[50] O2 non-confidential response to Further Consultation, paragraphs 62-64.

[51] O2 non-confidential response to Further Consultation, paragraph 3. The text gives reference to paragraphs A7.35-6 of the Annex 7 of the 13 March Statement.

[52] O2 non-confidential response to Further Consultation, paragraph 4.

[53] O2 non-confidential response to the Further Consultation, paragraph 13.

[54] O2 confidential response to Further Consultation, paragraph 7.

[55] O2 confidential response to Further Consultation, paragraph 14 and Figure 1.

4.6 O2 said that DSS was not currently available for the 2.3 GHz band.[56] [✂REDACTED].[57] Moreover, as far as O2 was aware, there were no end-user devices currently planned to be compatible with DSS using TDD spectrum, as the base station equipment did not exist, and as such there was no demand for the capability.[58] It considered that "*the only bands where DSS would be available for TUK are 800 MHz, 900 MHz and 2.1 GHz*".[59]

4.7 O2 went on to say that [✂REDACTED].[60] O2 was concerned that, in reaching our conclusions in the 13 March Statement we had not properly taken into account the impact and consequences this perceived disadvantage would have on competition.[61]

4.8 In its submission, H3G said "*Although there will be a lag in the availability of DSS for TDD bands, DSS in TDD will be widely supported as TDD ecosystems develop in 2021. We also understand that a leading handset manufacturer plans to support DSS on TDD bands in some devices in the second half of 2020*".[62]

4.9 H3G[63] expected demand for 5G services to be even lower in the short term than we forecast and said that the MNOs would be able to re-farm spectrum they used now for 4G and other services to support 5G earlier than we had anticipated. It asked us to consider the implications of the recently announced Virgin Media/O2 merger and noted that the merged entity plans to migrate 3 million Virgin Mobile customers to O2's network, which, H3G said, would be "*an odd thing to do if its network is capacity constrained as O2 says*". H3G also noted that Liberty Global (the parent company of Virgin Media) stated in an investor call that the merged entity would have a "*competitive spectrum position*".[64]

4.10 Commenting on O2's suggestion that capacity constraints would be a significant block to MNOs re-farming bands currently used for 4G to 5G, H3G considered that if an MNO were unable to re-farm 4G spectrum to 5G due to 4G network congestion, it would be because most customers were still on its 4G network. The 5G network would then be lightly loaded so the MNO would not be helped by having an 80-100 MHz 5G block in the 3.4-3.8 GHz band.[65]

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[56] O2 non-confidential response to Further Consultation, paragraph 6.

[57] O2 confidential response to Further Consultation, paragraph 9 and footnote 10.

[58] O2 non-confidential response to Further Consultation, paragraph 9.

[59] O2 non-confidential response to Further Consultation, paragraph 12.

[60] O2 confidential response to Further Consultation, paragraph 12.

[61] O2 non-confidential response to Further Consultation, paragraph 17.

[62] H3G's non-confidential response to the Further Consultation, paragraph 7.44.

[63] H3G's non-confidential response to the Further Consultation, paragraphs 4.3.

[64] H3G's non-confidential response to the Further Consultation, paragraphs 2.8-2.9.

[65] H3G's response to the Further Consultation, paragraph 7.12.

4.11 H3G[66] also noted that it carried much more traffic than O2 on a fraction of O2's spectrum: H3G has 70 MHz of spectrum for 3G and 4G (to which it has recently started to add 20 MHz of 1400 MHz spectrum) compared with O2's 126 MHz of spectrum for 2G/3G/4G.

Our position

4.12 We have carefully considered our conclusions in the 13 March Statement in light of the new evidence submitted by stakeholders regarding the challenges O2 could face in re-farming its 4G spectrum to 5G. Consistent with our analysis in the 13 March Statement, we conclude that there is a low risk of a competition concern arising from those challenges under any auction outcome.

4.13 Firstly, regarding potential capacity constraints, we have not seen evidence that persuades us that O2 is likely to face unavoidable future capacity constraints in 4G and 5G *simultaneously* to a degree that would raise competition concerns. We take into account that we would expect demands on O2's 4G capacity to be relieved to the extent that its users migrate from 4G to 5G services – in simple terms, that 4G customers take their traffic with them when they migrate to 5G.

4.14 Secondly, we consider that there is a low risk of a combination of circumstances occurring which would result in a competition concern related to the current non-availability of DSS for TDD bands, given the likely demands of future 5G services and the range of options likely to be available to operators to increase throughput and capacity, including those described in paragraph 3.14 above.

4.15 To the extent that O2 considers that it needs to improve its 5G capacity or throughput to strengthen or underpin its future commercial performance, it has an opportunity to do so by bidding in the auction. As noted in paragraph 3.7b) above, we concluded in the 13 March Statement that, if MNOs do need more spectrum in the 3.4-3.8 GHz band to compete, they are likely to be able to acquire some 3.6-3.8 GHz spectrum in this auction, because of the high intrinsic value they will in that case attach to it. There may also be additional potential opportunities to trade or acquire spectrum for either larger bandwidth or traffic-carrying capacity. We have built measures into the design of this auction to facilitate negotiation of such trades to achieve larger contiguous bandwidth.

H3G's incentives to trade to defragment the 3.4-3.8 GHz band

Stakeholders' submissions

4.16 According to Vodafone,[67] while it may be the case that private trades will facilitate defragmentation, "*the scenarios where this does not occur vastly outnumber the outcome where it does*". Vodafone submitted a report from consultants [✂REDACTED] describing a

[66] H3G non-confidential response to the Further Consultation, paragraph 7.13.

[67] Vodafone non-confidential response to the Further Consultation, page 2. See also page 14.

quantified model, based on game theory, of MNOs' incentives to trade spectrum in the negotiation phase of the assignment stage of 3.6-3.8 GHz frequencies in the auction process.

4.17 Vodafone claimed the report shows that, contrary to the view we took in the 13 March Statement, H3G would gain strategic value from depriving competitors of contiguous blocks of spectrum in the wider 3.4-3.8 GHz band, and hence that it would be incentivised not to trade. Vodafone said that this analysis gave significant cause to believe that we may be mistaken in leaving it to the market to resolve fragmentation through private trades.

Our position

4.18 We have considered the [✂REDACTED] report (noting that we have not received or reviewed a copy of the model itself). As set out in the report, the model makes various assumptions about costs, prices, network quality and customer churn, which, in our view, tend to overstate H3G's gain from refusing to trade.

4.19 Nevertheless, even if we take all of the assumptions and quantified results in the [✂REDACTED] report as given (and notwithstanding the way the conclusions are presented in Vodafone's response and the report), the underlying analysis in fact supports Ofcom's conclusion about incentives to trade as set out in the 13 March Statement. Interpreted appropriately, the [✂REDACTED] report implies that all MNOs have clear incentives to trade to achieve defragmentation (proximity and/or contiguity). The report shows [✂REDACTED]. As there are gains from trade, each MNO is made better off by agreeing to trade. In the case of a trade with H3G, this is due to its receiving a payment reflecting a proportion of the profit gain to the trading partner.

4.20 We therefore conclude that the report in fact lends some support to our position that H3G has an incentive to trade.[68] In any event, the report does not alter our conclusions in the 13 March Statement that H3G has an incentive to trade.

Addition of negotiation prior to assignment of 700 MHz FDD frequencies

Ofcom position in the 13 March Statement

4.21 In the 13 March Statement, we considered a suggestion from an MNO [✂REDACTED] that we allow bidders to express preferences for the identities of their neighbours in the 700 MHz FDD band.[69] The MNO proposed that either bidders should be allowed to make contingent assignment stage bids, or else the scope of the negotiations for 3.6-3.8 GHz

[68] See, for example, paragraph 6.60 in the 13 March Statement: "*To the extent that the gains to other operators from obtaining contiguous spectrum are significant, they would be able to provide an incentive for H3G to sell or move some of its existing holdings. H3G would have an incentive to trade in order to share in these gains.*"

[69] 13 March Statement, paragraph 5.162.

winners should be extended to permit winners of 700 MHz FDD to agree frequency locations in the 700 MHz band (either unanimously or partially). The MNO suggested that this would benefit any winners of just 2x5 MHz of 700 MHz FDD spectrum, who may wish to engage in spectrum pooling or post-auction trades to achieve larger blocks of low frequency spectrum. Under certain circumstances, this might help to reduce the impact of an aggregation risk of just winning a single 2x5 MHz lot.

4.22 As set out in our June 2019 consultation, we considered there to be material risks in allowing contingent bidding in the assignment stage.[70] We therefore did not consider this option further.

