REPORT FOR TPG TELECOM

ABSTRACT

This report reviews the characteristics of spectrum, standards and 5G ecosystem support for the various 2.3, 3.4, 3.6 and 3.7 GHz bands as referenced by the ACCC in advice on spectrum allocation limits.

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Disclaimer

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1.1 Introduction

1.2 Instructions and personal background

The following report has been prepared by Mike Wright of Quadrature Pty Ltd at the request of TPG Telecom.

I am a professional Telecommunications Engineer with over 40 years of experience in the planning, design, development, and operation of telecommunications networks ranging from pre-cellular technologies to 5G.

Since October 2018, I have been Director of Quadrature Pty Ltd which provides consultancy services to CEOs and CTOs of worldwide telecommunications companies. Additional roles have included Non-Executive Director to an Australian Tower Company, advisor to Australian start-up companies, and expert witness to the Federal Court of Australia.

Prior to September 2018, I was Group Managing Director of Networks at Telstra Corporation. I held that role from June 2013 to September 2018. I had over 37 years' experience in engineering roles at Telstra Corporation which included managing planning, design and deployment of fixed networks and mobile networks across over 5 generations of mobile telecommunications technology.

A copy of my CV outlining my experience in more detail is attached.

1.3 Report Overview

This report considers the 2.3 GHz, 3.4, 3.6 and 3.7 GHz bands when used for 5G and the extent to which they are substitutable or otherwise relative to the conclusions of the ACCC[1] in the August 2022 ACCC report "Allocation limits advice for the 3.4 GHz and 3.7 GHz spectrum allocation".

This report reviews the characteristics of each band and the associated 5G ecosystem in order to develop alignment or otherwise with the following ACCC findings and to offer any additional insights from practical experience. The ACCC's views are outlined below.

a. The ACCC considers that holdings in the 3.4, 3.6 and 3.7 GHz bands are substitutable due to their similar technical characteristics and device availability, as well as international harmonisation of the wider band.
b. Other potentially relevant spectrum bands canvassed in the ACCC's consultation paper included other mid-band spectrum, and 2.3 GHz band spectrum in particular. The ACCC does not consider 1800 MHz, 2100 MHz, and 2.6 GHz band spectrum substitutable because they do not offer the same large bandwidths available as 3.4-3.8 GHz spectrum.
c. The 2.3 GHz band has similar propagation characteristics, vendor availability and technical frameworks as the 3.4–3.8 GHz band.
d. However, the 5G equipment ecosystem is not as developed for 2.3 GHz as it is for the 3.4–3.8 GHz band.
e. Additionally, due to existing geographic asymmetries of holdings, including 2300 MHz as substitutable in this allocation may prevent affected operators from acquiring geographically contiguous spectrum in the 3.4 and 3.7 GHz bands. Where there are different licensees in

[1] https://www.accc.gov.au/system/files/ACCC%20advice%20to%20ACMA%20on%20allocation%20limits%20for%203.4%20and%203.7%20GHz%20spectrum%20allocation.pdf

[redacted]

two adjacent areas at the same frequency, the effective licence area may be smaller due to coordination.

2 Spectrum and performance characteristics of bands

2.1 Overview

This section considers characteristics including frequency, propagation, bandwidth, band configuration and capacity.

In this report the various frequency bands are referenced in MHz and the collective 3.4, 3.6 and 3.7 GHz bands are at times referenced as “3500 MHz” spectrum or the “3.5 GHz” band.

Cellular radio spectrum is characterised by the frequency of transmission and the bandwidth (total range of frequencies from the lowest to the highest) used in the transmission band.

In terms of propagation distance, lower frequencies travel further than higher frequencies and the wider the range of frequencies or bandwidth used in the transmission, the more information or data can be carried.

Lower bands are effective for broader coverage range and depth of coverage into buildings whilst higher bands, even though they propagate a shorter distance/depth, allow the allocation of a wider range of spectrum frequencies, thus supporting greater amounts of throughput.

In the context of spectrum configurations such as Frequency Division Duplex (FDD) and Time Division Duplex (TDD) there are various network technology standards that are capable of delivering material network performance and capacity difference between the two.

2.2 Frequency impact on Coverage Range

The range of coverage from a Macro mobile site is set by factors including tower height, antenna gain, transmit power and the radio path between the tower and the receiving mobile as well as the received signal quality and interference. Each of these factors contribute to the ‘Link Budget’ which is the total allowable amount of signal loss from the transmitter to the receiver whilst maintaining coverage.

An example of how various frequencies provide typical coverage ranges from Macro base station sites is shown in the table below, the outdoor ranges include approximations from Figure 4.1 of the 2015 ACCC document[2] : “*Competition limits advice for 1800 MHz spectrum in regional areas*”. The indoor ranges are adjusted by an approximate of free space path loss allowing for good in building penetration, noting that even for 700 MHz some indoor coverage can be received up to ~2km. These ranges are consistent with my professional experience.

Band (MHz)	Range Outdoor (km)	Range Indoor (km)	Typical Channel Configuration[@]
700*	3.1	1	FDD
850*	2.8	0.8	FDD
900*	2.6	0.7	FDD
1800*	1.4	0.4	FDD
2100*	1.1	0.3	FDD
2300	0.9	0.3	TDD
2600*	0.8	0.26	FDD

[2] https://www.infrastructure.gov.au/sites/default/files/ACCC%20-%201800%20MHz%20competition%20limits%20advice%20-%20Redacted.pdf

[redacted]

3500#	0.6	0.19	TDD

*As referenced in Figure 4.1 of the 2015 ACCC document #Used as typical mid-range of 5G bands 3400-3700 MHz
@ TDD – Time Division Duplex FDD – Frequency Division Duplex

The typical coverage range approximations above show that the 2300 MHz band provides a superior coverage range and depth when compared with the typical 5G Bands 3400-3700 MHz.

This is supported by plots provided to me by TPG Telecom showing coverage drive test plots comparing Optus TD2300 and Optus TD3500, these are included below.

