Three's response to Ofcom's Consultation on Award of the 700MHz and 3.6-3.8GHz spectrum bands: Further consultation on modelling and technical matters

Non-confidential

12 June 2020

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Executive Summary

The other MNOs want Three to be prevented from bidding for 3.6-3.8GHz spectrum in the upcoming 5G auction. They argue that there is a 'critical threshold' of 80MHz contiguous spectrum in the 3.4-3.8GHz band below which they can only provide a 'basic' 5G service – not one that can compete with Three's 5G service.

They suggest that, absent intervention, Three – the same MNO they have routinely outbid in previous auctions – will bid strategically to prevent them from achieving the 'critical threshold'. As Ofcom has found, however, this argument does not make any sense. The real intention is transparent: side-lining Three and splitting the 120MHz 3.6GHz for sale between them (40MHz each) at or near the reserve price.

We expect the other MNOs to use the consultation (which concerns a narrow technical modelling point) as an opportunity to reopen this debate. In summary, we agree with Ofcom's analysis and conclusions. As Ofcom has previously found, demand for 5G in the short term will be low (even lower than Ofcom forecasts).

The other MNOs are already using dual connectivity to aggregate their 3.4GHz holdings with other spectrum for their 5G service. MNOs will be able to use their existing spectrum for 5G earlier than Ofcom has anticipated. 5G devices supporting many existing bands are already available, and the other bands will follow in 2021.

MNOs in several countries are deploying Dynamic Spectrum Sharing to use their 4G spectrum for 5G. Here in the UK, Vodafone plans to do so in the short term. As demand for 5G grows over time, MNOs can use their existing spectrum (and 3.4-3.8GHz holdings) to expand 5G capacity in line with their needs. Technological advances are going to allow MNOs to aggregate more spectrum to achieve wide bandwidths earlier than Ofcom envisaged.

We have validated the results of Ofcom's modelling (with which we agree) and extended the model to consider the impact of having multiple users on cell performance. Our analysis confirms Ofcom's finding that MNOs will be able to support a wide range of 5G services without 80-100MHz of bandwidth specifically in the 3.4-3.8GHz band (whether contiguous or not).

Contents.

1. Other MNOs want Ofcom to side-line Three and split the 3.6GHz spectrum for sale at a low price.

1. Executive summary

1.1. This section serves as an introduction to our response. First, we discuss some opportunities for MNOs to increase 5G capacity that have arisen since publication of Ofcom's auction statement. These include [✂] and, for Telefonica, the use of Virgin Media's fixed infrastructure for site densification (after the Virgin/O2 merger completes).

1.2. We go on to consider why rivals want Three out of the bidding for 3.6-3.8GHz spectrum in the auction. In short, this would enable Telefonica, Vodafone and EE to split the spectrum between them (40MHz each) at a low price.

2. MNOs now have other opportunities to increase 5G capacity in line with their needs

2.1. Rival MNOs have repeatedly asked Ofcom to prevent Three from bidding for additional 3.6-3.8GHz spectrum in the upcoming auction.[1] At one time or another, they have all suggested to Ofcom that their 3.4GHz holding may be enough to launch a basic 5G service, but not to provide an equivalent service to Three's 100MHz 5G carrier.

2.2. The target of attack is always Three's 100MHz 5G carrier. Ever since we bought UK Broadband, the larger MNOs resent that they can no longer squeeze Three by restricting our access to spectrum. The length of their submissions to Ofcom has been roughly proportional to the size of their spectrum portfolio. Telefonica seems most aggrieved since it replaced Three as the MNO with the least amount of spectrum in the UK.

2.3. Telefonica acknowledges that the extension of 5G to other spectrum bands and advances in technology can erode any perceived advantage that Three may have by virtue of its 100MHz 5G carrier. The basis of its complaint is really that those advances *"do not necessarily apply to all operators*".[2]

2.4. With less 4G spectrum and limited use of its 40MHz 2.3GHz spectrum for its initial 5G rollout (see section 2), Telefonica may find it more difficult than Vodafone and EE to immediately repurpose some of its mid-band spectrum for 5G. But Telefonica never mentions that its low band spectrum affords it a much easier path to a high quality 5G coverage network than Three or EE.

2.5. If holding 80-100MHz in the 3.4-3.8GHz band is as essential as they claim, the other MNOs' spectrum valuations will be substantial. They can be trusted to buy the 3.6GHz spectrum they need in the upcoming auction. To justify the need for intervention, they claim that Three – the small player they have routinely outbid in

[1] Each of BT, O2 and Vodafone have argued that a 140MHz cap on 3.4-3.8GHz spectrum should be imposed in the auction in various consultation responses.
[2] Telefonica response to 2019 auction consultation, paragraph 82.

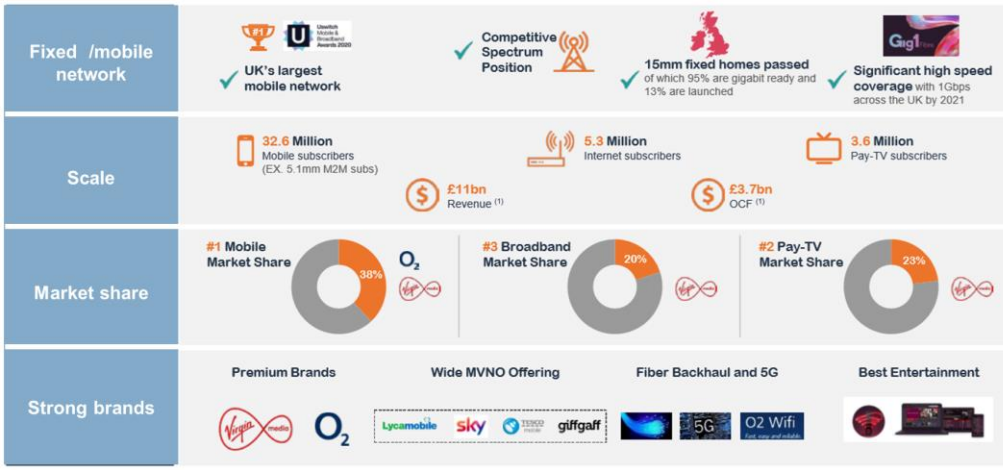
previous auctions – will bid strategically to deny them the spectrum required to deploy the widest 5G carriers.

2.6. This claim omits a simple fact: between them, O2, EE and Vodafone have left only 30MHz for Three to win (including 10MHz of 800MHz reserved for it in 2013) out of a total of 440MHz available in the 2013 and 2018 auctions. The more plausible explanation for wanting Three out of the 3.6GHz action is that Three competed for 3.4GHz in 2018, winning only a small amount (20MHz) but preventing a neat split of the band between them (50MHz each) at a low price.

2.7. The 5G auction is not the only opportunity for MNOs to expand 5G capacity in line with their needs. [✂][3]

2.8. Finally, we ask Ofcom to consider the implications of the recently announced Virgin Media/O2 merger. Liberty Global and Telefonica intend to merge their UK operations into a 50/50 joint venture. This will create a converged fixed/mobile giant with strong brands, large scale and (according to the parties) a "*competitive spectrum position*".

Figure 1: The Virgin Media / O2 merger in a nutshell



Source: Liberty Global Plc, Investor Call Q1 2020 (7 May 2020)

2.9. The parties have disclosed that the merger is expected to generate significant synergies, most notably:

- Migration of 3 million Virgin Mobile customers to O2's network from the end of 2021 – an odd thing to do if its network is capacity constrained as O2 says; and

[3] [✂]

- Use of existing infrastructure to provide services to each other at lower cost (compared to standalone / wholesale capabilities).

2.10. We anticipate that the parties will have made ample provision to secure spectrum in the upcoming auction, to enable O2 to host 3 million customers from Virgin Mobile. O2 will also be able to use Virgin's fixed infrastructure for mobile backhaul (replacing BT's) and to densify its mobile network in urban areas. Virgin's network is the second largest network in the UK, passing 15 million homes (roughly 50% of UK households).

2.11. O2 has already deployed a small cell network in London. O2 can use Virgin Media's street furniture and fibre backhaul to extend its small cell footprint, avoiding costly acquisitions from third parties.[4] For instance in the US cable operator Altice has built thousands of small cells for Sprint's wireless network by leveraging its fixed backhaul network.

3. The other MNOs want Ofcom to side-line Three in the auction and split the 3.6GHz spectrum for sale at a low price

3.1. Although they allege that competition will be harmed unless Ofcom precludes Three from bidding for 3.6GHz, the underlying motivation is clear – O2, Vodafone and BT want to side-line Three in the upcoming auction in order to:

- Ensure they each win at least 40MHz of 3.6-3.8GHz spectrum; and
- Artificially deflate the prices they pay for it.

3.2. There is an obvious three-way split of the unallocated 120MHz of 3.6-3.8GHz spectrum in the absence of Three's involvement. O2 admits as much where it says that *"the three other MNOs (BT, Telefonica and Vodafone) have a predictable aggregate minimum demand*".[5] This is a reference to a 40MHz:40MHz:40MHz split of the spectrum. The three-way split is so obvious that O2 has not even bothered to redact the 40MHz figure from its non-confidential submission to Ofcom.[6]

3.3. An equal three-way split of the available spectrum would give the three MNOs 80-90MHz of 3.4-3.8GHz spectrum. It would also facilitate simple trades in the assignment stage to achieve contiguity. However, an even split of the band might not be the efficient outcome. Rival MNOs may simply target it if they think they can obtain it cheaply.

3.4. By asking Ofcom to prevent Three from bidding for further 3.6-3.8GHz spectrum, there is nothing stopping the other MNOs from winning 40MHz each at (or close to) the reserve price. With such a clear focal point and an SMRA auction (which is more vulnerable to strategic demand reduction and accommodation of rivals),[7] an even split of the band is a near certainty.

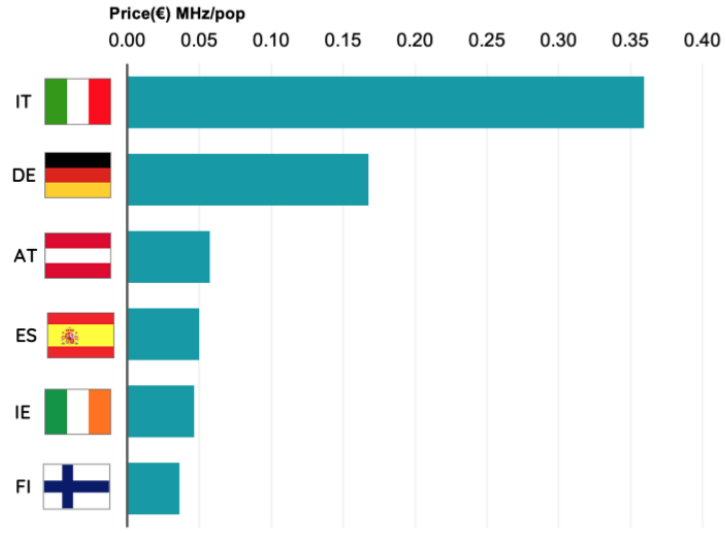
[4] Verizon is doing something similar in the US – by combining its 5G and fibre rollouts, it is able to deploy small cells more cost effectively. See RCR Wireless - Small cells and network densification: Policy, spectrum, fiber and mobile networks 2019
[5] Telefonica response to 2019 auction consultation, paragraph 68.
[6] Ibid, paragraph 133
[7] As Ofcom recognises: Ofcom 2020 Auction Statement , paragraph 5.16.