4.23 We explored the option of extending the negotiation phase to include the 700 MHz FDD band. In the 13 March Statement, we noted that were limited incremental benefits to extending the assignment stage for the following reasons[71]:

a) While there may be some aggregation risk in this band, we considered that 2x5 MHz of 700 MHz would still be a useable amount of spectrum.

b) The benefits of making the change would also likely only be relevant in a limited set of circumstances, notably where there are two winners of 2x5 MHz of 700 MHz FDD, that also have adjacent holdings in the 800 MHz band, and that would be willing to swap frequencies.

c) Under these circumstances, those winners could still bid to express a preference to be next to one another, e.g. by bidding highly for the frequencies second from the bottom or top, which would achieve adjacency.

4.24 In addition, we identified some downsides to extending the negotiation phase, which included[72]:

a) Facilitating price driving in the principal stage by reducing the impact to a price-driving bidder of accidentally winning a small amount of spectrum in 700 MHz FDD, as it would more easily be able to set up a post-auction trade as a mitigation.

b) Pursuing the suggestion at that stage would likely have an impact on auction timelines, including the likely need to re-consult.

4.25 We therefore decided not to adopt these alternative proposals because we considered that the incremental benefits would be limited. We also noted some practical implementation considerations, which would require that time and money be spent amending the regulations and software, and would potentially require re-consultation.

[70] 13 March Statement, paragraph 5.167.

[71] 13 March Statement, paragraph 5.168.

[72] 13 March Statement, paragraph 5.169.

Stakeholders' submissions

4.26 The same MNO who suggested that we should allow bidders to express preferences for the identities of their neighbours in the 700 MHz FDD band [✂ REDACTED] sent a letter to Ofcom on 12 June 2020, arguing that we should re-consider our decision and re-consult on extending the 3.6-3.8 GHz assignment stage negotiation process (including both the unanimous and partial agreement options) to the 700 MHz FDD band "*so as to ensure that a proper analysis of the applicable upsides and downsides is conducted in accordance with due process*".

4.27 First, the MNO stated that Ofcom had not considered the full range of circumstances in which bidders would like to have adjacent spectrum. It considered that[73]:

a) O2 and Vodafone are potential trading partners at 700 MHz FDD and 900 MHz, while all MNOs are trading partners at 700 MHz and 800 MHz;

b) existing infrastructure sharing arrangements make BT/H3G and O2/Vodafone natural partners for sharing spectrum;

c) the fact that the spectrum portfolios of O2 and Vodafone on the one hand and those of BT and H3G on the other have different relative strengths (sub 1 GHz and 5G capacity portfolios respectively) suggests scope for a broader trade, if any two bidders from these two groups end up with 2x5 MHz of 700 MHz FDD each; and

d) a bidder that had targeted 2x10 MHz but only won 2x5 MHz may want to be next to another winner of 2x5 MHz in order potentially to maximise its sale value.

4.28 Second, the MNO considered that Ofcom had not extended the logic for including a negotiation period in the 3.6-3.8 GHz band to the 700 MHz band.[74] It considered that there were similarities between the two situations, such that bidders would bid to achieve adjacency with other bidders rather than having other reasons to prefer a particular frequency (such as different intrinsic values for the frequency locations). The MNO did agree that there were mitigating bid strategies that would increase the likelihood of being placed next to a preferred partner in the assignment stage for 700 MHz FDD.[75] However, the MNO considered that there were incentives to underbid in this mitigating bid option due to the uncertain rewards and the possibility of relying (or free riding) on the potential adjacency partner's bids to reduce one's own assignment stage payment.

4.29 Third, the MNO considered that extending the negotiation period would not significantly increase the price-driving risk in 700 MHz FDD. It claimed that all four MNOs would want some 700 MHz FDD and therefore a price-driving MNO bidder would also potentially

[73] [✂REDACTED] letter to Ofcom of 12 June 2020, paragraph 6.3.

[74] [✂REDACTED] letter to Ofcom of 12 June 2020, paragraph 6.4.

[75] [✂REDACTED] letter to Ofcom of 12 June 2020, paragraph 6.5.

increase its own price.[76] Furthermore, it claimed that the negotiation period would increase the possibility of a 700 MHz trade, but that there would still be uncertainty and that significant risk would remain for a price-driving bidder with no reason to assume that the prospect of a negotiation round would be the swing factor leading it to engage in price driving.[77] It also claimed that the negotiation period could help to correct principal stage errors, such as a price-driving bidder winning spectrum.[78]

4.30 Lastly, the MNO considered that the 700 MHz FDD negotiation stage would not cause a delay in the auction if the negotiation period was done at the same time as in the 3.6-3.8 GHz band.[79] It also expressed the view that there was uncertainty as to when the 700 MHz FDD spectrum would be cleared and ready to use given the Covid-19 pandemic. It therefore stated that the introduction of a negotiation period for 700 MHz FDD would not create a delay to deployment if the auction were still to take place before 700 MHz was available.

Our position

4.31 As the MNO in question raised some new points, we have considered again whether we should extend the negotiation phase to include the 700 MHz FDD band.

Potential benefits of extending the negotiation phase to include 700 MHz FDD

4.32 We recognise that there may be more circumstances in which two winners in the band would want adjacent placements in the assignment stage than those set out in our 13 March Statement, which only explicitly referred to potential trading between licensees of 700 MHz and 800 MHz spectrum. We acknowledge, for example, that Vodafone and O2 could be trading partners across 700 MHz and 900 MHz, and that there could be some benefits to being placed adjacent to another bidder if those bidders wanted to set up future arrangements to share spectrum (see the 900 MHz band plan in Figure 4.1).[80]

Figure 4.1: 900 MHz band plan

[76] [✂REDACTED] letter to Ofcom of 12 June 2020, paragraph 6.6.

[77] [✂REDACTED] letter to Ofcom of 12 June 2020, paragraph 6.7.

[78] [✂REDACTED] letter to Ofcom of 12 June 2020, paragraph 6.8.

[79] [✂REDACTED] letter to Ofcom of 12 June 2020, paragraph 6.9.

[80] In the 13 March Statement (paragraphs 5.163-5.165) we also considered the benefits of adjacent assignments at the boundaries of the 700 MHz FDD and SDL bands to a bidder acquiring both (e.g. reduced deployment costs). As the MNO's submission did not make any new points about this, we do not discuss it in further detail in this document, although we note that it could be a further scenario relevant to a negotiation period.

4.33 However, we consider that the benefits of extending the negotiation period are not as high as the MNO has suggested. For example, it is not obvious to us that all MNOs would be trading partners across 700 MHz and 800 MHz, given that H3G is only adjacent to BT (not Vodafone or O2), and similarly BT is not adjacent to O2 (see the 800 MHz band plan in Figure 4.2).

Figure 4.2: 800 MHz band plan

4.34 More generally, we also note that an outcome of two bidders winning 2x5 MHz can only arise if at least one of the bidders intentionally bids for 2x5 MHz[81], which is a useable amount of spectrum, as noted at paragraph 4.23a) above. This is likely to place a limit on the range of possible circumstances in which these benefits would arise.

4.35 We continue to consider that there are alternative ways for bidders to achieve adjacency, other than by extending the negotiation phase to include the 700 MHz band. We previously observed that, if there were two winners of 2x5 MHz, a bidder ('Green') could bid on location two and/or five out of six 2x5 MHz placements, in order to increase its chances of being next to the other 2x5 MHz winner ('Brown'), because the winners of larger amounts could not be placed in locations 1 and/or 6. For example, if there were third and fourth principal stage winners with 2x10 MHz each (or alternatively, just a third winner with 2x20 MHz), then Green winning either of locations two or five would guarantee that it would end up adjacent to Brown - see Figure 4.3 for an illustration.

Figure 4.3: 700 MHz FDD frequency locations

	2x5 MHz	2x5 MHz	2x5 MHz	2x5 MHz	2x5 MHz	2x5 MHz
700 MHz	1	2	3	4	5	6
	1	2	3	4	5	6

4.36 The MNO agreed that this bidding strategy could increase the chances of achieving adjacency but argued that there were incentive problems with it. The MNO suggested that, for example, Green could underbid its true valuation, instead relying on Brown to bid for adjacency (i.e. bidding on location two and/or five), such that Green could pay less or nothing but still achieve adjacency. Simultaneously, Brown could also adopt the same approach of underbidding and relying on Green to bid and pay the fee for achieving adjacency.

[81] That is, one bidder intentionally bids for one, three or five 2x5 MHz lots. This is because a feature of the auction design is that there can be at most one partial standing high bidder in each band in each round. The situation could also arise if two bidders intentionally bid for 2x5 MHz (but it is not feasible as an outcome if neither does so).