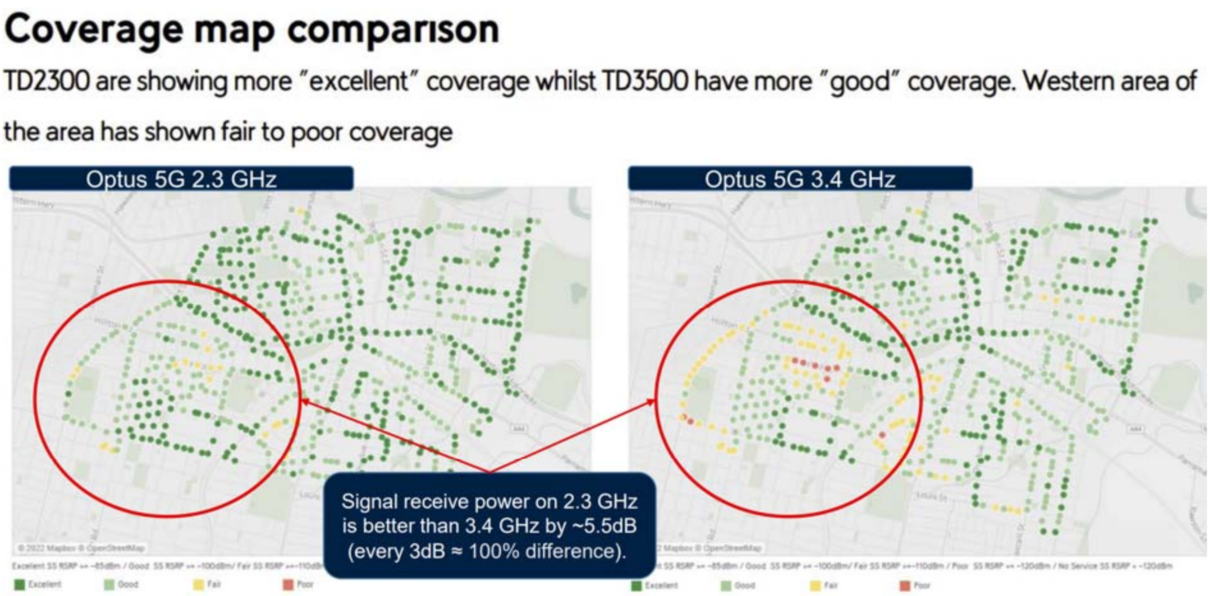

Figure 1: TPG Telecom Coverage comparison

Observation 1: The coverage characteristic of the 2300 MHz spectrum are superior to the other 5G spectrum in the 3500 MHz bands in terms of range and depth of coverage.

2.3 Network Capacity implications for different frequency bands

The following figure is an example comparing the indoor coverage range of typical 5G frequencies including a low band such as 700 MHz combined with 2300 MHz and/or 3500 MHz mid bands.

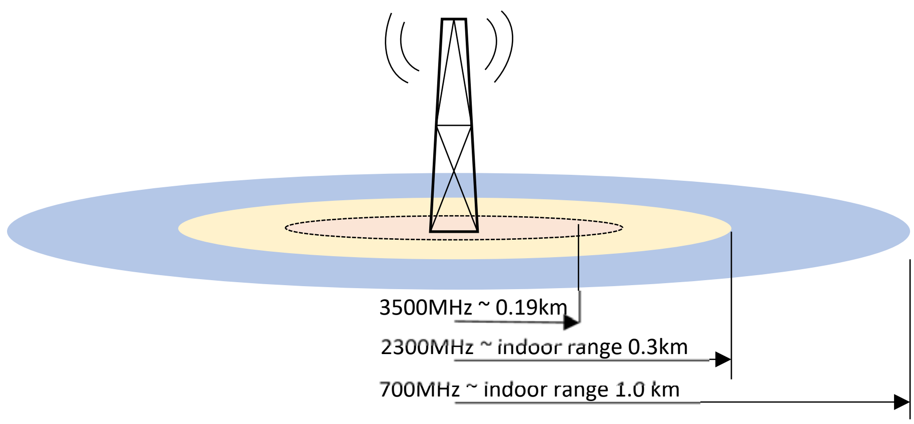

Figure 2: Spectrum coverage range comparisons

[redacted]

*Note that vendors offer 5G features including Dual Connectivity and Carrier Aggregation which can be used to combine mid band 5G signals with a low band FDD layer, this configuration improves the 5G coverage range.

The implication of the above figure is that the greater the range difference between the low band and mid band the more traffic will be carried by the low band alone.

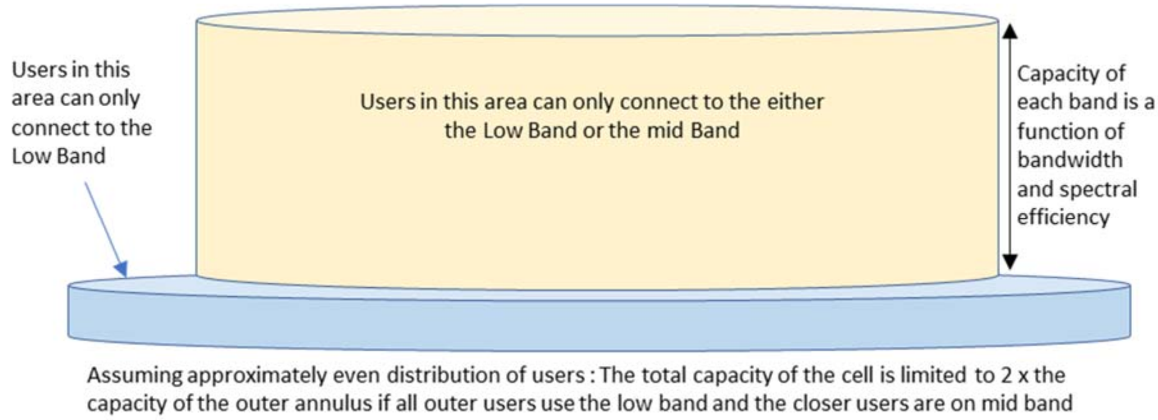

Figure 3: Coverage and capacity impacts of low vs higher bands

By taking into account the amount of spectrum in each band where sites are spaced without mid band overlap the useable capacity of the higher frequency band may be limited regardless of the bandwidth available. If an operator has access to the 2300 MHz as well as the 3.5 GHz band, the use of a 'wedding cake' Carrier Aggregation configuration will ensure that the size of the low band only coverage area is reduced further by the 2300 MHz layer whilst the 3.5GHz band can be utilised even more effectively, thus giving both superior speed and capacity performance.

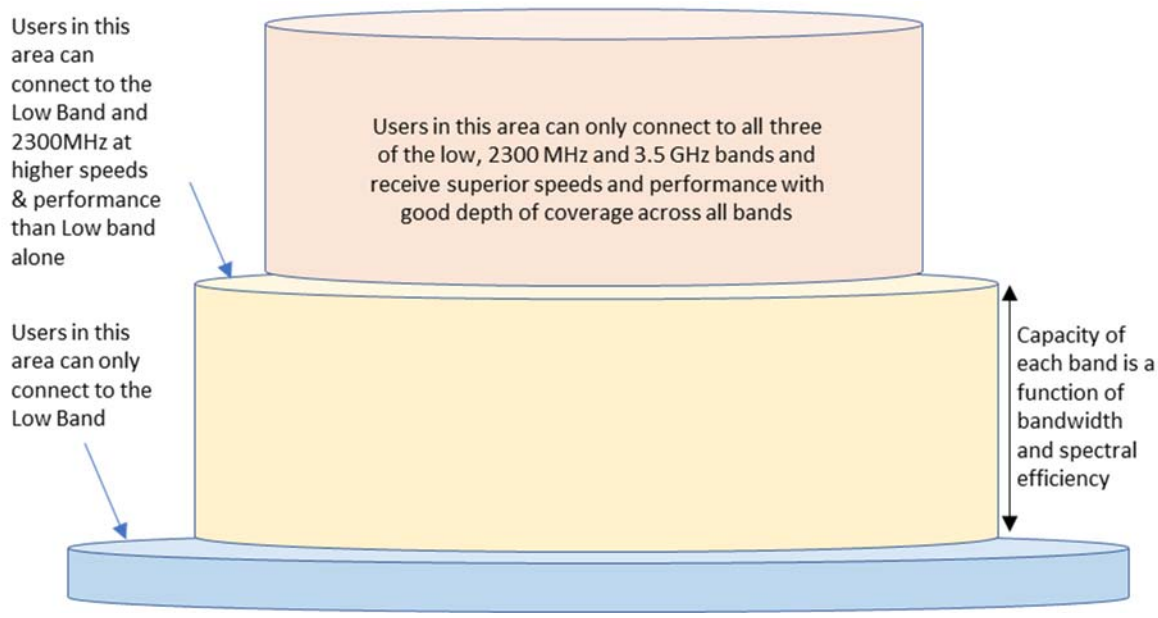

Figure 4: The 'wedding cake' configuration can deliver superior speeds and performance over wider spaced sites