3.5. It is no coincidence that, in their consultation responses, the other MNOs have variously invited Ofcom to i) adopt an SMRA format; ii) preclude Three from bidding for 3.6GHz (or alternatively link our 3.4-3.8GHz ALF to the 3.6GHz auction price); and iii) disclose the exact aggregate demand after each round.[8]

3.6. Ofcom should be concerned about the risk of market division when Telefonica says that bidders have a positive reason to reduce demand in the auction (i.e. reduce costs and preserve shareholder value),[9] and BT wants Ofcom to reveal the identity and the number of lots provisionally won by each standing high bidder.[10]

3.7. Essentially, this would pave the way for the other MNOs to know exactly when to reduce demand and close the 3.6GHz auction at a low price. But the other MNOs need Three side-lined to divide the 3.6GHz band at a low price. As shown in Figure 2, evidence from European 3.4-3.8GHz auctions shows that less competitive auctions inevitably result in low auction prices.

Figure 2: 3.4-3.8GHz prices in recent European auctions



Source: Cullen

3.8. Italy and Germany have seen the most competitive 3.4-3.8GHz auctions to date. Both countries restricted the amount available for four bidders (to 200MHz and 300MHz respectively). In Italy, Agcom split the 200MHz into two 80MHz blocks and two 20MHz blocks, creating artificial competition for the larger blocks, strong competition and very high prices. In Germany, Drillisch (an MVNO aiming to

[8] BT/EE response to 2019 auction consultation, paragraph 2.30. Telefonica response to 2019 auction consultation, paragraph 150.
[9]. Telefonica response to 2019 auction consultation, paragraph 63.
[10] BT/EE response to 2019 auction consultation, paragraph 2.30.

become the fourth national MNO) prevented an even split of the band between the three national MNOs (100MHz each), resulting in high prices as well.

3.9. By contrast, Finland awarded more spectrum (390MHz) with only three MNOs bidding, which led to an even split of the spectrum (130MHz each) at near-reserve prices. If Three were prevented from bidding, a sale of 120MHz to three MNOs is also likely to result in an even split of the band at low prices in the UK.

3.10. As Ofcom does not intend to preclude Three from bidding for 3.6GHz, the other MNOs' 'Plan B' has been to link our 3.6GHz ALFs to the 3.6GHz auction price. They have all invited Ofcom to do this and they seem to have succeeded. In the Statement, Ofcom has stated that it cannot preclude revisiting ALFs (also including those payable 900MHz spectrum) based on the auction outcome, if a material misalignment with the value of the relevant spectrum (3.6GHz or 700MHz) occurs.[11]

3.11. The intention is again to deter Three from bidding competitively (and artificially dampen the price of 3.6-3.8GHz spectrum). Interestingly, in the context of Ofcom's 2011 consultation on 900MHz/1800MHz ALFs the other MNOs said explicitly that linking ALFs to auction prices distorts bidder incentives, the outcome of the auction and competition.

Table 1: Vodafone, O2 and EE's statements on linking ALFs to auction prices

	What they said in 2011	What they say now
vodafone	Ofcom proposes to link the ALF for 900MHz and 1800MHz directly to the outcome of the auction. **The mechanical linking of ALFs will distort bidding, the outcome of the auction and competition**[12]	**We urge Ofcom to** be unequivocal and **make a firm statement that Three's 3.6 GHz fees will be reviewed** in light of the auction outcome
O2	Any decision by Ofcom to establish **a causal link** between auction prices and ALFs **will lead to an asymmetric pricing mechanism** in the auction[13]	**Ofcom must preserve an option to revise ALFs** if the auction produces a price outcome that is materially higher or lower than the 3.4 GHz price

[11] Ofcom 2020 Auction Statement, paragraph 5.48
[12] Vodafone's response to the 800MHz and 2.6GHz auction consultation
[13] Telefonica's response to the 800MHz and 2.6GHz auction consultation

	This approach **would distort the incentives of bidders** in the auction (at least those with 900MHz and 1800MHz licences) **and so reduce the efficiency of the auction**[14]	**We suggest that Ofcom reviews these new fees if the 3.6 GHz auction indicates materially lower prices than the 3.4GHz auction.**

3.12. It is clear, therefore, that our rivals are using a flimsy competition argument to achieve their goal of excluding Three from bidding and deflating the 3.6-3.8GHz price. Ofcom is perfectly aware of these intentions and has made it clear in the auction statement that Three will be able to bid for 3.6GHz spectrum. Ofcom's duty is to run an efficient auction, and this requires allowing Three to compete and bid strongly for 3.6-3.8GHz spectrum.

3.13. It is important that this broad perspective is retained both in this consultation and any potential future litigation. As such, we discuss and expand on each reason in this document.

- In Section 2, we provide technical evidence on the availability of other spectrum bands for 5G services and MNOs' ability to aggregate spectrum to achieve larger bandwidth. We show that the relevant metric in a competition assessment is the amount of spectrum held by each MNO capable of offering a 5G service, not the amount of 3.4-3.8GHz spectrum. Contiguity is of lesser importance than absolute bandwidths and fragmentation can be overcome with carrier aggregation and the availability of active antenna units spanning the entire 3.4-3.8GHz frequency range; and
- In Section 3, we discuss that 5G use cases do not rely on 80-100MHz of contiguous 3.4-3.8GHz spectrum.

[14] EE's response to the 800MHz and 2.6GHz auction consultation

2. Ofcom has taken too conservative a view about the timing of availability of mobile bands for 5G.

4. Executive summary

4.1. In the Auction Statement, Ofcom set out its views on the timing of usability of current mobile bands for 5G, including the availability of different technologies for MNOs to repurpose their existing spectrum for 5G. The consultation invites views on one of those options: Dynamic Spectrum Sharing (DSS).

4.2. Technology is moving very quickly in this area. There have some important developments since publication of the auction Statement in March – including of course the onset of COVID-19. This section discusses the options available to MNOs to repurpose their spectrum for 5G (and the associated timeframes) in light of these developments.

4.3. In summary, we believe that Ofcom has taken too conservative a view about the timing of the availability of existing spectrum for 5G, for the following reasons:

- In the short term, demand for 5G will be even lower than Ofcom anticipated – due to the impact of COVID-19, 4G will be the predominant technology well into Ofcom's longer term;
- Devices supporting the existing mobile bands for 5G will be available before Ofcom's 2021/2022 timeframe;
- Technological developments will enable 5G use in existing spectrum before 2022.

4.4. In relation to contiguity in the 3.4-3.8GHz band, technology advances are quickly eroding the importance of contiguity (faster than Ofcom anticipated in the Statement). We understand that non-contiguous intra-band carrier aggregation will now be available from end of 2020, with widespread adoption expected in 2021. Antenna units spanning all 400MHz in the 3.4-3.8GHz band will also be available by the end of 2020.

5. There will be limited demand for 5G in the UK before end of 2023 (at the earliest)

5.1. Ofcom is right to find no step change in demand for 5G. 4G and 5G will continue to coexist for a long time. As with all previous technologies, Three's internal forecasts

show a gradual increase in 5G penetration over time (both in terms of customer numbers and network traffic).

5.2. Figure 3 shows our forecast of 5G handset penetration in Three's base. [✂]

Figure 3: [✂]

[✂]

Source: Three

5.3. This prediction is likely to be optimistic due to COVID-19, particularly in the early years. Economic uncertainty and job losses will inevitably impact consumers' appetite for the latest 5G phone. We expect UK consumers to hold on to their smartphones a bit longer, which will slow 5G handset penetration.

5.4. COVID-19 is likely to have a ripple effect in the second half of the year and into 2021 (until economic conditions normalize), effectively shifting the curve to the right. Judging by the experience with 4G, we expect 5G adoption to take off once 5G handset prices come down in price and 5G coverage is extended beyond the highest density parts of the UK.

5.5. This analysis confirms Ofcom's assessment that there is likely to be limited demand for 5G in the next few years, certainly in 2020 and 2021. MNOs can rely on their existing 3.4-3.8GHz and 4G spectrum – they do not need 80-100MHz of 3.4-3.8GHz spectrum to serve this level of demand over such a short timeframe. We discuss below that, longer term, devices and technology will be ready for MNOs to support 5G in existing bands in line with their needs.

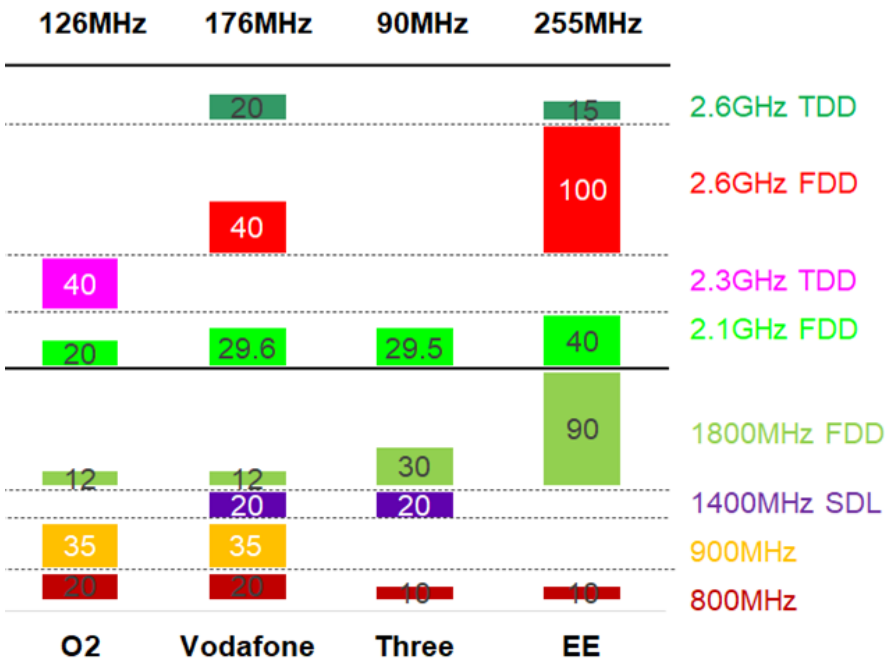
6. Devices which support existing bands for 5G will be available before 2021/2022

6.1. Ofcom expects its 'short term' to last until around 2021, with the 3.4-3.8GHz band being the main spectrum useable for 5G over this period. Ofcom believes that 5G

will be supported in most mobile bands by late 2021 or early 2022, as 5G devices supporting more bands gradually become available.[15]

6.2. We believe that this analysis is unduly pessimistic, as existing mobile bands will be supported in 5G devices earlier than Ofcom has suggested. As Ofcom has noted, all MNOs already have large holdings of spectrum which have been designated for 5G use by 3GPP.

Figure 4: Existing mobile spectrum usable for 5G (other than 3.4-3.8GHz)



Source: Ofcom Statement

6.3. All MNOs (except Three) already have over 100MHz that will be usable for 5G. O2 holds 126MHz. Vodafone and EE hold even more spectrum: 176MHz and 255MHz respectively. Their holdings at 2.3GHz and 2.6GHz TDD provide an optimal balance between coverage and capacity and are particularly well-suited for massive MIMO technology.

6.4. Table 2 compares Ofcom's views on the timing of 5G handset support for each band with ours. This is based on our discussions with suppliers about the availability of 5G-enabled handsets in the UK. Ofcom's 'cautious' view about the timing of usability

[15] 700 MHz, 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2300 MHz and 2600 MHz bands. The main exceptions are 800MHz and 2.6GHz TDD, which Ofcom considers more advanced. Ofcom considers that base station equipment availability should not be a constraint on the usability of bands for 5G. Statement, paragraph A7.30-A7.33

of mobile spectrum for 5G is much too cautious. In our assessment, existing mobile bands will be supported in 5G devices one or even two years earlier than Ofcom has suggested in the Statement.