4.37 We agree that, in theory, there is a possible free-riding incentive that could lead bidders to reduce their assignment stage bids and that, if both bidders underbid, there is the possibility that they would not achieve adjacency in circumstances where it would have been efficient for them to be placed next to each other.[82]

4.38 However, first, these free riding incentives are materially mitigated by there being only two winners of 2x5 MHz. This means each bidder is fully aware that it is taking a significant risk if it chooses to underbid and relies on the other to bid sufficiently high to achieve adjacency. For example, if Green underbids and relies on Brown to bid sufficiently high, it knows that, if Brown chooses to do the same, they could both fail to achieve the desired outcome of adjacent locations. This risk is likely to limit the incentives to underbid.

4.39 Second, as noted at paragraph 4.34 above, the situation can only arise if at least one of the two bidders intends to win 2x5 MHz, and (as explained below) this could make clearer to the bidders the extent of the risk from underbidding. To illustrate, we consider the example of Green winning 2x5 MHz unintentionally as a partial standing high bidder and wanting to obtain an adjacent location to Brown. Green would know that Brown had intentionally bid for 2x5 MHz, which could mean that Brown intends to deploy 2x5 MHz as a useable amount of spectrum. In this situation, Green could recognise that Brown may not be prioritising achieving adjacent locations for a possible post-auction trade. As such, it could be especially risky for Green to rely on Brown to achieve adjacent locations.[83]

4.40 Third, a larger efficiency gain for Green and Brown from being next to each other means their expected intrinsic values for adjacent locations are correspondingly higher. Therefore, if the efficiency gain from adjacent locations is larger, they would have to engage in a greater degree of underbidding to reduce their bids enough to prevent adjacent locations from being achieved.

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[82] The incentive Green and Brown could have to free ride on each other arises in an attempt to reduce the fee paid for the desired assignment stage outcome. In contrast, if there were a partial (or unanimous) agreement, no assignment stage fee would be paid by Green or Brown.

[83] There are other possibilities. Without seeking to be comprehensive, we discuss here some further scenarios, noting that Green and Brown would be informed of each other's identity before making their assignment stage bids, because we announce the principal stage results in advance of the assignment stage. First, Green and Brown could both win 2x5 MHz intentionally, with Green having a deliberate intention to rely on a post-auction trade to achieve a 2x10 MHz block and address the aggregation risk. In this case, it could again be especially risky for Green to free ride on Brown's bids. Second, both could intentionally win 2x5 MHz as useable amounts, but both could still see benefits from a post-auction swap (e.g. H3G and BT with 800 MHz, or Vodafone and O2 with 900 MHz). In this case, it could be less clear which of Green or Brown should refrain from underbidding, although both would know that free riding could lead to adjacent locations not being achieved. Third, Brown could have a reason not to bid for location two and/or five, such as if it prefers location one in order to be adjacent to 700 MHz SDL spectrum that it has also acquired (as the SDL frequencies are just below the FDD downlink frequencies). Green would know that Brown was in the position of having acquired both SDL spectrum as well as 2x5 MHz of FDD and this could clarify the location Green should bid for, if it has an interest in being adjacent to Brown (while an alternative option for Brown could be to bid for location two to be adjacent to Green and subsequently achieve adjacency to the SDL spectrum through a post-auction trade with Green).

4.41 Overall, we still consider that the mitigating bid strategy is generally likely to provide an effective opportunity for winners of 2x5 MHz of 700 MHz FDD that are seeking to achieve adjacent locations.

Differences between 700 MHz FDD and 3.6-3.8 GHz bands

4.42 The MNO asked us to extend the logic underlying a negotiation period for the 3.6-3.8 GHz band to the 700 MHz FDD band. While there are similarities, we have outlined below some distinctions which, in our view, mean that the same logic does not necessarily carry across.

4.43 One distinctive feature of 3.4-3.8 GHz is that we expect MNOs to want to defragment their overall holdings in the band. As such, the uncertainty is how this may be achieved. In other words, the expected or most likely outcome is that the assignment stage of the 3.6-3.8 GHz auction will not represent the final set of locations of operators' holdings, at least some of which are expected to be changed through post-auction trades. In contrast, although post-auction trades to change 700 MHz FDD locations are possible, this depends on specific principal stage outcomes (in particular where there are two winners of 2x5 MHz and they are both interested in a trade).

4.44 A second distinction is the scale of benefits that are at stake. Although we said in the 13 March Statement that there was a low risk of competition concerns related to 3.4-3.8 GHz from any auction outcome, we also recognised that defragmentation was desirable and likely to result in greater spectrum efficiency.[84] In the 700 MHz FDD band, the expected scale of benefits seems significantly smaller.

4.45 A third distinction is the number of possible trading partners. In relation to 3.6-3.8 GHz spectrum, different pairs of trading partners could achieve improved proximity and/or contiguity. In relation to 700 MHz spectrum, it is anticipated that only the two principal stage winners that win 2x5 MHz (if that outcome occurs) would participate in post-auction trading.

Price driving in the principal stage

4.46 A negotiation period for 700 MHz FDD would be a new element in the auction with the potential to affect the incentives of the bidders, including in relation to parts of the auction that would occur earlier, such as principal and assignment stage bids. In the 13 March Statement we set out the specific example of an increased risk of price driving in the principal stage.[85]

4.47 The MNO considered that the negotiation period was unlikely materially to increase the risk of price driving in the principal stage of the 700 MHz FDD band, claiming that all four MNOs would want to avoid increasing their own price for 700 MHz. We are not in a

[84] 13 March Statement, paragraphs 6.42 and 6.47

[85] There could also be other effects on bidding incentives, such as affecting the spectrum amounts that bidders wish to bid for in the principal stage, which could have positive or negative effects on spectrum efficiency.

position to presume that all MNOs would necessarily expect to win 700 MHz spectrum, and therefore that all bidders would be disincentivised to price drive.[86]

4.48 The MNO also claimed that significant risk would remain for the price-driving bidder. We do not consider that a negotiation period would remove the risk faced by a price-driving bidder, but we remain of the view that it could reduce it. We note that the MNO seems to accept this (since it acknowledged that the possibility of a 700 MHz trade is increased).

4.49 Overall, although the practical increase in the risk of price driving in the auction is difficult to quantify, we still consider that a downside of extending the negotiation period to 700 MHz is that it could facilitate price driving in the principal stage. This poses a potential risk to spectrum efficiency, even if we do not generally consider that risk to be large.[87]

Delay to auction timeline

4.50 We recognise that the change in circumstances due to the Covid-19 pandemic suggests the time that would be needed to make such changes is now less relevant in view of our revised planned timings.

Conclusion

4.51 Overall, we consider that there would be limited benefits and also downsides to extending the negotiation phase to include negotiation in respect of 700 MHz FDD spectrum. Benefits are limited, for example, by the ability of 2x5 MHz winners (if any) to achieve adjacent locations through a mitigating bid strategy (in particular, by bidding for location two and/or five in the band). The downsides are limited as we do not generally consider the risk to spectrum efficiency from price driving to be large. We consider that there is a much weaker case for a negotiation period in the assignment stage in the 700 MHz FDD band than for 3.6-3.8 GHz.

4.52 We disagree with the suggestion that we should re-consult on this issue "*so as to ensure that a proper analysis of the applicable upsides and downsides is conducted in accordance with due process*". We had already addressed this proposal in our 13 March Statement, despite it having been raised by a stakeholder after the deadline for consultation responses. We have now given further consideration to it in the light of some new points raised by the same stakeholder. Since we are not making any substantive change to the approach set out in our 13 March Statement, we do not consider that there is any need to re-consult on this issue to ensure a fair process.

4.53 In conclusion, we consider it appropriate to maintain our position as set out in the 13 March Statement. We would expect to look favourably on any trades after the assignment

[86] In Italy, for example, there is a market with four MNOs but with only three winners in its 700 MHz FDD auction (Telecom Italia, Illiad and Vodafone each won 2x10 MHz). The outcome of all four MNOs winning 700 MHz has also been observed, e.g. in France (with Bouygues and SFR each winning 2x5 MHz, and each of Free and Orange winning 2x10 MHz).

[87] 13 March Statement, paragraphs 5.16 d) and 5.32

stage of the 700 MHz band which include holdings won in that band, provided they do not give rise to competition concerns.

Impact of Government policy on high-risk vendors

Stakeholders' submissions

4.54 Vodafone[88] submitted that our analysis in the 13 March Statement failed to consider potential Government policy on high-risk vendors of equipment, particularly as it may impact on the effects of fragmentation of spectrum and on DSS.

Our position

4.55 In the 13 March Statement, we said that active antenna technology with wide instantaneous bandwidth would be one way to enable operators to deploy fragmented spectrum.