Typical metropolitan networks in Australia consist of closely spaced inner city sites with Inter Site Distances (ISDs) of approximately 500m or less, inner metropolitan sites are usually more widely spaced with ISDs of 500m-1km, and outer metropolitan sites commonly have ISDs of 1km -5km.

[redacted]

The coverage /capacity outcomes described above would have little impact on inner city sites (except for some deeper indoor locations), minor to medium impacts on inner metropolitan (more so on indoor locations) and more material network impacts on outer metro sites which cover a much larger proportion of the metropolitan land mass (where the majority of the population lives, and hence greater relative importance).

The plot below extracted from the ACMA website[3] shows an approximation of the location of Telstra's towers and sites. This plot shows that Metro site densities align with the above network site spacing description.

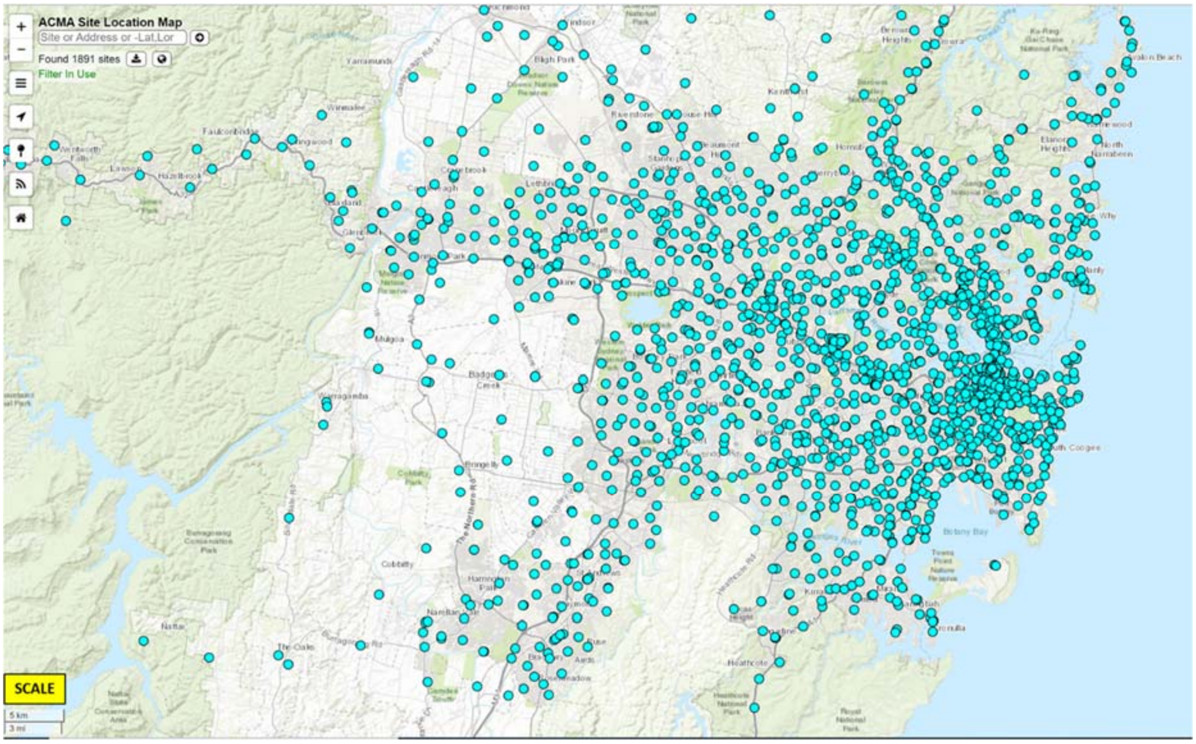

Figure 5: ACMA site location map filtered on 880MHz-890MHz Telstra 3G spectrum, note these sites do not necessarily use these specific bands in use but more typical of site distribution.

Observation 2: The implication of superior range and capacity characteristics of the 2300 MHz band in major metropolitan areas is that the range advantage allows the band to deliver superior network user performance when carrying mobile and FWA services compared to 3.5GHz. Operators without 2300 MHz spectrum would be required to make additional capital investment in additional sites to deliver the same capacity and performance across the broader outer metropolitan areas.

2.4 Spectrum Bandwidth at 2300 MHz

Channel bandwidth refers to the difference between the lowest and highest frequency used in a channel band.

The wider the channel bandwidth the greater the amount of capacity in the band and in the main this also equates to higher peak speeds.

[3] https://web.acma.gov.au/rrl/site_proximity.main_page

[redacted]

The ACMA website[4] displays mapped boundaries of spectrum licence areas. The figure below has been created by extracting information from that site for the 2300 MHz band. It shows the boundaries where Optus has access to the band which in the main covers all major metropolitan areas.

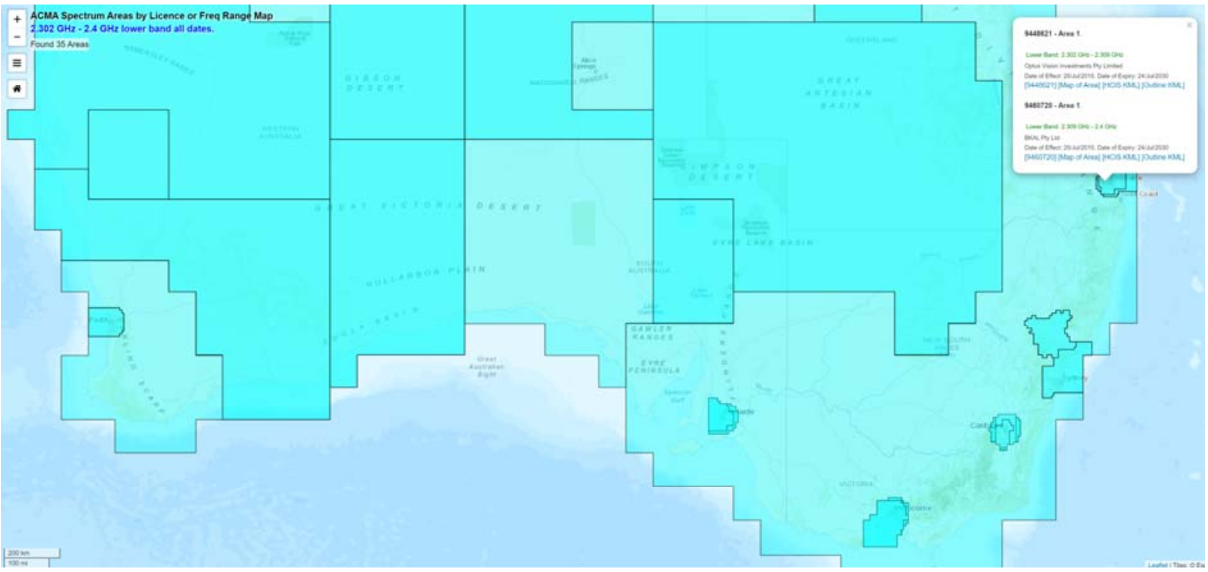

Figure 6: ACMA website image for 2300 MHz band boundaries

Based on this information Optus has access to the following spectrum bandwidths at 2300 MHz:

Melbourne	98 MHz
Sydney	98 MHz
Brisbane	98 MHz
Adelaide	98 MHz
Perth	98 MHz
Canberra	70 MHz

TPG Telecom does not have spectrum holdings in the 2300 MHz band. Telstra has 35-98 MHz of spectrum in the 2300 MHz in rural Australia.

2.4.1 Utilisation of the band

Typical modern hardware for 4G & 5G TDD can be configured in blocks of 10 MHz whilst 5G bandwidths less than 20 MHz can be configured using the Physical Resource Block (PRB) setting to blank out parts of the spectrum in use. In this way the allocations less than the full band such as 98 MHz could be utilised in various bandwidth combinations of 4G+5G.

The greater the total amount of spectrum bandwidth either in one band or over several 5G bands the greater the total network capacity is available. Further, by using techniques such as Carrier Aggregation, an operator can combine spectrums to achieve higher peak speeds and capacity.

[4] https://web.acma.gov.au/rrl/licence_area.map_by_frequency_range

[redacted]

Observation 3: Optus's current holding of 2300 MHz spectrum at between 70 and 98 MHz is greater in most capital cities than the existing 3.4-4 GHz band holdings of 5G spectrum of most operators, see ACCC Allocation limits advice August 2022[5] Table 3, page 14.

2.5 Spectrum boundaries and variations between current and proposed bands

As noted by the ACCC, the existing geographic asymmetries may result in different licences in two adjacent areas at the same frequency with implications for the effective licence area.

Taking into account that these boundaries are likely to be located away from the denser metropolitan areas where 5G coverage and capacity are likely to be in most demand, such boundaries are likely to have a somewhat limited impact.

Further, considering countries across much of the world operate with different spectrum ownership across country borders such as across Europe and Asia or across spectrum ownership boundaries as in the US (including the dynamic allocation of spectrum with CBRS), this is not an unknown nor unmanageable situation despite some of the complexity that arises.

2.6 Optus use of the 2300 MHz bandwidth and implications for network performance

The ACCC Infrastructure report[6] September 2022 table 4.1 extract below shows that at 31 January 2022 Optus had a larger number of metropolitan sites than the other operators at 5,294. The ACCC report provides a snapshot view as of 31 January 2022.

Table 4.1: Total number of sites by MNO & ABS Remoteness Area – Major Cities of Australia vs outside Major Cities of Australia – 2018 to 2022

	2018	2019	2020	2021	2022
Major Cities of Australia					
Optus	4,691	4,758	4,874	5,037	5,294
Telstra	4,736	4,800	5,059	5,166	5,257
TPG	4,207	4,268	4,306	4,503	4,337

The ACCC report also shows that Optus has so far deployed 2300 MHz at 3,701 sites using 4G and 988 sites using 5G.

As network traffic demand increases and as new generation hardware capable of supporting both 4G and 5G in the same radio becomes available it is likely that the 2300 MHz 5G site count will be further expanded.

This view is supported by RFNSA data supplied to me by TPG Telecom which shows the majority of Optus' 5G RAN configuration utilises both 2300 MHz and 3500 MHz spectrum.

- As at 7 Nov 2022, RFNSA shows the following stats for Optus' national 5G roll out using 2300 MHz and 3500 MHz:

[5] https://www.accc.gov.au/system/files/ACCC%20advice%20to%20ACMA%20on%20allocation%20limits%20for%203.4%20and%203.7%20GHz%20spectrum%20allocation.pdf

[6] https://www.accc.gov.au/regulated-infrastructure/telecommunications-and-internet/mobile-services-regulation/mobile-infrastructure-report/mobile-infrastructure-report-2022

[redacted]

Band	Existing site count	Proposed site count
2300 MHz + 3500 MHz	1437	1364
3500 MHz only	653	487
2300 MHz only	80	138

- A bar graph showing Optus' national 5G deployment trend over time sourced from RFNSA data collected periodically (last snapshot at 7 Nov 2022):

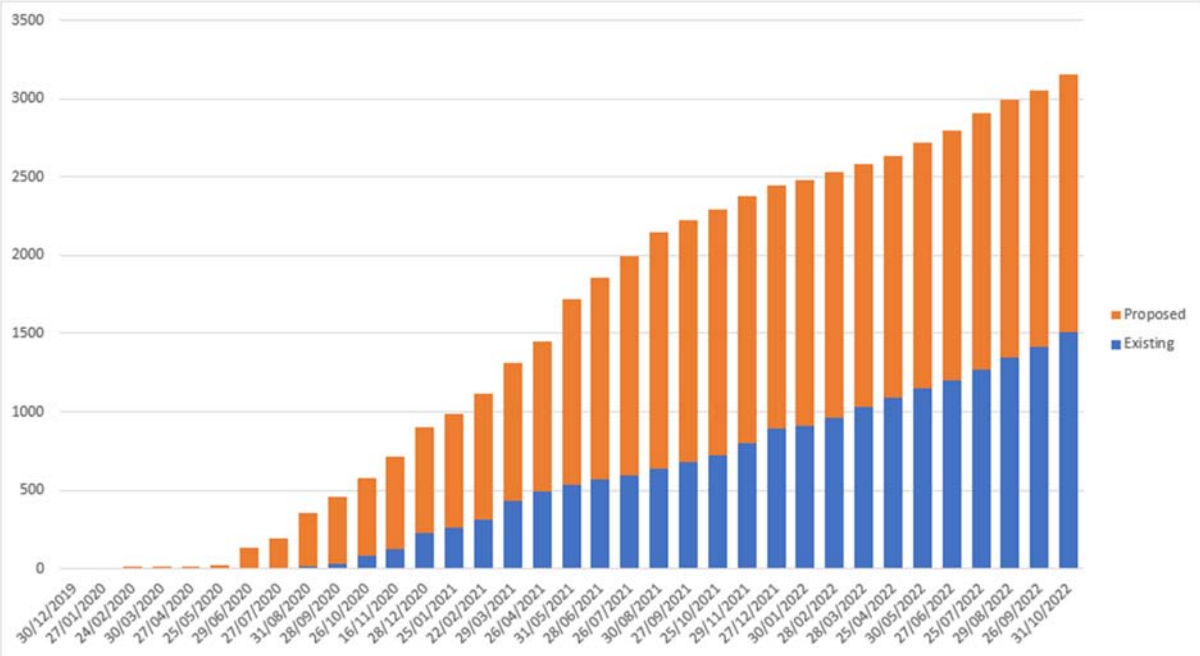

Figure 7: Table and graph showing extent of Optus 2.3GHz & 3.5GHz existing and proposed 5G sites derived from RFNSA

The 2.3 GHz and 3.5 GHz configuration would most likely allow the dual operation of both 4G and 5G without the level of total power demand required when running separate transmitters for each of 4G and 5G. An added advantage would be the ability to use software parameters to flex the percentage of spectrum allocated to each of 4G and 5G over time, ultimately utilising the majority or all of the spectrum for 5G at each site.