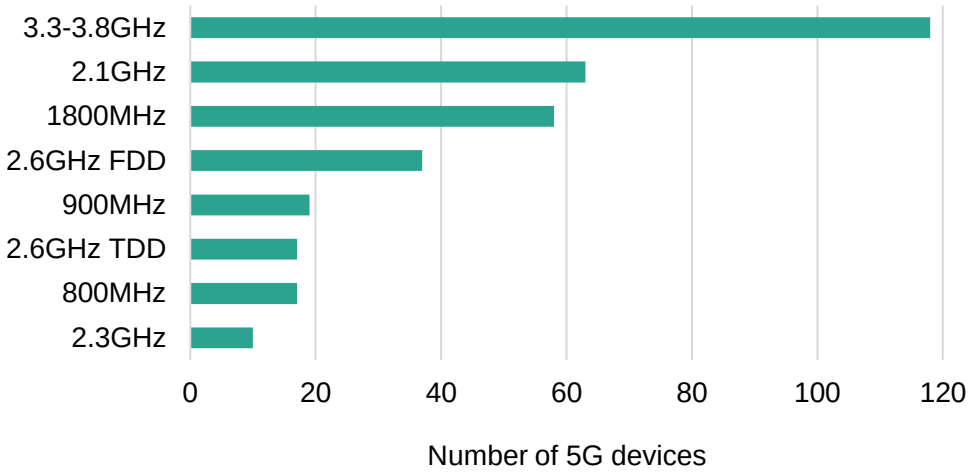
Table 2: Band availability for 5G Ofcom and Three's views

Band	Ofcom view	Three view	Comments
800MHz	2020 or 2021	2020-2021	Initial devices expected in H2 2020 / early 2021.[16]
900MHz	2021 or 2022	2020-2021	Initial devices expected in H2 2020 / early 2021.[17]
1800MHz	2021 or 2022	2020	Multiple device support in the UK in 2020.[18]
2.1GHz	2021 or 2022	2020	Multiple device support in the UK in 2020.[19]
2.3GHz	2021 or 2022	2020-2021	Some Tier 1 vendor device support in the UK in 2020. (e.g. Samsung s20 5G, Oppo Find X2 pro).
2.6GHz TDD	2020 or 2021	2020-2021	Some Tier 1 OEM device support in the UK in 2020 (e.g. Huawei Mate 30 pro-5G and P40).
2.6GHz FDD	2021 or 2022	2020	Multiple device support in the UK in 2020.[20]

[16] Devices which have 800MHz support in their roadmap cannot be disclosed as Three is subject to an NDA.
[17] Devices which have 900MHz support in their roadmap cannot be disclosed as Three is subject to an NDA.
[18] Currently supported in the Samsung s20, Huawei Mate 30pro and p40, OnePlus 8 5G, Oppo Find X2 pro and Xaiomi Mi 10 5G. Other devices cannot be disclosed as Three is subject to an NDA.
[19] Currently supported in the Samsung s20, Huawei Mate 30pro and p40, OnePlus 8 5G, Oppo Find X2 pro and Xaiomi Mi 10 5G. Other devices cannot be disclosed as Three is subject to an NDA.
[20] Currently supported in the Samsung s20, Huawei Mate p40, Oppo Find X2 pro and Xiaomi Mi 10 5G. Other devices cannot be disclosed as Three is subject to an NDA

6.5. This is confirmed by available evidence of handset support for 5G in each band globally. There are now 120 5G phones announced by 28 vendors. Figure 5 presents the number of 5G devices with known spectrum support by band.

Figure 5: 5G devices announced with known spectrum support



Source: GSA. 5G device ecosystem report. Executive Summary (June 2020)

6.6. The band with the widest support amongst announced commercial 5G devices is 3.3-3.8GHz (with 118 devices), but 2.1GHz, 1800MHz and 2.6GHz FDD are also widely supported by some 40-60 devices. There are already 10-20 devices supporting 5G in other mobile bands except 1400 MHz SDL (support for which is developing more slowly). Thus, Ofcom's "2021 or 2022" label is much too conservative even for a cautious assessment – certainly for 2.1GHz, 1800MHz and 2.6GHz FDD.

6.7. Strictly speaking, Ofcom should consider all bands (except 1400MHz) usable for 5G in 2020. Ofcom's criteria for usability considers the existence of "*a sufficiently developed range*" of user devices,[21] but Ofcom has always found that a band can be usable even if supported by only a minority of devices (as traffic can be offloaded to those frequencies, freeing up other bands).[22] In Table 2 we take a conservative view with 2020-2021 as timeframe for 900MHz, 2.6GHz TDD, 800MHz and 2.3GHz.

6.8. As demand for 5G grows over time, MNOs can gradually use these spectrum bands to supplement their 3.4-3.8GHz holdings for 5G in line with their needs. In the next

[21] Ofcom 2020 Auction Statement, paragraph A7.28-A7.29. Also Figure A4.1 of Annex 4
[22] 2.3GHz and 3.4GHz auction: Competition issues and auction regulations, paragraph 5.14

sub-section, we provide detail on the technical options they have to do so and the associated timeframe.

7. MNOs have many options to use their existing spectrum and support the use of multiple bands for 5G services

7.1. Ofcom's 'longer term' begins from 2022, when MNOs can refarm most of their spectrum for 5G (as devices and base stations able to use these bands for 5G will have developed).[23] Ofcom considers that MNOs are unlikely to need 80-100MHz of 3.4-3.8GHz spectrum over that timeframe, as they can support a wide range of 5G services by refarming their spectrum and using technologies such as carrier aggregation.[24] Ofcom is unsure that aggregating carriers to achieve wide bandwidths of 80MHz will be necessary for MNOs to compete strongly.[25]

7.2. We agree with Ofcom's assessment, although we consider that Ofcom has been too conservative with its timelines. Table 3 provides a high-level summary of the options available for MNOs to use their spectrum for 5G (and to support the use of multiple bands for 5G services, if they believe that is needed to compete strongly).

Table 3: Summary of technical options to increase 5G bandwidths

Solution	Summary	Handset support	Equipment support
(Static) refarming	Whole or a portion of existing spectrum is exclusively repurposed for 5G.	General availability from 2020-2021.	General availability from 2020-2021.
Inter-band / intra-band carrier aggregation (CA)	Aggregation of 5G carriers from different bands (and within the 3.4 – 3.8GHz band).	General availability for TDD+TDD and TDD+FDD bands in 2020-2021.	Supported for TDD+TDD and TDD+FDD in 2020-2021.
Dual connectivity	Aggregation of 4G and 5G carriers from	Widely available since 2019.	Widely available since 2019.

[23] Ofcom 2020 Auction Statement, paragraph 4.226
[24] Ofcom 2020 Auction Statement, paragraph 4.281
[25] Ofcom 2020 Auction Statement, paragraph 4.264

	different antennas.		
Dynamic Spectrum Sharing (DSS)	The same spectrum band is used for both different technologies (e.g. 4G and 5G).	General availability in FDD bands in 2020 (with TDD following in 2021).	Widespread in FDD bands this year. TDD support likely in 2021.[26]

7.3. In summary, each of the above options will be available before 2022. We discuss them in more detail below, first giving an overview of the technical solution and then discussing its feasibility in both handsets and base station equipment.

(Static) refarming

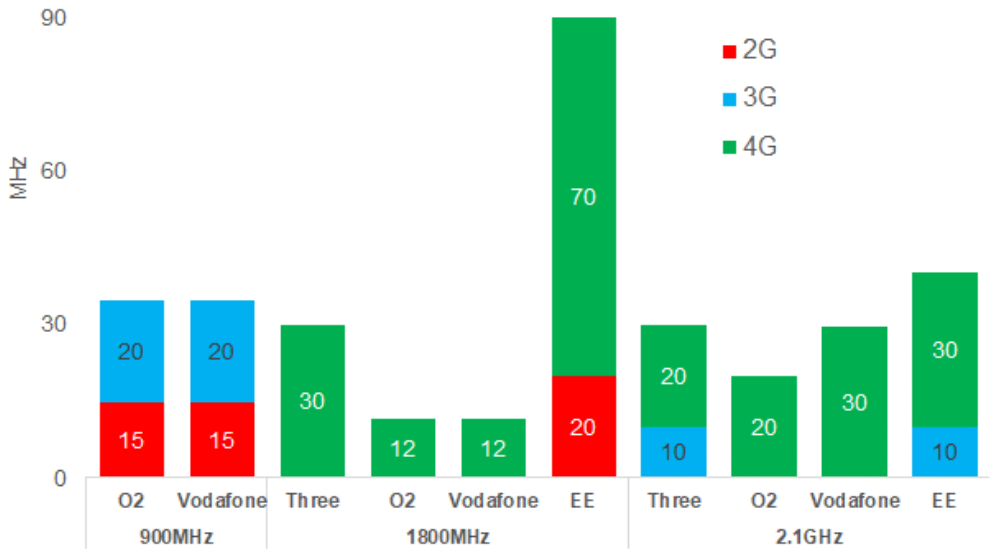
Overview

7.4. Refarming spectrum is the traditional way in which MNOs have repurposed existing spectrum to deliver a new technology. Traditionally, each technology has been deployed on dedicated spectrum blocks. Refarming requires clearing a block of spectrum of existing users, usually by incentivising customers (with attractive bundles and pricing) to migrate to the new technology.

7.5. The repurposed blocks can then be used for the new technology. As shown in Figure 6, UK MNOs have gradually refarmed most of their legacy 2G/3G spectrum (900MHz, 1800MHz and 2.1GHz) to 4G over time in high traffic areas of the country. Most of the spectrum which remains in 2G use (in red) and 3G use (in blue) will be reallocated to 4G in the short term.

[26] However, we understand that ZTE has launched DSS in TDD bands in China so this date may be brought forward as other suppliers follow. See mobileworldlive.com: ZTE 5G dynamic spectrum sharing helps operators build high-quality networks

Figure 6: current use of legacy 2G and 3G bands



Source: Three

7.6. Three and EE have repurposed most of their 1800MHz and 2.1GHz for 4G in high traffic areas. [✂] EE started repurposing 2.1GHz from 3G to 4G use back in 2018.[27] Both MNOs have left small blocks for legacy 2G or 3G use (2x10MHz 1800MHz for EE and a 2x5MHz block each at 2.1GHz) in the short term.

7.7. We understand that Vodafone and O2 have already refarmed their small 1800MHz holding (2x5.8MHz each) from 2G to 4G.[28] As regards 2.1GHz, both MNOs initially migrated a single 2x5MHz block but they have since refarmed the entire allocation to 4G (2x15MHz and 2x10MHz respectively). Both MNOs continue to use their legacy 900MHz spectrum for 2G and 3G.

7.8. [✂] Vodafone and EE [✂] intend to switch off 3G in the short term. [✂][29] 2G now accounts for a negligible share of the industry's mobile traffic,[30] but it is expected to have a longer lifespan than 3G to serve legacy uses (such as M2M and voice).