4.56 On 14 July, the Government stated that, from the end of this year, telecoms operators must not buy any 5G equipment from Huawei, and that once the Telecoms Security Bill is passed it will be illegal for them to do so. In addition, the Government said it had concluded that it was necessary and prudent to commit to a timetable for the removal of Huawei equipment from 5G networks by 2027.[89]

4.57 We understand that Huawei has the most advanced roadmap for active antenna technology with wide instantaneous bandwidth, and is therefore the most likely vendor to provide active antenna equipment which would span the worst-case range of 390 MHz of Vodafone's potential spectrum holdings in the 3.4-3.8 GHz band if Vodafone were to fail to defragment its holdings in the 3.4-3.8 GHz band after the auction. However, we consider that Vodafone is likely to have other options. Firstly, updated evidence we have now obtained from equipment vendors shows that active antennas with instantaneous bandwidth of 300 MHz [✂ REDACTED].[90] [91] Secondly, we have updated the view we took in the 13 March Statement of the potential impact on Vodafone of the availability of active antennas with instantaneous bandwidth of 300 MHz.[92] We now consider that, if active antennas with instantaneous bandwidth of 300 MHz but not 400 MHz were available, then Vodafone could use such antennas to aggregate 80 MHz in two proximate holdings within a span of 300 MHz IBW, if it were to secure a holding at the bottom location in 3.6-3.8 GHz band. It would have the opportunity to compete for that location in the assignment stage.

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[88] Vodafone non-confidential response to the Further Consultation, pages 2 and 12-13.

[89] Oliver Dowden's statement on telecoms to the House of Commons on 14 July 2020, https://www.gov.uk/government/speeches/digital-culture-media-and-sport-secretarys-statement-on-telecoms.

[90] [✂ REDACTED]
[91] [✂ REDACTED]

[92] See 13 March Statement, footnote 252.

4.58 Without active antenna technology with wide instantaneous bandwidth, Vodafone could still deploy fragmented spectrum but would need to use other mitigations e.g. dual antennas, or 'split mode' antennas, which are likely to be more costly and provide less capacity than non-split mode antennas in some deployment scenarios, particularly in dense urban areas.

4.59 While taking into account the potentially increased costs, we said in the 13 March Statement that, even if operators won no more 3.4-3.8 GHz spectrum, competition concerns were unlikely because they were likely to be able to use other frequencies to increase their 5G capabilities in line with their needs.[93] We also considered that MNOs had incentives to address any challenges of fragmentation by trading between them.[94]

4.60 We therefore do not consider that the Government's decision to ban the use of new Huawei equipment after the end of this year causes us to change our conclusions on competition concerns or defragmentation of the 3.4-3.8 GHz band.

4.61 Regarding the impact of the Government's decision on DSS, we understand from Vodafone's submission that, where Huawei equipment is used to provide 4G, the banning of Huawei means DSS with 5G cannot be deployed without replacing that equipment. Where a MNO uses Huawei equipment to provide 4G, it may therefore consider that DSS is not an attractive option, unless or until it decides to swap out its 4G equipment in order to comply with the Government's requirement to replace all Huawei equipment by 2027. Where it decides not to swap the equipment at the time that it re-farms its 4G spectrum to 5G, it would need to use static re-farming.[95] Where a MNO does not use Huawei equipment for 4G, its potential use of DSS is unaffected by the Government's decision.

4.62 Overall, therefore, DSS remains an option for MNOs to consider which could facilitate re-farming, although where a MNO uses Huawei 4G equipment, deployment of DSS could entail bringing forward its costs of replacing that equipment.

Proposal for a managed allocation of spectrum

Stakeholders' submissions

4.63 In its submission,[96] Vodafone reiterated its view that an auction was the wrong approach to awarding spectrum in the current climate. It was concerned that an auction would award spectrum to those who were most optimistic about Covid-19 and economic recovery, rather than those who valued it most and would make most efficient use of it. In addition,

[93] 13 March Statement, paragraph 4.209.

[94] 13 March Statement, paragraph 4.213

[95] It is worth noting that DSS is a very recent development, and MNOs have successfully re-farmed spectrum over many years, for example from 1G to 2G, from 2G to 3G and from 3G to 4G, before DSS was invented.

[96] Vodafone's non-confidential response to the Further Consultation, pages 4-7.

it suggested that the uncertain state of capital markets could mean that bidding would be driven by cash constraints even if all bidders approached valuation of the spectrum in the same way.[97]

4.64 Vodafone therefore advocated a managed award of the spectrum. Vodafone considered that, instead of running an auction, Ofcom could facilitate negotiation to award spectrum at reserve prices to the MNOs who would make the most efficient use of it. It claimed that this could be achieved in a competitively neutral manner by combining the negotiation with downward adjustments to annual licence fees on similar spectrum that has already been awarded.[98]

Our position

4.65 In the 13 March Statement we set out the reasons for awarding the spectrum in this award by auction, and why we believe that this is the best way to promote competition and secure optimal use of spectrum. We have previously considered Vodafone's proposal of a managed award and wrote to Vodafone explaining why we did not intend to pursue it. Among other things, we set out that:

a) A managed award would be a lengthy and complicated exercise. Before implementing such a proposal, Ofcom would need to run an extensive exercise to establish the details of the new process in light of the available evidence, run a full new consultation, and reach a reasoned decision. Moreover, given the importance of this spectrum, and the differing commercial interests of even just the MNOs, we think any such decision could be highly contentious and very likely to be subject to legal challenge.

b) It would be very difficult to make a managed award an open process (as it is inevitably likely to exclude any new entrant from winning spectrum), and as such it would conflict with Ofcom's statutory duties.

c) While Ofcom has no duty to maximise revenue from the allocation of spectrum, a managed award as proposed by Vodafone would involve the allocation of the spectrum at the reserve prices in the auction which we believe would be below market value, and potentially significant reductions in annual licence fees for other spectrum to secure agreement of all parties. Given that those fees are set to secure optimal use of the spectrum, it is not clear how any such reductions could be justified in the light of our duties.

4.66 We therefore remain of the view that the auction described in the 13 March Statement is the best way to fulfil our duties and award the spectrum for the benefit of consumers and to promote effective competition, notwithstanding the current circumstances.

[97] Vodafone's non-confidential response to the Further Consultation, page 5.

[98] Vodafone's non-confidential response to the Further Consultation, page 6.

Application of a cap on spectrum holdings in the 3.4–3.8 GHz band

Stakeholder's submission

4.67 BT[99] said that competition would be promoted if Ofcom improved the opportunity for all MNOs to secure 80 - 100 MHz of spectrum that can immediately be deployed for 5G. In particular, BT[100] said that competition would be promoted to the benefit of consumers if measures are included to address the risk of [✂ REDACTED][101]. It suggested that this could be achieved through application of a cap of 140 MHz on spectrum holdings in the 3.4-3.8 GHz band.[102]

Our position

4.68 BT has argued previously for a cap on spectrum holdings in 3.4-3.8 GHz band, and in this latest submission links its argument to its position on the importance of contiguous 3.4-3.8 GHz spectrum. We maintain the analysis in the 13 March Statement that there is a low risk of H3G successfully engaging in strategic investment and harming competition by either depriving competitors of 3.6-3.8 GHz spectrum or obstructing defragmentation.[103]

4.69 We maintain the conclusion that it would be neither appropriate nor proportionate to impose any competition measures in the 3.6-3.8 GHz band.[104]

Effects of 5G on health

Stakeholder's submission

4.70 One confidential respondent [✂REDACTED] raised concerns about the harm to human health from the addition of more wireless technology. The respondent stated that many scientists have concerns that the current ICNIRP levels are not representative of real-world exposure for living entities.[105] The respondent also raised environmental concerns about the power needed by new 5G systems and how that energy would be generated, as well as the extra raw materials required to build 5G networks and the impact of mining for these

[99] BT non-confidential response to the Further Consultation, page 2 (paragraph 3).

[100] BT non-confidential response to the Further Consultation, page 2 (paragraph 5).

[101] BT confidential response to the Further Consultation, page 2 (paragraph 5).

[102] BT non-confidential response to the Further Consultation, page 2 (paragraph 5).

[103] 13 March Statement, paragraphs 4.297-4.301.

[104] 13 March Statement, paragraphs 4.302.

[105] ICNIRP is the International Commission on Non-ionizing Radiation Protection. It publishes Guidelines on limiting exposure to electromagnetic fields are for the protection of humans.

materials potentially leading to the exploitation of resources and peoples of developing countries.