The following diagrams supplied by TPG Telecom show Optus is currently utilising this band in a large number of sites in NSW/ACT, Victoria, Queensland, South Australia and Western Australia.

[redacted]

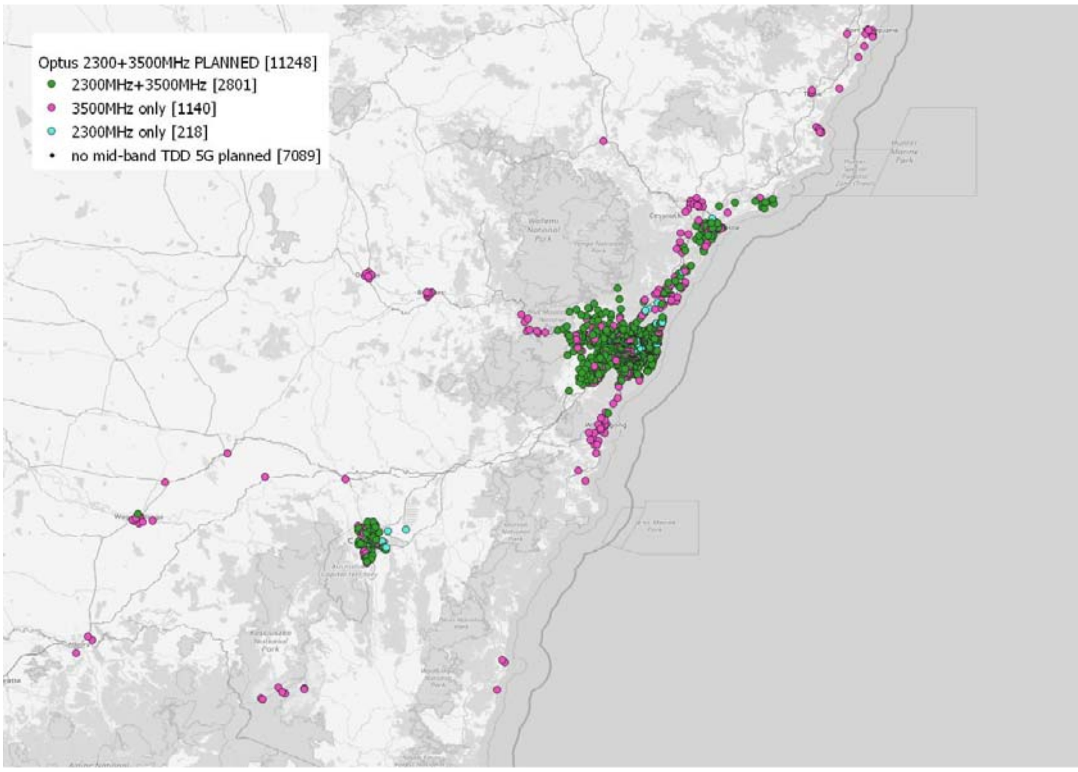

Figure 8: TPG Telecom plot of Optus 2.3 & 3.5 GHz sites in NSW/ACT

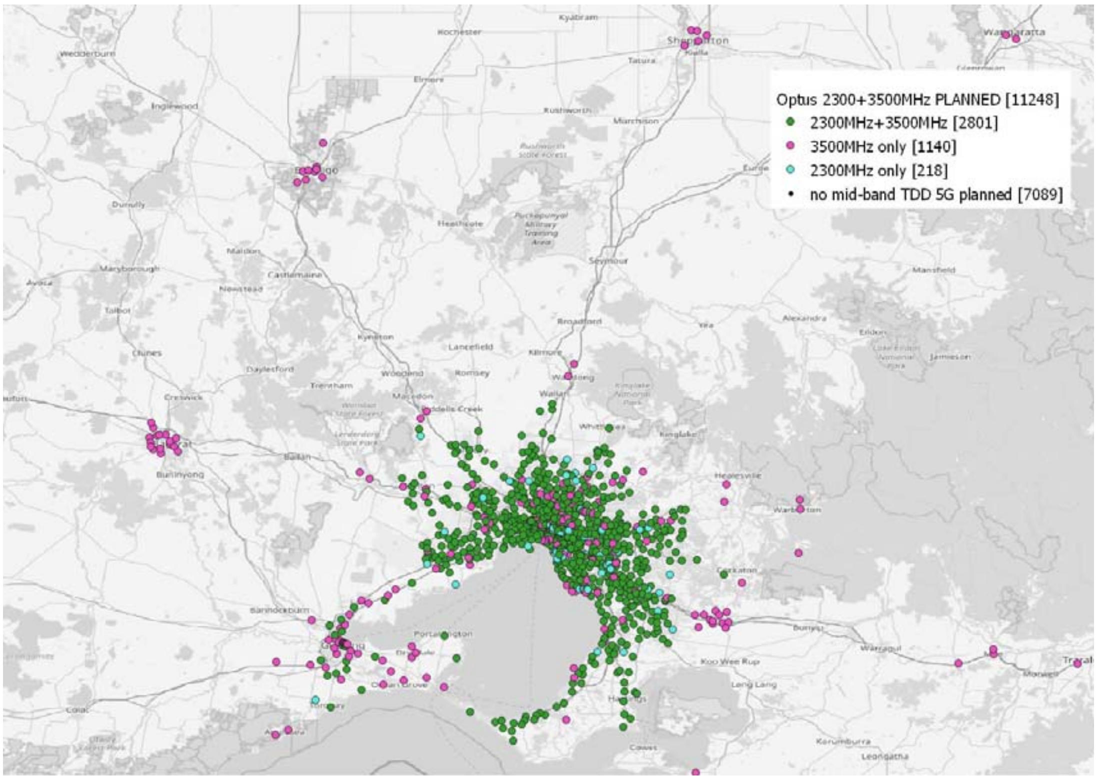

Figure 9: TPG Telecom plot of Optus 2.3 & 3.5 GHz sites in VIC

[redacted]