7.9. With 3G switch-off, the mobile industry can reallocate legacy 2.1GHz and 900MHz still dedicated to 3G for 4G and/or 5G. 2G is expected to have a longer lifespan to serve legacy uses (such as M2M), possibly until 2025 or 2030.[31] We expect the other MNOs to repurpose most of the legacy 900MHz and 1800MHz 2G spectrum

[27] ISP Review: EE refarms UK 3G spectrum bands into ultrafast 4G mobile broadband
[28] O2 uses it to add 4G capacity on macro sites, small cells and micro sites. Vodafone has deployed 4G 1800MHz only as capacity add in high density areas
[29] pocket-link.com: Vodafone: We'll switch off 3G in the next "two to three years" lightreading.com: BT aims to switch off 3G by 2022
[30] Ofcom's Connected Nations 2019 report, Figure 13.
[31] See for instance Real Wireless: The Potential Impact of Switching Off 2G in the UK. A report for the Spectrum Policy Forum (Oct 2019)

for 4G and/or 5G in the short term, leaving some residual spectrum for 2G use (e.g. 2x5MHz 1800MHz in the case of EE).

7.10. For instance, Vodafone has announced plans to use 900MHz for 5G after 3G switch-off.[32] O2 has also suggested that Vodafone and O2 could use 900MHz for 5G (as 5G devices already support the band).[33] In preparation, last year both MNOs traded positions in the 900MHz band to create a 2x12.4MHz contiguous block for each company. This could enable refarming of 2x10MHz 900MHz for 4G and/or 5G, leaving a small 2x2.4MHz 900MHz block for residual 2G uses (e.g. smart meters).

7.11. In summary, with few exceptions all mobile spectrum in the UK is already used for 4G or will be reallocated to 4G shortly. An MNO could refarm its spectrum to 5G in the traditional way (when 5G handsets support the band), but this is no longer necessary: technology enables MNOs to avoid refarming altogether (see below).

7.12. O2 has suggested that capacity constraints will be a significant block to MNOs re-farming 4G bands to 5G.[34] If an MNO is unable to refarm 4G spectrum to 5G due to 4G network congestion, it is because most customers are still on its 4G network. The 5G network will then be lightly loaded so the MNO would not be helped by having an 80-100MHz 5G block in the 3.4-3.8GHz band.

7.13. In reality, O2 can gradually refarm spectrum and customers from one technology to the other over time, as customer migration to 5G reduces the load on O2's 4G network.[35] Three carries much more traffic than O2 on a fraction of O2's spectrum: we have 70MHz for 3G/4G (to which we have recently started to add our 20MHz 1400MHz spectrum) compared with O2's 126MHz for 2G/3G/4G.

7.14. O2 has less 4G spectrum than EE and Vodafone for future 5G use, but its network traffic is much smaller than EE's and only slightly higher than Vodafone's (despite being the largest MNO in terms of subscribers).[36] The reason is that O2 has the lowest data traffic per subscriber of all UK MNOs (an average of 2GB per month, which is approximately half of EE's and 25% of Three's average monthly use).[37]

Handset and equipment support – static refarming

7.15. We expect each spectrum band to be usable for 5G as set out in Table 2 – MNOs should be able to start refarming spectrum by 2020-2021.

Inter-band carrier aggregation (CA) and Dual Connectivity (DC)

Overview

7.16. 5G NR has been designed to leverage large bandwidths. 5G allows MNOs to combine carriers from different bands (TDD and FDD) and technologies (e.g. 4G and 5G).

[32] pocket-link.com: Vodafone: We'll switch off 3G in the next "two to three years"
[33] Telefonica response to 2019 consultation on defragmentation of the 3.4-3.8GHz band, paragraph 40
[34] Ofcom 2020 Auction Statement, paragraph A7.35
[35] O2 may be able to use split mode antennas (where a single antenna panel is split between the two different technologies) to transmit 4G on some of its spectrum (e.g. a 20MHz 2.3GHz block) and 5G NR on the other half.
[36] Ofcom 2020 Auction Statement, Figure A3.29
[37] Ofcom 2020 Auction Statement, Figure A3.30

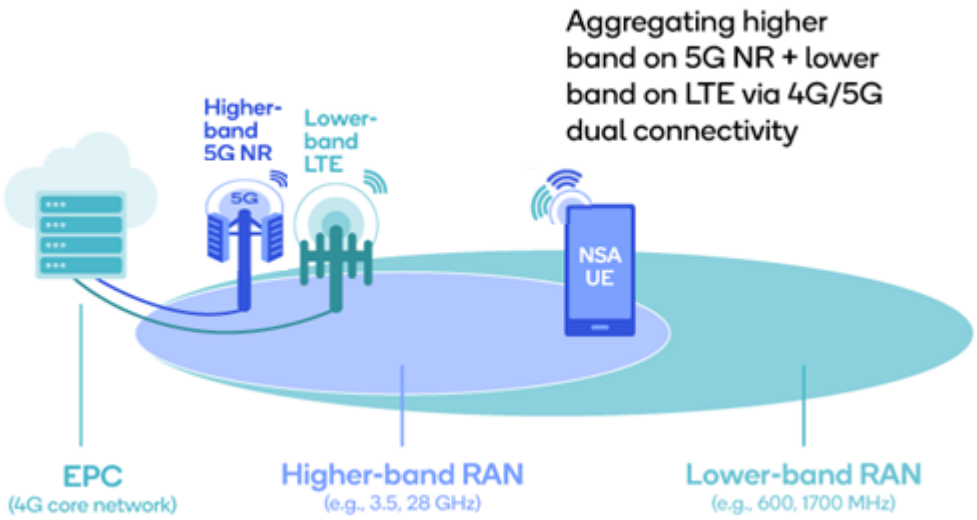
7.17. Inter-band CA in 5G enables MNOs to combine two (or more) 5G carriers from different bands to increase 5G bandwidth. Currently, a maximum of two 100MHz carriers can be aggregated, resulting in a total bandwidth of 200MHz. In the future, we expect aggregation of more than two carriers to be supported. To utilise inter-band CA for 5G, MNOs would need to refarm spectrum in 4G bands to 5G (using DSS, see below) and then aggregate it with 3.4-3.8GHz spectrum.

7.18. DC allows multiple base stations to transmit data over different technologies to a user. DC is used in all commercial 5G networks to date (including those in the UK), which are based on the Non-Standalone (NSA) version of the 5G standard. 5G NSA deployments rely on the existing 4G core and 4G radio access network – in effect, 5G works on top of the existing 4G network.[38]

7.19. 5G NSA networks use DC to combine one 5G carrier with multiple 4G carriers from different stations. Commercial 5G networks are using sub-6GHz (typically 600/850MHz, 2.5/2.6GHz, 3.4-3.8GHz or 4.2-4.9GHz) or mmWave spectrum (28GHz or 39GHz) for the 5G NR carrier and bands below 2.6GHz for the 4G anchor. In the UK, MNOs use 3.4-3.8GHz as a 5G carrier.

7.20. Figure 7 illustrates how DC works. The network carries traffic over 4G and 5G, with each technology using its own dedicated spectrum. The device receives 4G and 5G signals from different base stations and aggregates them. The data rate experienced by the user is the combined speed of the 5G and the 4G carriers.

Figure 7: Dual Connectivity in 5G NSA networks



38 Control and synchronisation between the base station and the user equipment are performed by the 4G network, while the 5G network is a complementary radio access network tethered to the 4G anchor.

Source: Qualcomm [39]

7.21. As Ofcom has reiterated, MNOs do not need 80-100MHz in the 3.4-3.8GHz band to be able to compete. The 80-100MHz 'critical threshold' is based on an illusion. MNOs can achieve similar performance by combining their 4G and 5G spectrum. 5G performance depends on the amount of 5G and 4G spectrum aggregated, not the size of the 5G 3.4-3.8GHz carrier. Even though Three has more 5G spectrum at 3.4-3.8GHz today, other MNOs can deliver greater throughput on the 4G side.

7.22. For instance, EE's 5G service leverages a huge 4G portfolio across 800MHz, 1800MHz, 2.1GHz and 2.6GHz. EE has used carrier aggregation (CA) on its 4G network since 2014 (2CA), with 3CA deployed on 2,500 sites between 2016 and 2017. In 2018, EE re-farmed 2.1GHz to 4G to deploy 5CA.[40] Busy sites were equipped with 2x80MHz 4G spectrum (not all of its 4G spectrum portfolio). A typical urban EE 4G site has 80-100MHz in the downlink just for 4G. EE does not deploy every band on every site, but high capacity sites have multiple active 4G carriers.

Table 4: Evolution of EE's 4G network

	Oct 2012	Apr 2013	Oct 2014	Sep 2016	Sep 2018
Launch	UK's first 4G network	"Double-speed 4G"	"4G+"	"4G+" Phase II	"4GEE"
CA	-	-	2 CA	3 CA	5CA
Spectrum	2x10MHz (1800MHz)	2x20MHz (1800MHz)	2x20MHz (1800MHz) 2x20MHz (2.6GHz)	2x20MHz (1800MHz) 2x20MHz (2.6GHz) 2x15MHz (2.6GHz)	2x5MHz (800MHz) 2x20MHz (1800MHz) 2x10MHz (1800MHz) 2x10MHz (2.1GHz) 2x20MHz (2.6GHz) 2x15MHz (2.6GHz)

Source: Three

7.23. EE's 5G NSA sites have been built on top of EE's max capacity 4G sites (i.e. 4G sites upgraded to 5CA in 2018).[41] EE 5G sites now have 100MHz downlink spectrum (or more) deployed per sector. This includes 60MHz of 4G spectrum (three 20MHz FDD carriers) plus EE's 40MHz of 5G spectrum at 3.4GHz. Busier

[39] Qualcomm: Key breakthoughs to drive a fast and smooth transition to 5G standalone
[40] ee.co.uk: EE turns 3G into 4G to boost smartphone speeds and lay foundation for 5G launch in 2019
[41] ee.co.uk: EE turns 3G into 4G to boost smartphone speeds and lay foundation for 5G launch in 2019

sites can have 125MHz deployed per sector, including 85MHz of 4G spectrum and 40MHz of 5G. Most EE 5G sites to date use 8T8R but 64T64R mMIMO is also used in busy locations.

7.24. Vodafone also has a large 4G portfolio (across 800MHz, 1400MHz, 1800MHz, 2.1GHz and 2.6GHz) to support its 5G NSA service. Vodafone was an early adopter of CA, with many 4G sites operating 3CA on 2x45MHz in 2016. Its 4G network today can have 85MHz deployed on the downlink. Vodafone's 5G NSA network can easily aggregate over 100MHz by combining 50MHz of Vodafone's 5G spectrum at 3.4GHz with several 20MHz 4G carriers. Most of Vodafone's 5G sites use 64T64R massive MIMO antennas, with some 8T8R sites where 64T64R cannot be accommodated.

7.25. O2 has 4G spectrum across 800MHz, 1800MHz, 2.1GHz and 2.3GHz. O2 4G sites in metropolitan areas have 55MHz of 4G spectrum deployed in the downlink. O2's 5G NSA network combines a 40MHz 3.4-3.8GHz 5G carrier with 10MHz of 4G spectrum at 2.1GHz (or at 800MHz). O2 cannot currently achieve 100MHz bandwidth for 5G because DC handsets do not yet support 2.3GHz, but this is only a temporary problem (see below). O2 is mostly using 8T8R antennas, with mMIMO deployed in built up areas.

Handset and equipment support – inter-band carrier aggregation

7.26. Handset support for 5G inter-band carrier aggregation is most advanced where one of the aggregated bands is TDD. This is most relevant to Ofcom's competition assessment as we expect MNOs to aggregate their TDD spectrum in the 3.4-3.8GHz band with other carriers (either TDD or FDD).

7.27. We expect a limited selection of handsets to support aggregation of two TDD 5G carriers in 2021 (for instance, of O2's 2.3GHz and 3.4GHz holding). Aggregation of a TDD and FDD carrier is likely to be supported earlier from H2 2020 onwards by a wider selection of suppliers.