Our position

4.71 In the 13 March Statement, we set out our position in relation to health concerns from electromagnetic fields (EMF) including those from 5G base stations. We said:

a) In the UK, Public Health England (PHE) takes the lead on public health matters associated with radio frequency electromagnetic fields, or radio waves, and has a statutory duty to provide advice to Government on any health effects that may be caused by exposure to EMF emissions.

b) PHE's main advice is that EMF emissions should comply with the ICNIRP Guidelines.[106] On 5G, PHE's view is that "*the overall exposure is expected to remain low relative to guidelines and, as such, there should be no consequences for public health*".[107]

c) Ofcom is responsible for managing the use of radio spectrum in the UK. We take PHE's advice into account, as appropriate, in our management of the radio spectrum.

d) We have carried out EMF measurements around mobile phone base stations for many years and published the results of these measurements on our website.[108] In recent months, Ofcom has measured EMF levels in locations near newly deployed 5G-enabled base stations. In all cases, the measured EMF levels have been well within the levels for general public exposure provided for in the ICNIRP Guidelines. The highest level measured in our recent measurements was approximately 1.5% of these levels.

e) A summary report of these measurements has been published on our website.[109] We have also recently published a consultation setting out proposals to include a condition in spectrum licences (and other spectrum authorisations) that will require spectrum users to ensure they comply with the levels for general public exposure from the ICNIRP Guidelines.[110]

f) We will publish a statement on this proposed licence condition in 2020. If we proceed with the proposals and do so prior to the grant of the new licences in the 700 MHz and 3.6-3.8 GHz bands, we will revise the licences accordingly before grant. If we decide to

[106] The current set of guidelines is available at the following link: https://www.icnirp.org/cms/upload/publications/ICNIRPemfgdl.pdf. A summary of PHE advice on radio waves can be found on its website

[107] https://www.gov.uk/government/publications/5g-technologies-radio-waves-and-health/5g-technologies-radio-waves-and-health

[108] https://www.ofcom.org.uk/spectrum/information/mobile-operational-enquiries/mobile-base-station-audits

[109] https://www.ofcom.org.uk/__data/assets/pdf_file/0015/190005/emf-test-summary.pdf

[110] https://www.ofcom.org.uk/consultations-and-statements/category-1/limiting-exposure-to-emf

proceed with the proposals after grant of these new licences, then we will vary the licences to include the new conditions.

4.72 Our position on these matters has not changed. The consultation referred to in point e) above has now closed and we are considering responses to that consultation and, if we decide to proceed with the proposals, we will do so as outlined in point f).

4.73 In response to the more general environmental concerns raised regarding power and the impact of mining for the extra raw materials needed, we note that even without the introduction of new 5G technologies in these bands, the MNOs would take measures to address the growing demand for mobile services by, for example, expanding their 4G networks. Given that 5G technology is inherently more energy efficient for the data carried than earlier mobile technologies, the deployment of 5G technology is likely to have less environmental impact than the alternatives.

5. Conclusions

5.1 Our assessment remains that the results of the SUT Model, as revised, support our view that it is likely to be technically feasible for MNOs to support a wide range of 5G services with channel bandwidths in their current holdings smaller than 80 MHz, including 40 MHz, though we recognise that the new results differ from those we presented in the 13 March Statement.

5.2 In conjunction with other parts of our competition assessment, this view contributes to our overall conclusion that there is a low risk of competition concerns related to 3.4-3.8 GHz spectrum from any auction outcome.

5.3 Our view also remains that DSS could facilitate re-farming of most bands currently used for 4G to 5G, including 800 MHz, 900 MHz, 1800 MHz, 2.1 GHz and 2.6 GHz, and so is likely to be an option for operators to consider.

5.4 In relation to the other matters on which we have received further submissions, we conclude that, to the extent they contain any new evidence, they do not give us cause to change the conclusions set out in the 13 March Statement.

5.5 We therefore confirm the decisions set out in the 13 March Statement.

6. Next steps

6.1 We will now proceed with our preparations to hold the auction as soon as is reasonably practicable in the light of the Covid-19 pandemic. We will work with all interested bidders to ensure the auction can proceed in a secure and safe way. Given the practical steps that we will need to take in this regard, we are aiming for a formal start to the auction process in late November 2020 with a view to starting bidding in mid-January 2021.

6.2 Any claim for judicial review would inevitably further delay the auction, and the use of this important spectrum. We therefore remain of the view that any claim for judicial review should be brought promptly, with a request that the courts expedite the matter. We request that, if any stakeholder intends to bring a claim for judicial review, they should do so by the end of August at the latest, having indicated such intention in pre-action correspondence to us and any interested parties within two weeks of the date of this document.

A1. Stakeholders' responses on the SUT Model

Suitability of the SUT Model

A1.1 Some stakeholders said that the SUT Model was not suitable for us to consider as part of our evidence for the competition assessment. Specifically:

a) In a report submitted by O2, Professor William Webb said that the model might show that high bandwidth 5G services may be technically feasible with 40 MHz but added that technical feasibility is not the same as practical plausibility.[111]

b) BT questioned whether "*an analysis that gives 'some indication'" about the extent to which operators could support high data rate 5G services on 40 MHz of spectrum was "an appropriate standard or is a sufficient basis for decisions on competition assessment/auction structure*."[112]

c) Vodafone said that "*[w]e cannot see any errors in Ofcom's Single User Throughput (SUT) analysis, but consider that Ofcom has placed undue emphasis on its output and conclusions about use cases that can theoretically be supported*".[113]

A1.2 In the 13 March Statement, we noted that stakeholders had not provided clear evidence of 5G use cases which were likely to require 80-100 MHz of 3.4-3.8 GHz bandwidth (contiguous or otherwise) and which were likely to be of significant commercial and competitive importance.[114] As part of our overall assessment, we checked whether the results of our SUT Model suggested that 80-100 MHz bandwidth in the 3.4-3.8 GHz band would be necessary to support a range of potential future 5G services.

A1.3 In the Further Consultation, we noted that there was inherent uncertainty over what future 5G services might be important for consumers.[115] These future services may have a wide range of technical requirements. We used the 3GPP document TR 22.891 to inform our analysis.[116]

A1.4 We recognised that the SUT Model is a simplified theoretical model and that in an actual deployment many users would share the spectrum resources of a carrier but considered its

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[111] Professor William Webb's report, submitted by O2 in response to the Further Consultation, paragraphs 27 and 64.

[112] BT non-confidential response to the Further Consultation, page 3.

[113] Vodafone non-confidential response to the Further Consultation, page 2.

[114] 13 March Statement, paragraphs 4.211, 4.258, 4.290(b) and A7.39.

[115] Paragraph 1.7, the Further Consultation.

[116] Paragraphs A1.2 to A1.3, the Further Consultation.

results could nonetheless give us some indication of what services carriers of different bandwidths might technically be capable of supporting.[117]

A1.5 We drew no conclusions as to the associated commercial incentives or the competitive significance of future hypothetical services.[118]

A1.6 Taking into account stakeholders' criticisms in response to the Further Consultation, we remain of the view that the SUT Model is informative and supports our view that it is likely to be technically feasible for MNOs to support a wide range of 5G services with channel bandwidths in the current holdings smaller than 80 MHz, including 40 MHz.

A1.7 We address stakeholders' proposals on extensions to the SUT Model below, under the heading "stakeholder comments on extending the SUT analysis to model capacity".

Modelling SINR distribution across a cell

Stakeholders' comments

A1.8 Some stakeholders considered that we could have modelled SINR distribution across a cell.

A1.9 Vodafone[119] said "*The findings of Ofcom's analysis are striking, however, for what is left unsaid in the consultation. For example, if we look at Figure 1 of the consultation, the differential in the required SINR for 4K mobile video between a 50MHz connection and a 100MHz connection is 9dB. What the consultation fails to address is the question of "so what?". The "so what?" answer is 9dB equates to a tripling in cell radius size for the larger block of spectrum – this equates to a requirement for an operator stranded with lower spectrum stocks to deploy thousands of additional masts nationally – potentially tens of thousands – to achieve the same level of service with the smaller spectrum block*". Vodafone also provided an SUT model of its own to show downlink throughput versus distance from the base station.

A1.10 H3G also provided a model considering the trade-off between carrier bandwidth and cell size. H3G's goal was to show to what extent operators could densify their networks to achieve the same throughput with a 40 MHz carrier as they could with an 80 MHz carrier with a sparser base station deployment.[120] It concluded that "*[o]ur analysis […] shows that an MNO with a 40 MHz carrier can replicate the user throughput of an 80 MHz carrier by adding another macro site (strictly, 1.3 sites) near the existing site in our model*".[121]

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[117] Paragraphs 1.18 to 1.19, the Further Consultation.

[118] Further consultation, paragraph 1.20.

[119] Vodafone non-confidential response to the Further Consultation, page 9.

[120] H3G non-confidential response to the Further Consultation, paragraphs 12.13-12.18.