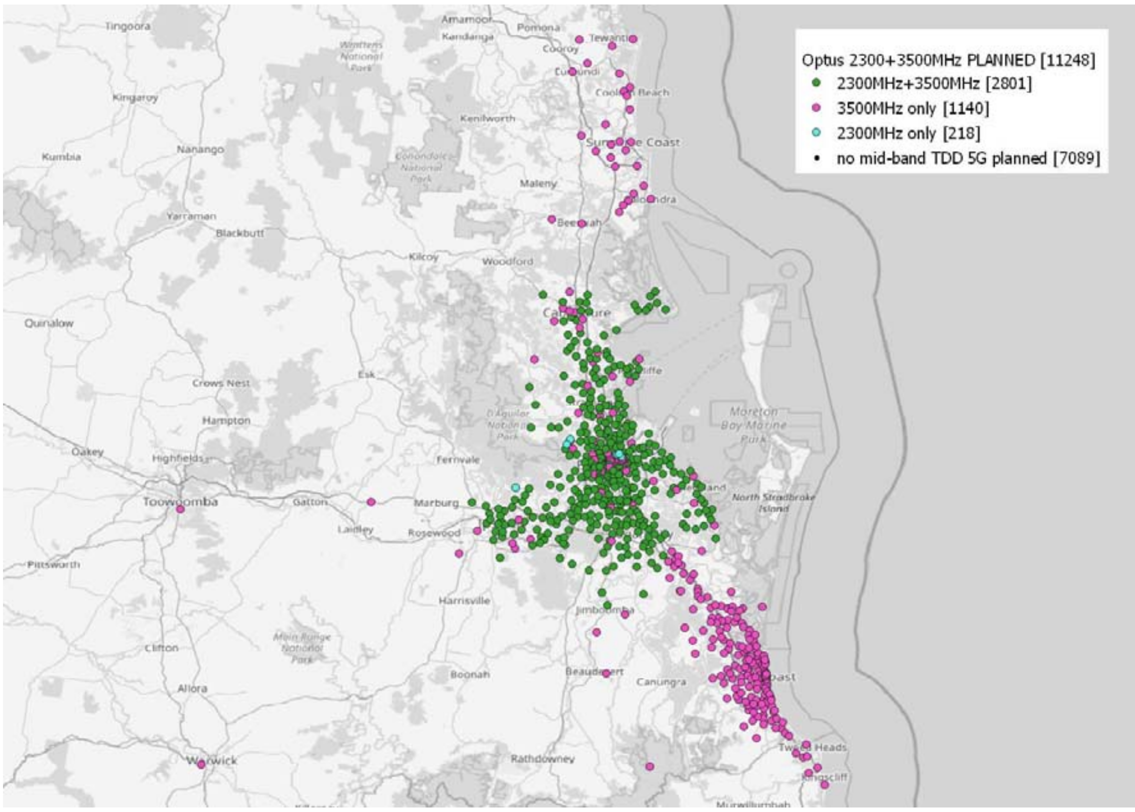

Figure 10: TPG Telecom plot of Optus 2.3 & 3.5 GHz sites in Queensland

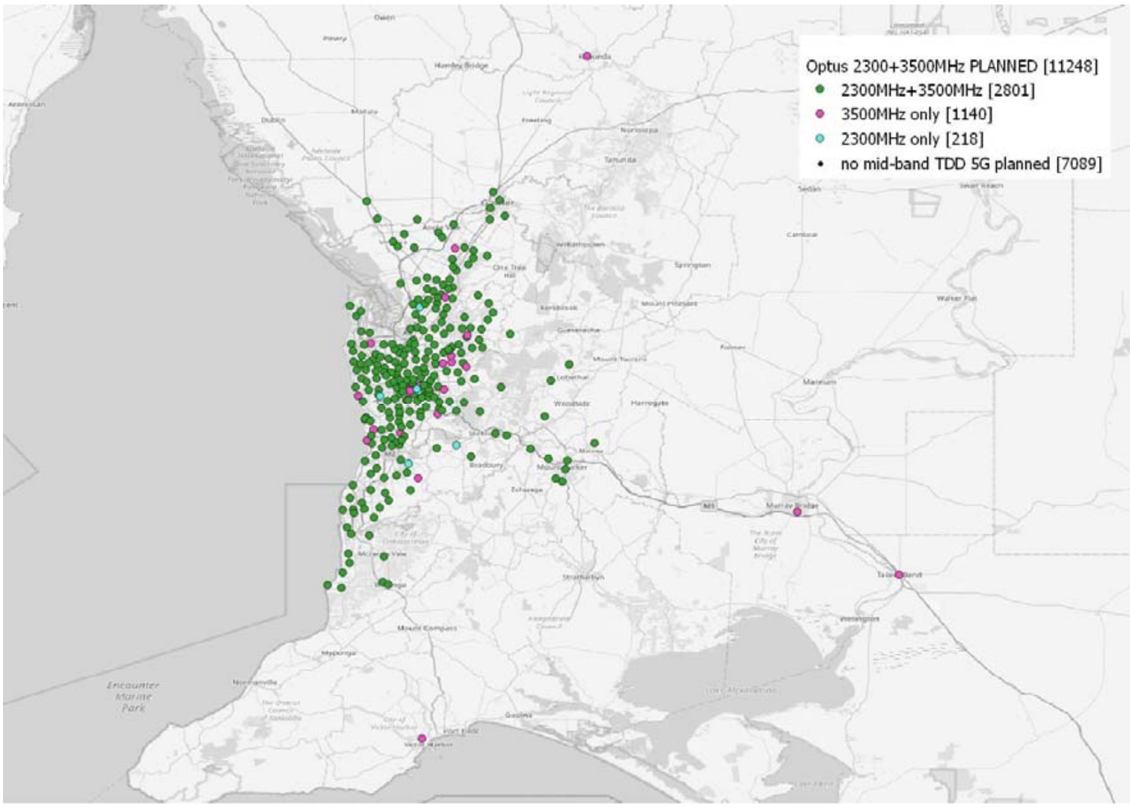

Figure 11 : TPG Telecom plot of Optus 2.3 & 3.5 GHz sites in South Australia

[redacted]