7.28. 3GPP releases have supported a number of combinations of 5G carriers in both SA and NSA 5G networks. Our understanding is that equipment vendors are planning to follow this by supporting aggregation of a TDD carrier with either TDD or FDD carriers by 2020-2021.

Handset and equipment support – DC

7.29. Handset support for DC is already widely available. We expect devices with support for combinations of the 3.4-3.8GHz with all other LTE bands with similar propagation characteristics (i.e. 1800MHz to 2.6GHz FDD and TDD) to be generally available in 2020.

7.30. O2 cannot currently use 2.3GHz with 3.4GHz for its 5G NSA service, as DC combinations involving 2.3GHz (as a 4G carrier) and 3.4GHz (as a 5G carrier) are in 3GPP standards but not yet supported by devices. We expect devices supporting these combinations to be available later this year or in 2021 at the latest.

7.31. There are already some handsets available (e.g. Samsung S20 5G) which support DC on 2.3GHz (as a 5G carrier) and 800MHz / 2.1GHz / 2.6GHz (as 4G carriers). From next year it will be possible to aggregate two 5G carriers and use DC to add 4G carriers as well. A device vendor will support DC on 2.3GHz and 3.4GHz (two 5G carriers for 80MHz 5G) combined with 700MHz / 1800MHz / 2.1GHz (as 4G carriers) in 2021.

7.32. Once MNOs begin refarming 4G spectrum to 5G, they will also be able to use DC to combine these newly refarmed bands with most other LTE bands from 2020.[42] For example, MNOs will be able to combine a 2.1GHz 5G carrier with an LTE anchor. Our understanding is that equipment vendors will also support a wide range of DC options from 2020 onwards.

Dynamic spectrum sharing (DSS)

Overview

7.33. DSS is a key technological breakthrough designed to ease the transition between Non-Standalone (NSA) and Standalone (SA) 5G deployments. 5G SA is a truly end-to-end 5G network – from core to radio access layer – which no longer relies on an anchor 4G network.

7.34. With NSA DC the network carries traffic over 4G and 5G, but each technology uses its own dedicated spectrum. With the traditional approach to refarming, an MNO wanting to deploy an all 5G SA network would have to clear some of its 4G spectrum of users and repurpose it for 5G. A rigid static allocation of spectrum to 5G is not very efficient, as there will be very few customers initially on the 5G network and 4G users no longer have access to that capacity.

7.35. DSS obviates the need to refarm spectrum in this way. With DSS, 4G and 5G can operate together on the same spectrum, enabling a smooth transition between the two technologies. As Ofcom identifies, DSS does this by enabling the dynamic allocation of resources for both 4G and 5G users at each cell site in 1ms increments, based on demand for each service.[43]

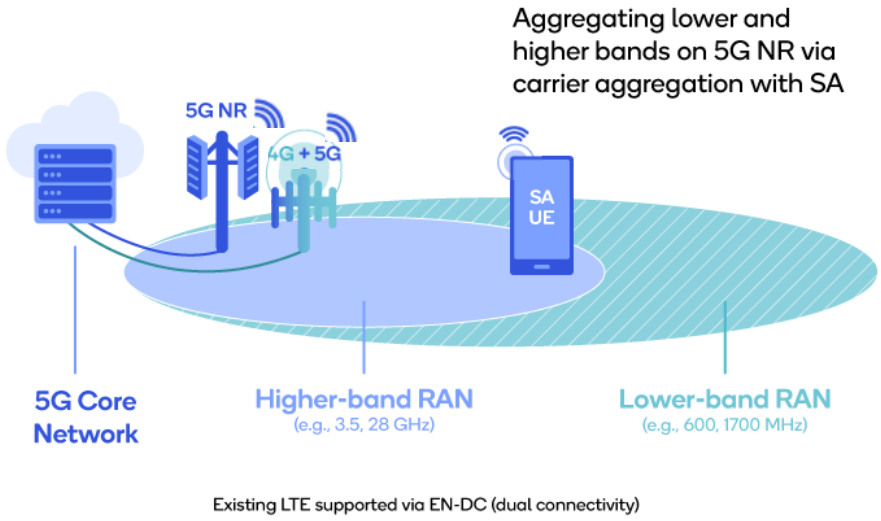
7.36. With DSS, spectrum becomes technology-agnostic: 4G users and 5G users share the same frequency at the same time. MNOs no longer need to dedicate spectrum to a specific technology. There is no longer '4G spectrum'. In effect, DSS turns any band used for 4G into one in which 5G can be deployed immediately. Again, this means that the notion of an 80-100MHz 'critical threshold' in the 3.4-3.8GHz band is illusory.

7.37. Figure 8 illustrates how DSS works. An MNO initially uses DC between 4G on low band spectrum (e.g. 800MHz) and 5G on higher band spectrum (e.g. 3.4GHz, which covers a smaller area). By deploying DSS in low band spectrum, 5G coverage is expanded across the 4G coverage layer. Users with legacy 4G devices receive 4G, while 5G NR devices receive 5G. Inter-band CA can be used to aggregate 5G carriers. 4G and 5G NSA devices using DC continue to be supported after the DSS

[42] We note that a combination of a 5G 2.6GHz TDD carrier with a LTE anchor might be more technically challenging. Support for this combination is expected to develop from 2021.
[43] Ofcom 2020 SUT Consultation, paragraph 1.50.

upgrade. The MNO just needs to transition to a 5G core to have a 5G SA deployment.

Figure 8: Dynamic Spectrum Sharing



Source: Qualcomm [44]

7.38. We expect to see three main types of commercial DSS deployments initially:

- **Nationwide 5G coverage**: deploy DSS in sub 1GHz spectrum to create a nationwide 5G coverage layer – for instance, in due course Telefonica could use DSS to deploy a high quality 5G coverage network with its extensive sub 1GHz holding, to complement its 3.4GHz 5G capacity layer (as in Figure 8). This possibility does not appear in Telefonica's submissions to Ofcom;
- **Increased 4G capacity in the coverage layer**: share 'clean' sub 1GHz spectrum (e.g. new 700MHz or 900MHz cleared of 2G/3G) dynamically between 4G and 5G, combining it with another low frequency band (e.g. 800MHz) as 4G anchor – this expands capacity in a congested 4G 800MHz layer. This could be Vodafone's approach (as it tested it earlier this year) but it could also be used by Telefonica;[45] and
- **Increased 5G capacity in the capacity layer:** DSS can also be deployed in mid-band spectrum to provide additional capacity for 5G (e.g. as Deutsche Telekom in Germany and Vodafone in the Netherlands are doing, see below).

[44] Qualcomm: Key breakthroughs drive fast and smooth transition to 5G standalone
[45] vodafone.com: Dynamic spectrum sharing: the key to a quicker 5G rollout?

7.39. Ofcom notes that DSS might reduce capacity by 7 to 10% compared with a 4G-only carrier, which is inevitable due to the additional NR control signals. As Ofcom notes, however, DSS improves spectrum efficiency compared with traditional refarming (e.g. splitting a 20MHz carrier into two 10MHz 4G and 5G carriers). This the relevant comparison for an MNO planning to use its 4G spectrum for 5G.

7.40. DSS gives both 4G and 5G devices access to the entire carrier bandwidth, whereas refarming creates a significant capacity loss as 4G and 5G NR device traffic load will not match the rigid split of spectrum between the two technologies (e.g. 50% in the above example) required by refarming. As market demand shifts between 4G and 5G, DSS enables an MNO to shift its spectrum efficiently in real time to meet those demands.

7.41. Vodafone has neatly summarised the benefits of DSS:

"2G, 3G and 4G standards were initially rolled out on dedicated blocks of spectrum, which meant that re-allocating for the next generation was an extremely slow – not to mention expensive – process. With dynamic spectrum sharing, this can be done overnight with a simple software upgrade.

For operators, this technology means they will be able to unleash the potential of 5G quicker, both for consumers and in industry, and ensure coverage over a wider area than ever before. It will also lay the foundations for the future technologies that will rely on 5G.

But how does DSS benefit for the end-user? Most importantly, it means better 5G coverage, with lower latency and higher quality (in addition to faster download speeds) for consumers sooner."[46]

7.42. The industry expects 2020 and 2021 to see large scale adoption of DSS. [✂] Ericsson [✂] expects 80% of commercial 5G networks using its equipment to deploy it in the next 12 months.[47] Many operators across the world have started to deploy it or plan to do so in 2020/2021. To cite a few examples:

- Here in the UK, at its 5G launch event Vodafone UK announced that it will deploy DSS in 2021. Vodafone has helped develop and push DSS through the 3GPP specification. Vodafone UK's 5G roadmap indicates that the 2021 DSS launch will be on low-band spectrum. [48] [✂];
- German MNOs are also embracing DSS. Vodafone Germany has launched 5G in rural areas using DSS, sharing 700MHz dynamically between 4G and 5G.[49] Deutsche Telekom is also implementing DSS, initially using 5MHz of its 2.1GHz 3G spectrum for 4G and 5G (with 15MHz by year end).[50] Deutsche Telekom expects the first DSS-enabled devices in the summer;

[46] vodafone.com: Dynamic spectrum sharing: the key to a quicker 5G rollout?
[47] ericsson.com: ericsson spectrum sharing is now commercially available
[48] Operator watch: Vodafone UK launches 5G plans. The mobile network: How Vodafone can support its unlimited ambitions
[49] vodafone.com: Vodafone Germany launches new technology to expand 5G network
[50] telekom.com: 5G for Germany

- VodafoneZiggo has been able to launch the first 5G network in the Netherlands using DSS, as the Dutch regulator has not yet auctioned 5G spectrum. Vodafone uses DSS to offer a 5G service over its 1800MHz spectrum,[51] dividing the spectrum between 4G and 5G based on user demand;

- US MNOs are planning to use DSS due to the limited availability of mid-band spectrum for 5G and poor propagation of mmWave spectrum.[52] AT&T has launched DSS in its network commercially, initially in parts of Texas. The company says DSS will play an important role in its expansion to nationwide 5G.[53] AT&T intends to deploy DSS using low-band 5G on refarmed 4G spectrum in H2 2020. T-Mobile/Sprint also plans to deploy DSS;[54]

- Verizon has indicated that DSS is key to its 5G rollout strategy, which relies on rolling out low band 5G coverage on existing spectrum. It has said its nationwide launch of 5G on its low band spectrum will be contingent on DSS. Verizon plans to introduce DSS on its US network in 2020, using technology from three vendors (Ericsson, Nokia and Samsung);[55] and

- Swisscom is using DSS to provide 5G services to 90% of the Swiss population.[56] Telstra in Australia has also rolled out 5G coverage in many areas, using DSS to serve the needs of 4G and 5G customers in the same location at the same time.[57] Other operators such as Ooredoo, Play and Hrvatski Telekomare using DSS to expand 5G coverage in Qatar, Poland and Croatia.[58]

Handset and equipment support

7.43. We understand that major chipset and handset vendors are experiencing strong demand for DSS in 5G devices. We expect UK devices to support DSS for 5G FDD bands imminently, as early as the second half of 2020.[59] In the US, several 5G devices already support DSS, with more devices to follow: Samsung's Galaxy S20, the Galaxy Note10+ 5G and LG's V60 ThinQ 5G;

7.44. A stakeholder has suggested that DSS is not available to facilitate refarming of the 2.3GHz band for 5G, as the band is licensed for use with TDD. 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.[60] We also understand that a leading handset manufacturer plans to support DSS on TDD bands in some devices in the second half of 2020. This is well before Ofcom expects its 'longer term' to begin.