[121] H3G non-confidential response to the Further Consultation, paragraph 12.16.

A1.11 BT[122] said "*The signal quality varies considerably across the coverage area of the cell. Users at the edge of the cell and deep indoor locations would demand significantly more capacity to deliver the same service. The penetration loss of walls can be as high as 20 – 30 dB with the latest building types. In parallel, it is widely considered that c.80% of the mobile data is consumed indoors. This results in significantly higher radio resources required for those users. It is not reasonable to assume that this can be resolved by operators for all indoor customers through the deployment of indoor solutions. Consequently, the operator will require more capacity in terms of wider bandwidths to serve the same service to customers irrespective of their environment*".

A1.12 In a report submitted by O2,[123] Professor William Webb said "*Ofcom have not presented analysis showing how SINR levels are distributed across a typical cell and therefore in what fraction of the cell a user would be able to receive a sufficient SINR to enable a particular 5G data service. Even without further analysis it is clear that there may be issues – if the cell edge SINR is -5dB as Ofcom suggest, and if the majority of users are located towards the edge and experience levels of this sort, then if 40MHz bandwidth is available, these users will only be able to access two of the five 5G services Ofcom have chosen to illustrate in Figure 1. The Figure also shows that if 100MHz bandwidth is available then an SINR between 6-9dB less is needed to deliver these 5G services, which [my] [Professor William Webb's] simplified modelling suggests could result in as many as 60% more of the users in the cell being able to receive some of the more demanding 5G services*".

Our conclusions

A1.13 We acknowledged in the Further Consultation that a significant range of SINR values may be experienced by users in a different location in a cell. We said that a SINR as low as -5dB might be encountered in environments such as at the edge of a macro cell in a rural area. Very low SINR can also occur where either fixed or moving objects, such as buildings or buses respectively, obstruct reception of the signal, although we noted that MIMO antenna configurations are designed to minimise the impact of such obstructions. We said that higher SINR values might be expected nearer a base station in a rural area and at many locations in macro cells in urban and suburban areas, except in harder to reach locations such as deep indoors.

A1.14 In theory, it would be possible to estimate the throughput at a certain distance from a base station by adding a propagation model to the SUT Model. However, the results would be highly dependent on the specific environment modelled, the propagation model used and the choice of input parameters. It would be very difficult to generalize the results. We therefore do not consider it would add significant additional insight.

A1.15 The considerations and analyses in stakeholders' responses on distribution of SINR values across a cell illustrate that radio carriers of larger bandwidth support better coverage of a

[122] BT non-confidential response to the Further Consultation, page 4.

[123] Professor William Webb's report, submitted by O2 in response to the Further Consultation, paragraph 34.

given throughput and/or greater capacity, and we agree that this is the case. They do not, however, show that bandwidths of 80 MHz or more are necessary to support a wide range of future 5G services, and do not, therefore contradict the conclusions we draw from the results of our SUT Model.

Modelling 5G use cases

Technical characteristics of possible future 5G services

A1.16 BT said "*Ofcom identified possible future 5G services described in 3GPP document Technical Report (TR) 22.891. That document is a technical study and was part of Release 14 which does not specify 5G standards. […] The 5G Service requirements for the 5G system are detailed in Technical specification (TS) 22.261.*"[124]

A1.17 We said in the Further Consultation that we had used 3GPP document TR 22.891 as the primary source of information about potential future 5G services. We said that this document was a feasibility study published by 3GPP which aims to identify the market segments and industry sectors which might be supported by future mobile networks.[125] We said that there were 74 use cases set out in that document and that we had selected a sample of the most demanding use cases from those listed to test which of those cases are likely to be technically feasible to be delivered by a network with 40 MHz of spectrum.[126]

A1.18 We agree that TS 22.261 also includes definitions of 5G services but BT has not identified where, in its view, this document conflicts with the service definitions for the services we extracted from TR 22.891.

The exclusion of gigabit-per-second services from our analysis

A1.19 BT said that it is clear from Figure 1 of the Further Consultation "*that only 80 MHz and 100 MHz spectrum allocations are capable of delivering 1 Gbps. Excluding services that require 1 Gbps from analysis leads to the incorrect conclusion that "none of the services is strictly infeasible technically in any of the scenarios.""* (BT quoted paragraph 1.35 of the Further Consultation).[127]

A1.20 In the Further Consultation we identified two categories of services which may require speeds of "up to 1 Gbps" to individual users: wireless local loop (fixed wireless access); and mobile broadband for indoor and hotspot scenarios. We said that it was likely that operators would need to deploy mmWave spectrum and/or small cells to deliver the

[124] BT non-confidential response to the Further Consultation, page 5.

[125] Paragraph A1.2, the Further Consultation.

[126] Paragraph 1.34, the Further Consultation.

[127] BT non-confidential response to the Further Consultation, page 5.

throughput required for these scenarios to multiple users, and therefore we had not included them in our analysis.[128]

A1.21 To support our judgement on fixed wireless access ("**FWA**"), we provided evidence from existing FWA deployments which showed that it was unlikely that Gbps FWA throughput can be supported on existing mobile networks using sub-6 GHz spectrum. We considered that Gbps FWA might only be supported by future networks with access to several hundred MHz of spectrum, probably in the mmWave bands. Accordingly, we excluded FWA from our analysis, which only considers bandwidths of 40 to 100 MHz.[129]

A1.22 We believe that even with 80 or 100 MHz allocations, operators would struggle to deliver 1 Gbps services. We agree with BT that Figure 1 in the Further Consultation shows that only 80 MHz and 100 MHz carriers are capable of 1 Gbps in the downlink. However, this is only under very favourable signal conditions, namely SINR greater than 22 dB and 17 dB for 80 MHz and 100 MHz carriers respectively when accessed by a single user only, which is unlikely to be sustainable for a significant length of time in a real scenario. Accordingly, we remain of the view that it is appropriate for us to exclude gigabit-per-second services from our analysis.

Industrial use cases

A1.23 Vodafone[130] said that we had focused too narrowly on consumer use cases and had not considered enough industrial use cases which could also be important. It said that its white paper on industrial 5G spectrum policy[131] showed that there was demand for industrial services requiring large blocks of spectrum.

A1.24 In the Further Consultation, we considered one industrial scenario, industrial control applications which require high reliability and very low latency (~1ms). We said that high data rates may be required in some circumstances, e.g. in the uplink, to deliver live video stream to an operator or automated system controlling the equipment (tens of Mbps per user in a dense environment). We said that these services might typically be supported by small cells within an industrial complex.[132]

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[128] Paragraph A1.22, the Further Consultation.

[129] Paragraph A1.23, the Further Consultation.

[130] Vodafone non-confidential response to the Further Consultation, pages 10-11.

[131] *An Industrial 5G Spectrum Policy for Europe*, Vodafone with input from Arthur D Little & Compass Lexecon, November 2019, https://www.vodafone.com/content/dam/vodcom/files/public-policy/5g-report/an-industrial-5g-spectrum-policy-for-europe.pdf, accessed 29 June 2020

[132] Table A5, the Further Consultation.

A1.25 We recognised in the 13 March Statement that there is a general consensus that optimal deployment of 5G is best achieved through the use of large blocks of spectrum,[133] but observed that the main benefit was higher peak speeds, which are rarely experienced by consumers in practice and only one element of the mobile service experienced.[134] We also note that Vodafone characterises its existing spectrum holdings in 3.4-3.8 GHz as "*a huge block*".[135]

A1.26 Vodafone's paper on industrial 5G spectrum policy[136], which we have considered, does not say that there is a minimum spectrum requirement for delivering certain industrial services. We have considered the table in that paper which specifies data rates for industrial applications, Figure 2.

A1.27 In Figure 2, there is one service which exceeds the tens of Mbps that we have considered for industrial control and that is the 30-200 Mbps which may be needed for video streams. That table is sourced from a 2019 white paper from Huawei, ZPMC, China Mobile and Vodafone on 5G Smart Ports.[137] This paper makes it clear that the upper end of the 30-200 Mbps range is the aggregated uplink throughput requirement from more than 20 cameras on a quayside container crane with potentially 8 – 12 container cranes deployed along 1 km of port coastline.[138] The SUT Model was, however, used to assess the data rate necessary for a single user in a cell. An application involving several cameras would entail multiple users of a cell. The scope for such combined usage is a network capacity consideration. We discuss why we do not consider capacity concerns to be relevant to the analysis for which we have used the SUT Model at paragraph A1.47.

[✂ REDACTED] use case

A1.28 Vodafone said that "*Ofcom's analysis shows that some services are impossible to provide without spectrum stocks being boosted from those that it was possible to acquire in the*

[133] Paragraph 1.13, the 13 March Statement.