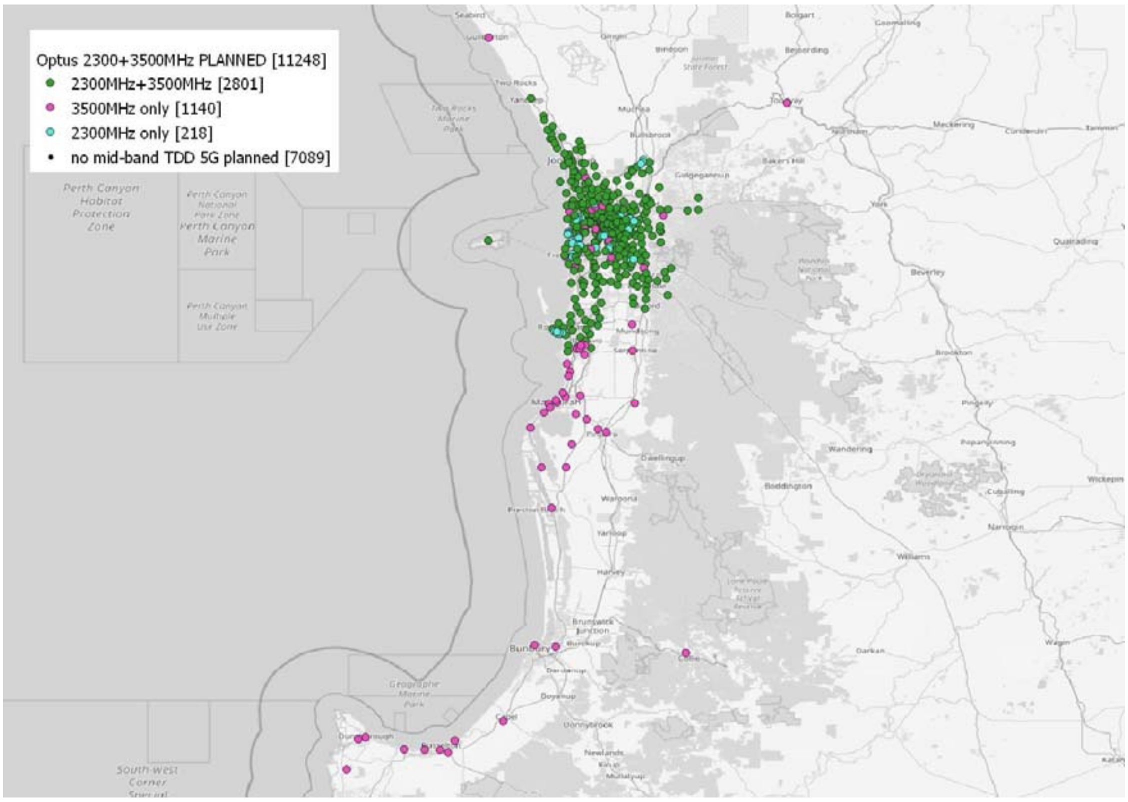

Figure 12: TPG Telecom plot of Optus 2.3 & 3.5 GHz sites in Western Australia

This 2300 MHz spectrum and available bandwidth can be used by Optus to create significant additional capacity and coverage depth at 5G as well as create a peak speed marketing advantage in these highly contested areas by using existing sites.

Public information shows that Optus is currently achieving superior peak speed outcomes using both spectrum and Carrier Aggregation.

> Moving from 2 to 3CC CA enables us to deliver higher speeds to our customers in more places as we are able to aggregate the coverage layers (FDD bands) with our capacity/speed layers [3500, 2300 MHz].
>
> *Optus VP networks Lambo Kanagaratnam, CommsDay, 3rd May 2022*

> **Optus wins the 5G Download Speed award for the third time in a row**
>
> Optus has continued its impressive winning streak for the average 5G download speeds observed by our users. It wins this time with a score of 240.5 Mbps and a lead of 8.1 Mbps over second placed Telstra's 232.3 Mbps. Vodafone is in last place with 122.1 Mbps. Optus first won the award outright in the October 2021 report, when it broke out of a statistical tie with Telstra, and has held onto it since then.

Open Signal[7] : Australia Mobile Network Experience Report October 2022

Observation 4: The band holdings and coverage performance of the 2300 MHz spectrum are already affording Optus peak speed and economic capacity advantages that can be readily expanded over time as more sites are deployed with 5G using this band.

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[7] https://www.opensignal.com/reports/2022/04/australia/mobile-network-experience

[redacted]

2.7 Performance differences between FDD and TDD channel configurations

2.7.1 Frequency Division Duplex

Frequency Division Duplex (FDD) describes the radio channel configuration where the band of frequencies utilised for transmission from the tower to the mobile (downlink) are different to the frequencies from the mobile to the tower (uplink). This configuration can operate in full duplex where both directions can transmit simultaneously.

Each of the downlink and uplink are separated by a frequency gap or guard band known as the duplex separation, this separation in the main protects transmit signals from leaking back into the receiver which must receive low signal levels from mobiles.

In general, FDD based mobile standards are aligned with lower total channel bandwidths, typically in increments of 5-20 MHz.

A disadvantage for FDD is that the separation of uplink and downlink channel frequencies also means that the radio path is different between the downlink and the uplink (no channel reciprocity). This makes some more sophisticated features such as massive MIMO more difficult to implement.

Lower orders of MIMO are typical in lower spectrum bands as the longer wavelengths make the very large antenna arrays for M-MIMO less practical, so most low-band FDD transmitters also use lower orders of MIMO (2x2, 4x4).

In my professional experience, I have noted that whilst some mid-band massive MIMO FDD systems have been developed there has been limited deployment, in part due to the requirement for specific 3GPP features in the devices.

2.7.2 Time Division Duplex

Time Division Duplex (TDD) describes the channel configuration where a single band of frequencies is used for both sending and receiving signals to and from the mobile.

In this configuration the transmit and receiving signal transmission must be separated in time, thus requiring an adjustment in the signal timing as the mobiles move further away from the tower.

Because the transmit and receive frequencies are in the same band this provides a reciprocal channel which can be used to enable enhanced M-MIMO features and beam forming.

TDD spectrum bands are typically in the mid and higher frequency bands and usually defined with much wider total channel bandwidths than FDD. The use of higher frequencies means that shorter wavelengths make larger scale MIMO antenna arrays more practical in terms of size for tower mounting.

2.7.3 Spectral efficiency

Spectral efficiency is a measure of how much data a radio transmission method can transmit in a specific amount of spectrum bandwidth, the greater the efficiency the more bits per second of data can be transmitted per Hz of spectrum used.

The more sophisticated M-MIMO system features and beamforming deliver step changes in spectral efficiency, in particular in the TDD mid and upper bands.

[redacted]

Typical values for expected spectral efficiency for each of the typical orders of MIMO used in FDD and TDD are referenced in documents by 5G Americas/ Rysavy[8] and Ofcom[9].

In summary:

- Low order of MIMO such as used in FDD typically deliver 1.2-3 bps/Hz
- Higher orders of M-MIMO such as used in TDD and mid band deliver 3-11bps/Hz
- Taking into account the amount of spectrum available in typical FDD and TDD scenarios combined with the difference in spectral efficiency shows that TDD in mid and higher bands is a vastly superior configuration for peak speed and capacity.

3 Standards alignment and support for the 2300 MHz band

3.1 Overview

This section considers the extent to which the 2300 MHz band has been included as a defined band for 5G use in both the 3GPP spectrum standards and associated feature roadmaps.

3.2 3GPP Inclusion of Band n40

The 2300 MHz band was previously defined as Band 40 for the LTE standard and has been added to the 3GPP Standard 3GPP TS 38.104 as n40. Table 5.2-1: NR *operating bands* in FR1 is inserted below.