[51] lightreading.com: VodafoneZiggo uses dynamic spectrum sharing to get ahead with 5G
[52] lightreading.com: AT&T takes DSS commercial on 5G, albeit very carefully
[53] venturebeat.com: AT&T begins DSS rollout, enabling some 5G phones to share 4G spectrum fiercewireless.com: AT&T turns on dynamic spectrum sharing in parts of North Texas
[54] rcrwireless.com: Verizon updates on DSS plans - focus on 'overall customer experience'
[55] fiercewireless.com: Swisscomm, Telstra use spectrum sharing to make transglobal 5G call
[56] rcrwireless.com: What's the outlook for operator adoption of Dynamic Spectrum Sharing?
[57] rcrwireless.com: Ericsson launches its dynamic spectrum sharing technology
[58] rcrwireless.com: Ericsson launches its dynamic spectrum sharing technology; telcotitans.com: Hrvatski Telekom flags DSS 5G success
[59] Or potentially at a slightly later date – via an over the air software update - after completing testing.
[60] Some 2020 devices may also receive a future update to support DSS on TDD bands via an over the air software update.

7.45. In terms of base station equipment support for DSS, our understanding is that all vendors support, or plan to support, DSS in 5G designated FDD bands in 2020.

7.46. Support for TDD bands is less certain in the short term but it is in vendors' plans. ZTE already supports DSS on 2.6GHz TDD spectrum in China which shows that it is technically feasible and there is demand for the service.[61] The timing of more widespread support will depend to some extent on the completion of 3GPP's Release 16 in June 2020.

8. Technology advances are eroding the importance of contiguity of spectrum in the 3.4-3.8GHz band more quickly than Ofcom anticipates

Non-contiguous intra-band carrier aggregation will be available from the end of 2020 and will be widespread in 2021

8.1. In the auction Statement, Ofcom considers that downlink non-contiguous intra-band carrier aggregation in the 3.4-3.8 GHz band is likely to be available for future downlink combinations in chipsets by around late 2020 or 2021, and then in base station equipment and devices in 2021 or 2022. On this basis, Ofcom expects it to be widely supported in devices from 2022.

8.2. Our understanding is different. Based on our commercial conversations with vendors, device and equipment support for non-contiguous intra-band carrier aggregation is developing at a similar pace to inter-band carrier aggregation. We expect initial availability of devices supporting intra-band carrier aggregation in the 3.4-3.8GHz band by the end of 2020, with increasing availability in 2021 and similar support from equipment vendors in the same timeframe.

8.3. Ofcom considers that there will be a 'moderate capacity inefficiency' from aggregating two 5G carriers in the order of 2-15%[62] but this can be more than outweighed by the increase in capacity from deploying massive MIMO and beamforming.[63] We support this view: massive MIMO equipment offers capacity gains of 300-500%, which dwarves a 2-15% capacity loss. We explain above that most of Telefonica's and EE's 5G deployments to date seem to be based on 8T8R antennas.

Antennas covering 400MHz bandwidths in 3.4-3.8GHz will be available by the end of 2020

8.4. As Ofcom has recognised, intra-band carrier aggregation can only be supported where the instantaneous bandwidth (IBW) of an MNO's antennas cover its entire spectrum holding in a band. Although it is theoretically possible to deploy additional antennas on a mast to increase the bandwidth over which carriers can be aggregated, this is not always feasible and can be a costly solution.

8.5. O2 considers that it is 'essential' to avoid more than 300MHz separation between spectrum blocks in the 3.4-3.8GHz band.[64] Since its holding in 3.4-3.8GHz starts at 3500MHz, what O2 means is that covering 3.5-3.8GHz with a single antenna would

[61] See mobileworldlive.com: ZTE 5G dynamic spectrum sharing helps operators build high-quality networks
[62] Where the capacity drop-off lies between these bounds depends on handset capabilities.
[63] Ofcom 2020 Auction Statement , paragraph 4,267.
[64] Telefonica response to 2019 auction consultation , paragraph 157.

save it the cost of a second antenna. But one equipment vendor has informed us that they expect to supply 64T64R equipment with a 400MHz IBW by Q3 2020 (and a 32T32R equivalent by Q1 2021). This indicates that the technology is available and it is a matter of time before all equipment vendors offer similar equipment.

8.6. We also understand that split mode antennas can be used to increase the bandwidth over which MNOs can aggregate within bands. This might provide an alternative to antenna systems with 400MHz IBW if, for whatever reason, MNOs are unable to use them.

8.7. Split mode technology divides antennas into two. For example, a 64T64R massive MIMO antenna can be split into two 32T32R massive MIMO antennas, transmitting on different frequencies within a band. An MNO with fragmented spectrum could assign one half of the antenna to its spectrum at one end of the band and the other half to the remainder. This would allow it to utilise all its spectrum within the 3.4-3.8GHz band without deploying two antennas or a single antenna with a 400MHz IBW. Our understanding is that equipment vendors are starting to support split mode antennas for this purpose.[65]

Carrier aggregation in the uplink will be supported but may not enable important 5G services

8.8. Both O2 and Vodafone have argued that carrier aggregation is unlikely to be supported in the uplink.[66] Our understanding is that this is not the case. Carrier aggregation in the uplink is expected to be finalised in 3GPP Release 16. Although we expect equipment support to lag carrier aggregation in the downlink, suppliers have indicated that it will be supported in radio equipment towards the end of 2020 or early 2021. We expect support in initial handsets in a similar timeframe.

8.9. We agree with Ofcom that there are unlikely to be any services which require intra-band carrier aggregation in the uplink that will be critical for competition in the future.[67] MNOs should be able to aggregate carriers to increase their downlink capacity while providing competitive services on non-aggregated uplink spectrum.

Three is ready and willing to proceed with trading

8.10. Fragmented spectrum can also be overcome by trading – i.e. MNOs agreeing to trade spectrum to reconfigure the 3.4-3.8GHz band. Ofcom has introduced measures in the upcoming auction to facilitate this. These include, inter alia, a negotiation period in the assignment stage of the auction.

8.11. Three set out a trading process in 2019 to give other MNOs the opportunity of achieving large contiguous blocks in the band. Based on feedback from the other MNOS, we (reluctantly) put the process on hold until the negotiation period in the auction (or after the Ofcom auction). Three continues to be ready and willing to proceed with the proposed trading process.

[65] For example, we know that Sprint is using split mode antennas in the 2.5GHz band in the US. See sprint.com: Sprint 5G overview.
[66] Telefonica response to 2019 auction consultation , paragraph 156 and Vodafone response to 2019 auction consultation , page 13
[67] Ofcom 2020 Auction Statement, paragraph 2.269.

3. 5G use cases do not rely on 80-100MHz of contiguous 3.4-3.8GHz spectrum.

9. Executive summary

9.1. Ofcom's SUT model is intended to answer the question of whether MNOs can support 5G use cases in the longer term with and without requiring additional spectrum in the 3.4-3.8GHz band. The model contributes to Ofcom's overall conclusion that there is a low risk of competition concerns related to 3.4-3.8GHz spectrum.

9.2. We consider that Ofcom's SUT analysis is inconsistent with its competition assessment, which assesses competition separately in the short and longer term. The SUT model conflates the two: it asks the peculiar question of whether MNOs can support the more demanding 5G use cases which will only arise in the longer term with their short term holdings of 5G spectrum – i.e. the 40/50MHz of 3.4GHz they have today.

9.3. We have nevertheless undertaken technical analysis to answer this artificial question. In the first instance, we have validated the results of Ofcom's SUT model, which considers the performance that a single user would experience if there were no other users active on that carrier in the cell.

9.4. Anticipating predictable objections from other MNOs, we have extended Ofcom's SUT modelling to consider the impact of multiple users on a 5G cell (a Multi-user Model, MUT). Both models support Ofcom's analysis: MNOs can support a wide range of 5G services with channel bandwidths smaller than 80MHz, and they can aggregate spectrum to match the performance of a larger carrier.

Ofcom's SUT modelling is inconsistent with its competition assessment

9.5. In the auction Statement, Ofcom found three reasons why the risk of competition concerns in the longer term arising from either an asymmetry in the relative scale of spectrum holdings or fragmented holdings in the 3.4-3.8GHz band is low:

1) In the longer term, spectrum in other bands in which Vodafone, O2 and BT/EE have holdings will be available for 5G, which the operators can "refarm" for 5G use;

2) If MNOs really 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; and

3) There is no clear evidence suggesting there are likely to be future 5G services which i) would be of significant commercial importance; and ii) which would require 80-100MHz of contiguous spectrum.[68]

[68] Ofcom 2020 SUT Consultation, paragraph 1.7.

9.6. The SUT analysis is relevant to Ofcom's longer-term competition assessment in (3ii) above:

"*We referred to the SUT model in support of our view that operators were likely in the longer term to be able to support a wide range of 5G services without 80-100MHz of spectrum in the 3.4-3.8GHz band (whether contiguous or not)*"[69]

9.7. The model is intended to answer the question of whether an MNO can support 5G use cases in the longer term without additional spectrum in the 3.4-3.8GHz band in an unlikely situation. In effect, this assumes that (1), (2) and (3i) do not hold – i.e. that the MNO will not be able to buy 3.6GHz in the auction, will not be able to refarm its spectrum for 5G and will have to provide 5G services (which are likely to be important for competition) in the future with its current 3.4GHz holding.

9.8. Essentially, Ofcom's SUT analysis asks whether an MNO can provide some of the most demanding 5G use cases that will only arise in the longer term (such as live mobile broadband or cloud computer games for connected vehicles with 4k 3D graphics) with their short term spectrum holdings – i.e. the 40/50MHz of 3.4GHz which they have today.

9.9. This is inconsistent with Ofcom's competition assessment, which assesses competition separately in the short and the longer term. Ofcom's view is that enhanced mobile broadband (eMBB) and, possibly, FWA are likely to be the predominant 5G services in the short term (and FWA is not relevant to a mobile competition assessment).[70,]

9.10. By broadening the set of use cases beyond eMBB, Ofcom is effectively taking a longer term view of the potential 5G throughput requirements. We have nevertheless undertaken technical analysis to answer this artificial question. In this section:

- We first describe the main parameters of the SUT and MUT models we have used;
- We replicate the results of Ofcom's SUT model, which considers the performance that a single user would experience if there were no other users active on that carrier in the cell;
- Finally, we extend Ofcom's model to consider the validity of the results when multiple users are sharing cell resources.

9.11. We conclude that both models support the view that MNOs can provide a wide range of 5G services with channel bandwidths smaller than 80MHz.

10. Description of our Single User and Multi-User throughput (SUT and MUT) models

10.1. Our MUT analysis uses a dynamic simulator to estimate the throughput distribution within an 'area of interest'. The MUT simulator is essentially an extension of Ofcom's SUT analysis with an increased number of users sharing the resources in a cell.