[134] Paragraphs 4.253 and 4.268, the 13 March Statement.

[135] *From London Pride to the Epsom Derby, why Vodafone is the best network for special events*, Vodafone UK News Centre, 31 October 2019, https://newscentre.vodafone.co.uk/our-network/best-network-for-special-events/, accessed 17 July 2020

[136] *An Industrial 5G Spectrum Policy for Europe*, Vodafone with input from Arthur D Little & Compass Lexecon, November 2019, https://www.vodafone.com/content/dam/vodcom/files/public-policy/5g-report/an-industrial-5g-spectrum-policy-for-europe.pdf, accessed 29 June 2020.

[137] https://www-file.huawei.com/-/media/corporate/pdf/x-lab/2019/5g_smart_port_whitepaper_en.pdf?la=en accessed 27 July 2020.

[138] Section 2.2.2 of the 5G Smart Ports white paper.

2018 auction".[139] In particular, it claimed that our SUT Model showed that a major use case for [✂ REDACTED] was problematic.[140]

A1.29 In the Further Consultation we did not consider a [✂ REDACTED] use case. Vodafone did not specify the technical requirements for this use case in its response to the Further Consultation. [✂ REDACTED] requires a throughput of 2-4 Mbps.[141] The SUT Model results of Figure 2 of the Further Consultation show that delivering 2-4 Mbps in the uplink would need a SINR of approximately -5 dB, which would be technically feasible using a 40 MHz carrier. Our analysis therefore does not support Vodafone's view that providing a [✂ REDACTED] service would be problematic using a 40 MHz carrier.

Small cells

A1.30 Some stakeholders considered that we could have modelled factors which might hinder an operator's ability to deploy small cells:

a) BT said "*Clearly operators can densify their networks using small cells to boost capacity. Reflecting this, Ofcom's modelling should have taken into account the limits to small cells densification as well as the implications of combinations of 5G services and multiple simultaneous users which affect the technical feasibility of delivering 5G services. We do not think that the modelling provides helpful input to a position on competition measures without taking these factors into account*".[142] It asserted that small cells might not be practical to provide the required data rates in some scenarios, such as live news broadcasts which might in the future rely on wide area macrocell coverage.[143]

b) BT went on to say that "*there are no multi-band 5G small cell devices and we do not believe there will be any in the future. It is, therefore, technically infeasible for an operator to provide a 1 Gbps service with less than 80 MHz of spectrum*." It believed that the lack of multiband small cells would persist in the longer term because of the constraints of the small cell form factor and that the demand for multi-band small cells is likely to remain small.[144]

[139] Vodafone non-confidential response to the Further Consultation, page 10.

[140] Vodafone confidential response to the Further Consultation, page 10.

[141] [✂ REDACTED]

[142] BT non-confidential response to the Further Consultation, page 4.

[143] BT non-confidential response to the Further Consultation, page 6.

[144] BT non-confidential response to the Further Consultation, page 5.

c) Professor William Webb (in his report submitted by O2) considered that we had relied too heavily on small cells as a way to deliver 5G services without an analysis or evidence of how practical they were to deploy. He described several constraints on the practical deployment of small cells: the challenge of getting suitable sites; managing interference between macrocell networks and small cell networks; the fact that building shadowing can lead to users receiving poor SINR; and the high costs of using small cell, which include equipment, installation, site rent, and providing power.[145]

A1.31 In our analysis of the results of the SUT Model in the Further Consultation, we considered small cells as a possible mitigation for a lack of spectrum in a limited set of scenarios for a subset of the most demanding future applications that we studied. These were:

a) "mobile broadband live video" in a hot spot environment (e.g. football stadium);[146]

b) "Cloud computer games for connected vehicles with 4k 3D graphics" in a heterogenous network environment;[147] and

c) "industrial control" indoor small cell deployment.[148]

A1.32 We said that our analysis suggested to us that, in the three cases we had identified for which deployment on a macro cell network at 3.4-3.8 GHz looked challenging (at 40, 80 or even 100 MHz bandwidths), a different network deployment pattern – such as small cell deployment at a hot spot for mobile broadband live video, or deployment indoors with a 1:1 uplink/downlink ratio for industrial control – would reasonably support the higher SINR values likely to be needed for these services. We said that we might expect operators to deploy such alternatives if these services proved to be commercially important.[149]

A1.33 In summary, we considered that small cells may be necessary for providing a limited sub-set of the potential future 5G services, and only those where there was a reasonable expectation that small cells could be deployed. For example, a football stadium hot spot deployment might reasonably use small cells. We therefore do not consider that it was necessary for us to model the practical limits of small cells deployment with our SUT Model.

[145] Professor William Webb's report, submitted by O2 in response to the Further Consultation, paragraph 37.

[146] Paragraph 1.39, the Further Consultation.

[147] Paragraphs 1.40 and 1.41, the Further Consultation.

[148] Paragraph 1.42, the Further Consultation.

[149] Paragraph 1.48, the Further Consultation.

Specific modelling inputs and assumptions

1:1 uplink/downlink ratio in industrial contexts

A1.34 In a report submitted by O2, Professor William Webb said that we could not rely on an uplink/downlink ratio of 1:1 in industrial contexts. This is because outdoor networks will use an uplink/downlink ratio of 3:1 and industrial locations will therefore need sufficient isolation from outdoor networks if they wish to use an uplink/downlink ratio of 1:1 with no degradation in throughput. He asserted that sufficient isolation might only be available for remote factories and considered that it was unrealistic for Ofcom to regard an uplink/downlink ratio of 1:1 as practical for industrial areas close to coverage from outdoor mobile networks.[150]

A1.35 In the Further Consultation, we said that a downlink to uplink ratio of 1:1 might be appropriate in some "industrial control" indoor small cell scenarios where uplink traffic demand may equal or exceed downlink traffic. We considered that this downlink to uplink ratio is likely to be practicable in controlled indoor environments, in which wireless networks can be built and operated without interference with outdoor macro cell networks, which are likely to operate with a downlink to uplink ratio of 3:1.[151] The existing mobile licences in 3.4-3.6 GHz contain provisions for indoor small cells to operate with a different uplink/downlink ratio to the outdoor network[152] as do the example 3.6-3.8 GHz licences.[153]

A1.36 The ECC 3.4-3.8 GHz synchronisation report notes that geographic separation may be required between an unsynchronised outdoor macrocell network and co-channel indoor networks and that "*the lack of out of block filtering on the Macro BS and on the indoor BS transmitters' sides will need to be considered.*"[154] This suggests that it may be harder for operators to use a 1:1 uplink/downlink ratio in areas where indoor industrial deployments of 3.4-3.8 GHz are co-channel with a macrocell network using a 3:1 uplink/downlink ratio.

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[150] Professor William Webb's report, submitted by O2 in response to the Further Consultation, paragraph 32.

[151] Paragraph 1.42, the Further Consultation

[152] For example, see Paragraph 15 of Schedule 1 of the Vodafone 3410-3460 MHz licence.
SPECTRUM ACCESS 3.4 GHz, Licence no. 1151573, Ofcom, 25 June 2019,
https://www.ofcom.org.uk/__data/assets/pdf_file/0016/114271/sa-3.4ghz-licence-vodafone.pdf, accessed 26 June 2020

[153] Paragraph 15 of Schedule 1 of the Example 3.6-3.8 GHz licence in Annex A2 of the Information Memorandum.
Award of the 700 MHz and 3.6-3.8 GHz spectrum bands – Information Memorandum, Ofcom, 13 March 2020,
https://www.ofcom.org.uk/__data/assets/pdf_file/0019/192412/information-memorandum-award-700mhz-3.6-3.8ghz-spectrum.pdf, accessed 26 June 2020

[154] Page 3, *National synchronisation regulatory framework options in 3400-3800 MHz: a toolbox for coexistence of MFCNs in synchronised, unsynchronised and semi-synchronised operation in 3400-3800 MHz*, ECC Report 296, 8 March 2019,
https://www.ecodocdb.dk/document/9067, accessed 29 June 2020

There are, however, mitigations that operators could deploy in order to facilitate the deployment of 3.4-3.8 GHz indoor industrial networks and outdoor macrocell networks unsynchronised and in the same area, such as careful installation of indoor base stations and site shielding,[155] where necessary.