10.2. The model we have used is consistent with 3GPP specification 36.873, R1-070674, assuming a "site to site" distance of 700 metres. We ran Monte Carlo simulations with 100 iterations. In each iteration the users were dropped randomly within the area and the average throughput was recorded for each user. A video traffic model

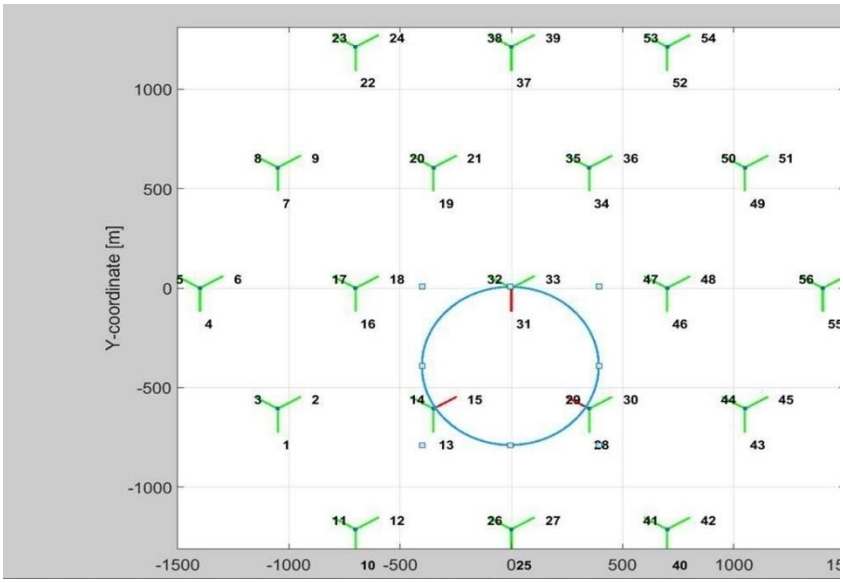
[69] Ofcom 2020 SUT Consultation , Overview
[70] Ofcom 2020 Auction Statement , paragraph 4.253. We agree that FWA is irrelevant to Ofcom's competition assessment as it is a separate service to mobile and can be provided using spectrum outside of the 3.4-3.8GHz band.

was deployed consistent with 3GPP model specifications and users were assigned to cells on the basis of the receive strongest signal.

10.3. The modelling was based on the following assumptions:

- Deployment of a Proportional Fair scheduler and log-normal shadowing effect;
- 32T32R massive MIMO multibeam technology - approximated by using multiple beams;
- All users are streaming video with 10, 50 or 100 Mbps download speeds and a test user is doing a speed test;
- All surrounding sites are fully loaded to generate interference in the area of interest;
- An antenna downtilt of 9 and 12 degrees applied to each antenna to minimise interference;
- A standard 3:1 ratio TDD frame structure;
- Video traffic consistent with 3GPP specifications (R1-070674); and
- A 19 site deployment. The blue polygon in the middle of Figure 9 was selected as the 'area of interest'.

Figure 9: Our site deployment model



10.4. We considered three loading scenarios:

Table 5: Network load scenarios

Scenario	Number of users
Low load	5 per sector (4 watching video, 1 conducting speed test)
Medium load	15 per sector (14 watching video, 1 conducting speed test)
High load	30 per sector (29 watching video, 1 conducting speed test)

10.5. The output of the simulations was to estimate the proportion of outdoor[71] locations in the area that can receive a certain video encoding speed. We used the MUT simulator to undertake the following analyses, the results of which are reported below:

- Replication of Ofcom's SUT analysis (Figure 10);
- The throughput distribution of a randomly placed test user, where other users are streaming video in three different traffic load scenarios (Figures 11–13);
- The relationship between throughput and the number of users in an area (Figure 14); and
- Densification analysis to match the performance of 80MHz spectrum network by increasing the number of sites in a 40MHz network (Figure 15).

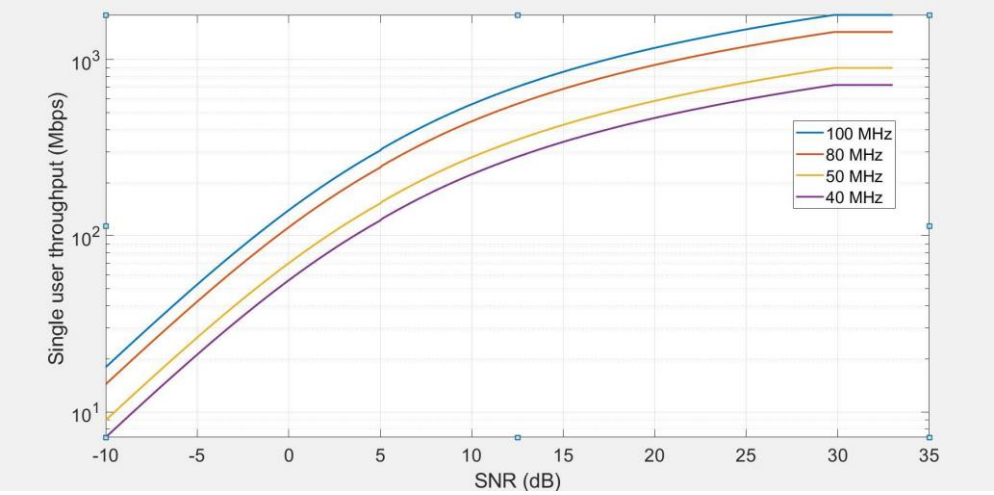
11. The results of our SUT model are consistent with Ofcom's

11.1. Ofcom's SUT model estimates the throughput that a theoretical mobile cell could offer across its coverage area with different carrier bandwidths. To do this, the maximum data throughput which a single user could experience at a location at which the assumed SINR applies (if there were no other users active on that carrier in the cell) is estimated.

11.2. This exercise is repeated using spectrum carriers with different bandwidths and then compared against the throughput requirements of different longer term 5G use cases. We have been able to replicate Ofcom's SUT analysis using our simulator, finding similar results (see Figure 10, below).

[71] We have modelled outdoor mobile coverage as Ofcom's most demanding long term 5G use case, 'professional mobile video', requires mobile broadband services with wide area coverage.

Figure 10: SUT/SNR relationship in a SUT model



Source: Three simulation

11.3. The results are remarkably close to those of Ofcom's SUT model. For example, Ofcom estimates a SUT of 1Gbps for a 100MHz bandwidth at a SINR of approximately 16dB.[72] Our simulation shows an equivalent SUT at a SINR of between 16dB and 17dB. Similarly, for a 40MHz bandwidth, both our modelling and Ofcom's estimates a SUT of 100Mbps at a SINR of approximately 3dB.

11.4. Ofcom uses its SUT model to predict the minimum signal quality needed to deliver the service in each scenario.[73] Ofcom believes that, in real situations with many active users, a user will likely require a higher SINR than the minimum. The greater the margin, the more of the radio carrier's resources can be allocated to other users to provide the same and other services.

11.5. Ofcom finds that none of the 5G use cases it considers are technically infeasible in the longer term, even with a 40MHz carrier. We agree. In Figure 10, the maximum throughput achievable with each bandwidth always exceeds the minimum data rate required by each of Ofcom's 5G use cases. In fact, in the best signal conditions all bandwidths meet the service requirement of the most demanding application (mobile broadband live video, which requires a downlink data rate of 300Mbps).

11.6. Ofcom concludes that a network of macro cells with 40MHz deployed is likely to support all of the 5G use cases considered, apart from three 'excepted cases' which would be better provided with a different type of deployment. In reaching this view Ofcom has taken into account some alternatives available (beyond increasing spectrum holdings), such as the use of small cells / indoor deployments or higher performance antennas (i.e. mMIMO, which provides better performance than the 4x4 SU-MIMO base configuration modelled by Ofcom).

[72] Ofcom 2020 SUT Consultation , Table 1.
[73] i.e. the SINR value at the point where the dotted horizontal line of a service meets the solid curve of a scenario.

11.7. This is a reasonable finding and we support the technical assumptions Ofcom has made to estimate the SUT/SINR relationship. An MNO should be able to achieve the minimum SINR to provide each use case across a significant proportion of a cell (including a margin to allow resources to be allocated to other users), using when needed (e.g. for the most demanding applications) the alternatives considered by Ofcom.

11.8. In the next sub-section, we extend Ofcom's model to explicitly consider the impact of multiple users using a cell on the SUT/SINR relationship.

12. Our MUT analysis shows that MNOs can provide a wide range of 5G use cases with channel bandwidths smaller than 80MHz

12.1. In the longer term, 5G traffic is forecast to grow significantly over time. Even then, there will remain some cells which are relatively lightly loaded, while others become more congested. Average user throughputs decrease as the loading in a cell increases. At loaded sites, contention between users accessing the cell will constrain speeds to below the theoretical peak determined by carrier bandwidth.

12.2. In this sub-section, we present the results of our MUT analysis. These show that in the longer term:

- An MNO can aggregate a 40MHz 3.4GHz carrier with other spectrum to provide a comparable 5G performance to an 80MHz carrier – there is no 'critical threshold' of 80MHz at 3.4-3.8GHz;
- An MNO can use other alternatives (beyond aggregating more spectrum, such as site densification), to provide a comparable 5G performance to an 80MHz carrier.

12.3. We discuss each of these findings in turn.

<u>An MNO can aggregate a 40MHz 3.4GHz carrier with other spectrum to provide a comparable 5G performance to an 80MHz carrier</u>

12.4. As we discuss in Sections 1 and 2, MNOs have various options in the longer term to use their spectrum for 5G (and to support the use of multiple bands for 5G services, if they believe that is needed to compete strongly).

12.5. For instance, MNOs can refarm their existing holdings to 5G (in the traditional way or through DSS) and aggregate them with their 3.4GHz spectrum. MNOs can also combine 4G carriers with their 3.4GHz holding through DC. Technological advances will allow new combinations and the amount of spectrum that can be aggregated to increase over time. Additionally, MNOs can acquire new spectrum to extend 5G capacity (such as [✂] 3.6GHz in the upcoming auction).

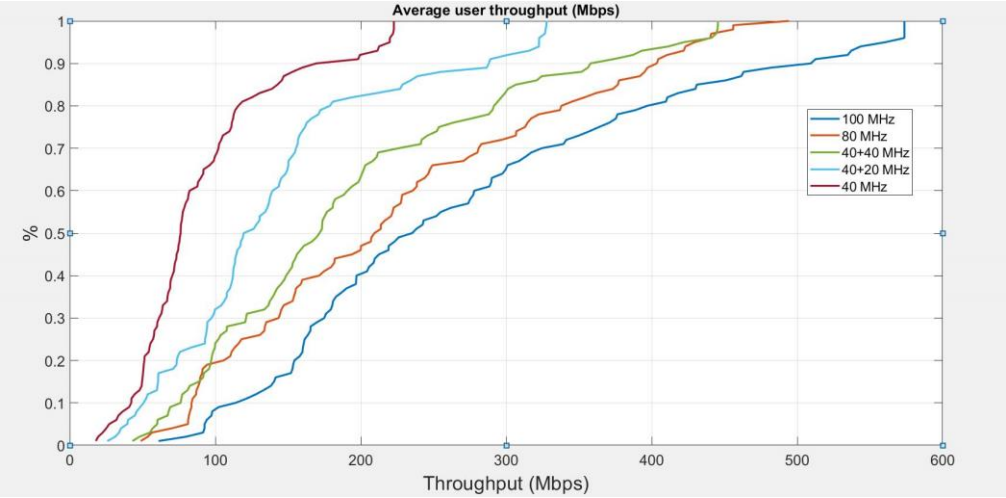
12.6. Figures 11 to 13 report the results of our MUT modelling for the different loading and bandwidth scenarios considered in our modelling (as described above). Consistent with Ofcom's findings, the figures show that:[74]

- MNOs can achieve similar performance to a single 80 or 100MHz carrier by using other mobile bands in combination with their 3.4-3.8GHz spectrum – e.g. by using inter-band carrier aggregation or dual connectivity;

[74] Ofcom 2020 Auction Statement, paragraphs 4.262 – 4.270

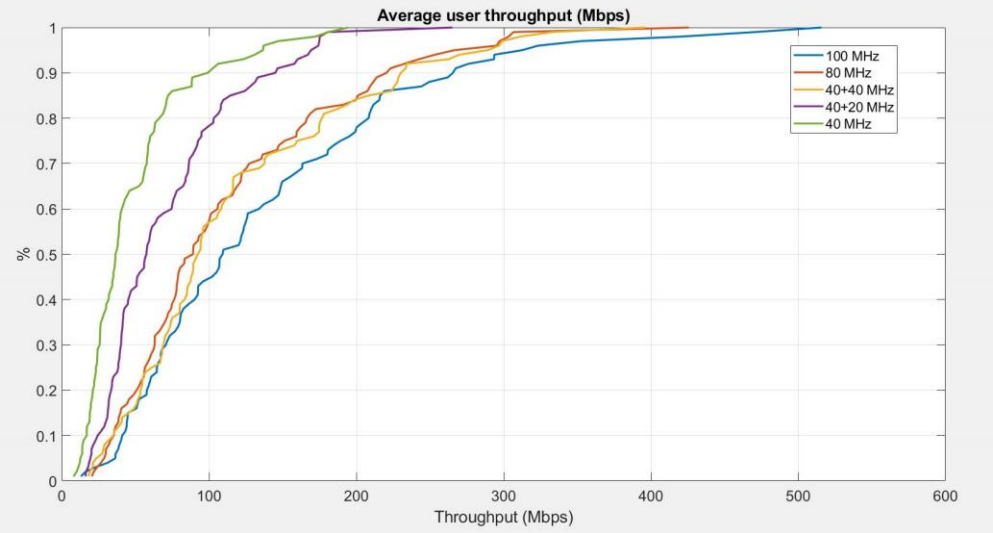
- Carrier aggregation can substitute for contiguous spectrum by achieving similar performance.