SU-MIMO limitations in low SINR and carrier aggregation scenarios

A1.37 In his report submitted by O2, Professor William Webb also said that it was not valid to use 4x4 SU-MIMO spatial multiplexing at low SINR and that the receive antennas would need to be shared for carrier aggregation scenarios (i.e. the four antennas in a phone which might normally be used to support a single 4x4 SU-MIMO carrier become a pair of 2x2 SU-MIMO antennas). It said that subscribers using its 4G network were unable to use 2x2 SU-MIMO for [✂ REDACTED] of the time because the signal level was insufficient.[156] Vodafone provided evidence from its modelling tools which showed that the spectral efficiency of single user spatial multiplexing (e.g. two and four spatial streams) fell below that of no spatial multiplexing (e.g. one spatial stream) at low SINR.[157]

A1.38 In the Further Consultation we acknowledged that SU-MIMO (e.g. two and four spatial layers) may not be supported at low SINR[158] and there may be some limitations to the number of spatial layers which can be supported by some devices, particularly lower cost devices, when aggregating carriers.[159] We acknowledged that this was a limitation of our analysis, however, we did not consider it to be a significant shortcoming of the Model and we remain of that view. We expect that any impact on throughput of not supporting higher order SU-MIMO at low SINR would be proportional to carrier bandwidth (e.g. in absolute terms, any change in throughput would be approximately twice as much for an 80 MHz carrier as for a 40 MHz carrier) because antenna mode selection is dependent on SINR and is not dependent on carrier bandwidth.

Reduction in the base station spatial layer support from eight layers to four layers

A1.39 BT said that "*when radiating two carriers through an 8x8 MIMO antenna, each carrier can only use 4x4 instead of all 8 layers, reducing performance when compared to contiguous spectrum. It is unclear whether Ofcom considered this in its estimate of reduced efficiency of non-contiguous spectrum.*"[160]

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[155] §4.4 *COEXISTENCE BETWEEN UNSYNCHRONISED INDOOR BSS AND MACRO BS - STUDY #7*, ECC Report 296

[156] Professor William Webb's report, submitted by O2 in response to the Further Consultation, paragraph 39.

[157] Vodafone non-confidential response to the Further Consultation, page 10, Figure 1.

[158] Paragraph A1.13, the Further Consultation.

[159] Paragraph A1.15, the Further Consultation.

[160] BT non-confidential response to the Further Consultation, page7.

A1.40 The maximum SU-MIMO order we considered in the SUT Model was four spatial layers so a reduction in the number of layers supported by the base station from eight layers to four layers would have no impact on the results of our modelling. For this reason, we consider it was appropriate for us to model four spatial layers in the downlink.

Signalling overheads associated with fragmented spectrum

A1.41 Vodafone said that "*fragmenting spectrum reduces the capacity that can be supported; Ofcom has quoted 6% but our analysis shows the true figure to be 10-20%.*"[161]

A1.42 We used a figure of 6% to model the signalling overhead when aggregating two 5G NR carriers instead of a single carrier of the same total aggregate transmission bandwidth.[162] This is not the same as the total capacity loss, which would also include losses other than just signalling overheads,[163] and which we have previously quantified to be 2-15%.[164] As we discuss below in paragraph A1.47, modelling of capacity was not the purpose of the SUT Model and so we consider the 10-20% figure given by Vodafone is not relevant to the SUT Model.[165]

Spectrum scenarios

A1.43 H3G said our spectrum scenarios conflated the short term with the long term. This was because we had considered how operators could support 5G use cases which may only arise in the longer term with operators' short term 5G spectrum holdings (40 or 50 MHz). It said that this was wrong because operators would have the opportunity to gain access to more 5G spectrum in the auction and they would also be able to re-farm their existing spectrum holdings to 5G in the longer term.[166]

A1.44 We considered bandwidths which could be representative of a wide variety of possible future auction outcomes including bandwidths as small as 40 MHz but also including carrier aggregation of two non-contiguous 40 MHz carriers.[167] The reason we considered 40

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[161] Vodafone non-confidential response to the Further Consultation, page 11.

[162] Paragraph A1.45, the Further Consultation.
This figure was taken from the ECC C-band defragmentation report which notes that carrier aggregation across two 50 MHz carriers might require signalling overheads of around 12% (depending on the precise implementation) compared with signalling overheads of 6.3% for a single contiguous carrier of 100 MHz. See: Table 13, *Guidance on defragmentation of the frequency band 3400- 3800 MHz*, ECC Report 287, 26 October 2018 https://www.ecodocdb.dk/document/7245, accessed 29 June 2020

[163] For example, the capacity lost to additional guard bands, see footnote 146 of the December 2018 Consultation.

[164] Paragraph 5.258 of the December 2018 Consultation and paragraph 4.267 of the 13 March Statement.

[165] We discuss our view on capacity in paragraphs 4.255 and 4.259 of the 13 March Statement.

[166] H3G non-confidential response to the Further Consultation, paragraphs 9.5-9.11.

[167] Table A6, Annex A1 to the Further Consultation.

and 50 MHz carriers was that we wanted to show to what extent it might be technically feasible for operators to support a wide range of future 5G services even if they did not acquire more spectrum in the auction or chose not to re-farm their existing spectrum holdings to 5G.[168] We continue to consider that the spectrum scenarios that we modelled were appropriate for this purpose.

Stakeholder comments on extending the SUT analysis to model capacity

Modelling multiple users in a cell

A1.45 Some stakeholders considered that we could have modelled multiple users in a cell:

a) BT said that we could have used more sophisticated alternatives to a SUT model, asserting that system level simulations which considered multiple simultaneous users would have been a more suitable alternative.[169] It said "*Our conclusion from our analysis of the SUT Model is that an operator having just 40 MHz of spectrum to provide high data rate 5G services to multiple users simultaneously would be seriously disadvantaged compared to an operator having 100 MHz or more,* [170] [✂ REDACTED]."[171]

b) BT went on to say that we may have underestimated the data demand for some services, particularly when multiple 5G services were being requested in the same cell. Its own internal analysis had shown that the aggregate demand from connected and autonomous cars could be up to 70 Mbps in the downlink per cell.[172]

c) Vodafone said that "*[w]e agree that SUT modelling is a tool in operators' planning repertoire that assists in predicting the likely idealised performance experienced by a single user of a single service in a mobile mast sector.*"[173] However, it also said that in our consideration of the SUT Model we had "*not adequately taken account of capacity issues*".[174]

[168] Paragraph 1.20, the Further Consultation.

[169] BT non-confidential response to the Further Consultation, page 3.

[170] BT non-confidential response to the Further Consultation, page 2, paragraph 3.

[171] BT confidential response to the Further Consultation, page 2, paragraph 3.

[172] BT non-confidential response to the Further Consultation, pages 5-6.

[173] Vodafone non-confidential response to the Further Consultation, page 9.

[174] Vodafone non-confidential response to the Further Consultation, page 2.

d) Professor William Webb (in his report submitted by O2) said that we should have considered multiple users in a cell in our modelling[175] and gave some examples of scenarios in which multiple users were accessing a high data rate 5G service and the difference in bit rate each user might expect when serviced by a 40 MHz or a 100 MHz carrier.[176] He concluded from his studies that "*there are plausible scenarios where 40 MHz is not enough bandwidth to deliver 5G services to the number of simultaneous users likely to demand them*".[177]

e) H3G also provided a model which considered multiple users in a cell. This was a Monte Carlo model which considered users randomly distributed across an area covered by 5G base stations and calculated the distribution of data rates received by those users. It concluded that "*our MUT analysis shows that MNOs can provide a wide range of 5G use cases with channel bandwidths smaller than 80 MHz*".[178]

A1.46 We recognise that there are sophisticated capacity models which can model the throughput served to multiple users, however, we do not consider that these would have given us any greater insight than the SUT Model when considering whether an operator can support a wide range of 5G services using its current spectrum holdings. It is self-evident that, other things equal, capacity increases proportionally to the radio carrier bandwidth. Our SUT study concerns the technical feasibility of supporting demanding future 5G services and to what extent there is a minimum radio carrier bandwidth necessary for providing each of those services to a user.[179]

A1.47 We recognise that a multi-user throughput study could provide some insight about how network capacity affects the throughput that users might receive. This was, however, not the purpose our analysis or of the SUT Model, which was not intended as an input to our consideration of future capacity demands and MNOs' ability to provide for them.[180]

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[175] Professor William Webb's report, submitted by O2 in response to the Further Consultation, paragraphs 4, 5 and 41-50.

[176] Professor William Webb's report, submitted by O2 in response to the Further Consultation, paragraphs 46-60.

[177] Professor William Webb's report, submitted by O2 in response to the Further Consultation, paragraph 62.

[178] H3G non-confidential response to the Further Consultation, paragraph 12.
"MUT" is defined as "a multi-user model" in paragraph 9.4 of H3G non-confidential response to the Further Consultation.

[179] The SUT Model is part of the evidence we used to support our conclusions in paragraphs and 4.258 of the 13 March Statement.

[180] We discuss our view on capacity in paragraphs 4.255 and 4.259 of the 13 March Statement.