Figure 11: Light load scenario



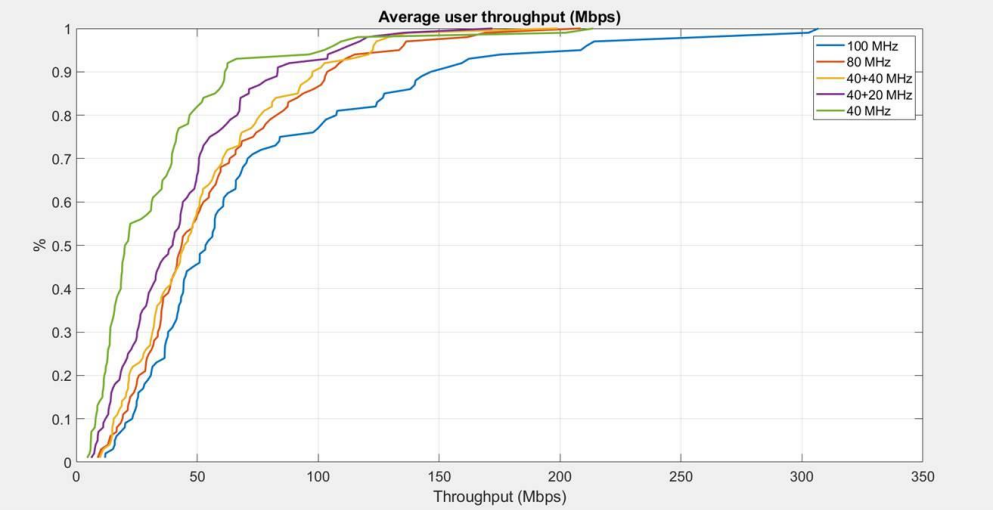
Source: Three

Figure 12: Medium load scenario



Source: Three

Figure 13: Heavy load scenario



Source: Three

12.7. The figures above show that there is a minimal difference between the performance of two aggregated 40MHz carriers and that of one contiguous 80MHz carrier. As Ofcom has found, there is only a small capacity inefficiency from carrier aggregation (which Ofcom has quantified at 2-15%).[75]

12.8. Moreover, the difference is performance is smaller in medium and heavy load sites, where capacity needs are greatest. This is seen most clearly by looking at the difference between the 80MHz and 40MHz + 40MHz curves in Figures 11 to 13. Both curves offer similar throughputs to a similar proportion of the cell (and more so in Figures 12 and 13 than in Figure 11).

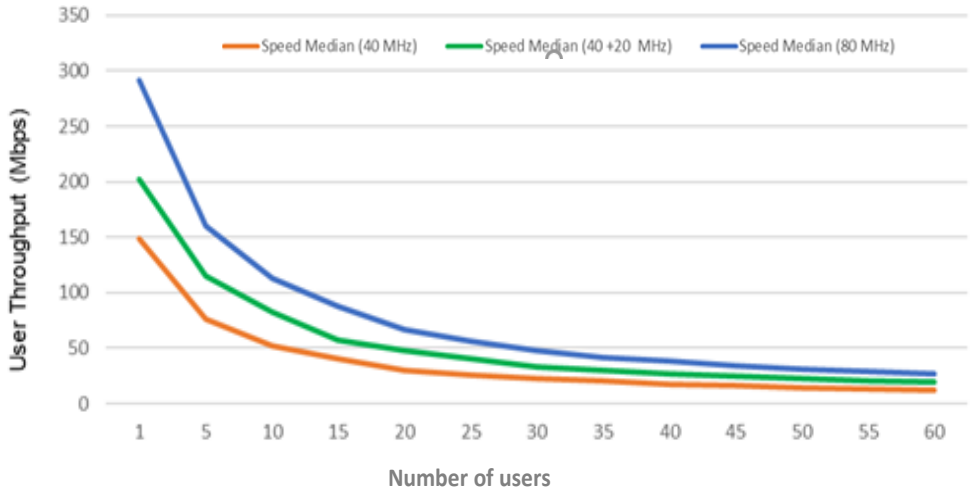
12.9. In practice, O2 will be able to aggregate its 40MHz of 3.4GHz spectrum with its 40MHz of 2.3GHz spectrum to provide a similar 5G service to a 80MHz carrier. This confirms Ofcom's finding that an MNO does not require 80-100MHz of spectrum in the 3.4-3.8GHz band to remain competitive.

12.10. The other MNOs have argued that there is a 'critical threshold' of 80-100MHz in the 3.4-3.8GHz band needed to be competitive. In their view, any holding below 80MHz may only be used to provide a 'basic service' – one that could not compete with Three's 100MHz 5G carrier.

12.11. Our analysis shows that there is no such 'critical threshold'. Instead, there is a simple relationship between the amount of 5G-capable spectrum an MNO holds, the loading in a cell and the data rates that an MNO can provide. Figure 14 highlights this for carriers of 40MHz, 60MHz (40+20MHz) and 80MHz bandwidths.

[75] Ofcom 2020 Auction Statement, paragraph 4.262

Figure 14: Relationship between download speeds and cell loading (40MHz vs 40+20MHz vs 80MHz carriers)



Source: Three

12.12. This shows no 'critical threshold' at 80MHz:

- Comparing the different bandwidth curves (for a given number of users), speed is roughly proportional to bandwidth – i.e. there is no "cliff-edge" drop in performance at 80MHz; and
- Along each individual curve, as the number of users in a cell increases, user throughput falls regardless of bandwidth. In fact, the drop in performance falls more rapidly for the 80MHz carrier – even a 80MHz 5G carrier will struggle to provide good performance in a heavily loaded cell.

<u>An MNO can use other alternatives (beyond aggregating more spectrum, such as site densification), to provide a comparable 5G performance to an 80MHz carrier</u>

12.13. We fully expect MNOs to use technical solutions to aggregate existing spectrum with their 3.4GHz holdings where they need to increase their 5G performance in the long term. However, we have also investigated other options they have to increase the data rates they provide using only a 40MHz carrier at 3.4GHz.

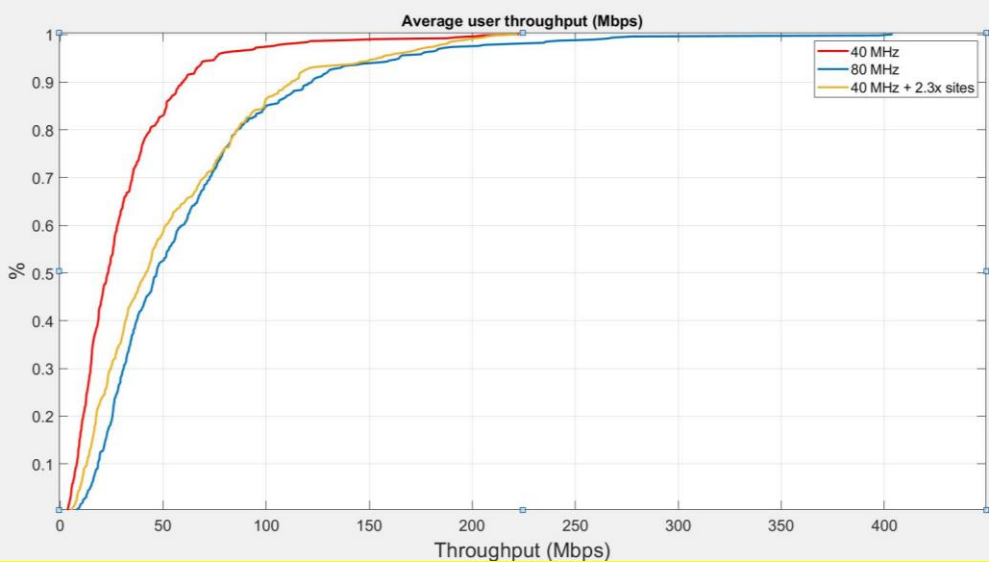
12.14. One option is to use more advanced base station equipment. We discuss in Section 2 that O2 and EE are mostly using 8T8T antennas for their 5G deployment. Our analysis has assumed a 32T32R massive MIMO antenna configuration. MNOs could increase the data rates they support by using more advanced antenna configurations (such as 64T64R). Our understanding (from commercial discussions with vendors) is that a 64T64R antenna can increase a cell's capacity by 50-100% compared to 32T32R, allowing MNOs to support faster download speeds in more heavily loaded cells.

12.15. A second option is to selectively densify a network where additional 5G capacity is required. For example, MNOs might deploy small cells to provide more capacity-

demanding 5G services in hotspots such as a stadium or within an industrial complex, as Ofcom recognises.[76]

12.16. We have undertaken modelling to determine the impact of densification on MNOs' abilities to provide 5G services. Our analysis in Figure 15 shows that an MNO with a 40MHz carrier can replicate the user throughput of an 80MHz carrier by adding another macro site (strictly, 1.3 sites) near the existing site in our model. This supports Ofcom's view that MNOs can support a wide range of 5G services with channel bandwidths smaller than 80MHz (including 40MHz).

Figure 15: Site densification vs greater bandwidth



Source: Three

12.17. We are taking a conservative approach by assuming a macro cell densification programme. Densification using small cells would be more efficient i.e. would require fewer sites than our macro cell analysis in Figure 15. This is because MNOs can target small cell deployments more effectively at locations which require greater capacity. [✂]

12.18. This analysis is likely to be particularly relevant to converged operators like BT/EE and O2 (once it merges with Virgin Media). By leveraging the street furniture and fibre backhaul of their fixed broadband arm, these operators can reduce acquisitions from third parties, allowing them to densify their networks quickly and cheaply.

Summary

We have extended Ofcom's SUT modelling to consider the impact of multiple users within a cell on an MNO's ability to provide a 5G service. Our analysis reflects the variety of options that MNOs have to increase their 5G data rates in the long term. We conclude, consistent with Ofcom's analysis, that MNOs can support a wide range of 5G services without 80-100MHz of bandwidth in the 3.4-3.8GHz band.

[76] Ofcom 2020 SUT Consultation, Table A5.