NR operating band	Uplink (UL) operating band BS receive / UE transmit FUL,low – FUL,high	Downlink (DL) operating band BS transmit / UE receive FDL,low – FDL,high	Duplex mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
n13	777 MHz – 787 MHz	746 MHz – 756 MHz	FDD
n14	788 MHz – 798 MHz	758 MHz – 768 MHz	FDD
n18	815 MHz – 830 MHz	860 MHz – 875 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n247	1626.5 MHz – 1660.5 MHz	1525 MHz – 1559 MHz	FDD
n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
n26	814 MHz – 849 MHz	859 MHz – 894 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n29	N/A	717 MHz – 728 MHz	SDL
n30	2305 MHz – 2315 MHz	2350 MHz – 2360 MHz	FDD
n34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
n40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n46	5150 MHz – 5925 MHz	5150 MHz – 5925 MHz	TDD (NOTE 3)
n48	3550 MHz – 3700 MHz	3550 MHz – 3700 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n53	2483.5 MHz – 2495 MHz	2483.5 MHz – 2495 MHz	TDD
n65	1920 MHz – 2010 MHz	2110 MHz – 2200 MHz	FDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n67	N/A	738 MHz – 758 MHz	SDL
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	3300 MHz – 4200 MHz	3300 MHz – 4200 MHz	TDD
n78	3300 MHz – 3800 MHz	3300 MHz – 3800 MHz	TDD
n79	4400 MHz – 5000 MHz	4400 MHz – 5000 MHz	TDD
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL
n85	698 MHz – 716 MHz	728 MHz – 746 MHz	FDD
n86	1710 MHz – 1780 MHz	N/A	SUL

[8] https://www.5gamericas.org/wp-content/uploads/2019/09/Global-5G_Implications-of-a-Transformational-Technology_Reference-Presentation.pdf
[9] https://www.ofcom.org.uk/__data/assets/pdf_file/0017/232082/mobile-spectrum-demand-discussion-paper.pdf

[redacted]

n89	824 MHz – 849 MHz	N/A	SUL
n90	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n91	832 MHz – 862 MHz	1427 MHz – 1432 MHz	FDD (NOTE 2)
n92	832 MHz – 862 MHz	1432 MHz – 1517 MHz	FDD (NOTE 2)
n93	880 MHz – 915 MHz	1427 MHz – 1432 MHz	FDD (NOTE 2)
n94	880 MHz – 915 MHz	1432 MHz – 1517 MHz	FDD (NOTE 2)
n95 (NOTE 1)	2010 MHz – 2025 MHz	N/A	SUL
n96 (NOTE 4)	5925 MHz – 7125 MHz	5925 MHz – 7125 MHz	TDD (NOTE 3)
n975	2300 MHz – 2400 MHz	N/A	SUL
n985	1880 MHz – 1920 MHz	N/A	SUL
n996	1626.5 MHz -1660.5 MHz	N/A	SUL
n100	874.4 MHz – 880 MHz	919.4 MHz – 925 MHz	FDD
n101	1900 MHz – 1910 MHz	1900 MHz – 1910 MHz	TDD
n1024	5925 MHz – 6425 MHz	5925 MHz – 6425 MHz	TDD3
n1048	6425 MHz – 7125 MHz	6425 MHz – 7125 MHz	TDD

3.3 Additional 3GPP features supporting the 2300 MHz band

The 3GPP standards include the ability to combine carrier frequencies in a configuration known as Carrier Aggregation.

Over time the number of carriers that can been combined have been increasing. A more recent example has been outlined by a Nokia executive in CommsDay, a copy of that statement is included below.

> The 3GPP standard allows for up to five component carriers, and each increase is like stacking lanes of highways. The more stacked lanes you have the more throughput you can have and, given Optus's large spectrum holding at 3500, 2300 and 2100MHz, 3CC gives [Optus] a lot more throughput than 2CC.
>
> *Nokia Oceania CTO Dr Robert Joyce, CommsDay, 3rd May 2022*

Optus made early claims in relation to Carrier Aggregation with Ericsson via a press release[10] on 26 Aug 2020 claiming that "Optus demonstrates **world's first** 2300MHz + 3500MHz 5G Carrier Aggregation Call" including the following statement.

"5G Carrier Aggregation is a significant technology milestone that provides us with the ability to combine two spectrum frequencies to improve and extend the coverage, speed and capacity of our 5G network," said Lambo Kanagaratnam, Optus Managing Director Networks.

3.4 Evolution of the 2300 MHz band from 4G to 5G

According to a report "2300MHz spectrum, a key component of mid-band spectrum for 5G" in July 2020 by UK consulting firm Coleago[11], 2300 MHz spectrum is a key component of mid-band spectrum for 5G.

In their report, Coleago say the following:

"The 2300MHz band is attractive to operators because there is a 3GPP specification for TD-LTE (band 40) as well as 5G (band N40). As of June 2020, 2300MHz TD-LTE had been deployed in 39 countries by 61 operators and 5,827 devices including smartphones and routers are available. But what makes the 2300MHz band especially attractive is its role in the transition from 4G to 5G NR."

Observation 5: Based on the above, the 2300 MHz n40 band is an established 3GPP band for 5G and is being included in major 3GPP standards and vendor roadmaps.

[10] https://www.optus.com.au/about/media-centre/media-releases/2020/08/Optus-demonstrates-worlds-first-2300MHz-3500MHz-5G-Carrier-Aggregation-Call

[11] https://www.coleago.com/keynote-presentations-and-resources/

[redacted]

4 Vendor support for 5G RAN equipment in the 2300 MHz band

4.1 Overview

This section looks at the level of vendor support for 5G and the related 3GPP roadmap features in the 2300 MHz band. Only vendors providing traditional end-to-end RAN hardware are dealt with in this section, Open RAN is not considered.

4.2 5G RAN equipment vendor overview

The major providers of 5G RAN hardware worldwide include, Nokia, Ericsson, Samsung, Huawei and ZTE.

According to a report by Trendforce[12], the top three equipment manufacturers Huawei, Ericsson, and Nokia will account for 74.5% of the global base station market in 2022.

The two main suppliers in Australia for 5G hardware are Nokia and Ericsson and as shown in the following section, each of these suppliers already supply RAN equipment which supports the 2300 MHz band for 5G.

Further, according to an Optus Press Release[13] in March 2017, Huawei was already capable of supporting 5G in the 2300 MHz band.

4.3 Vendors supporting 2300 MHz 5G RAN in Australia

Optus is currently operating 5G in the 2300 MHz band in Australia as shown on the RFNSA website and is using hardware from both Ericsson and Nokia as recorded on the ACMA Site Location Map.[14]

Examples of the registration of each type of hardware below show that Nokia AENB model and Ericsson model AIR3239 are in use for 5G at 2300 MHz.

Also refer to Section 2.6, figures 7-12 for RFNSA record summaries of number and location of existing and proposed sites using 2300 MHz 5G.

4.3.1 Nokia AENB

4.3.1.1 Example Brisbane: ACMA Site ID 198371

498 Waterworks Rd ASHGROVE QLD 4060

According to RFNSA[15] Optus operates 4G and 5G in the 2300MHz band from this site labelled 4060001.

[12] https://www.trendforce.com/presscenter/news/20220801-11324.html
[13] https://www.optus.com.au/about/media-centre/media-releases/2017/03/optus-and-huawei-take-another-step-towards-5g
[14] https://web.acma.gov.au/rrl/site_proximity.main_page
[15] https://www.rfnsa.com.au/4060001

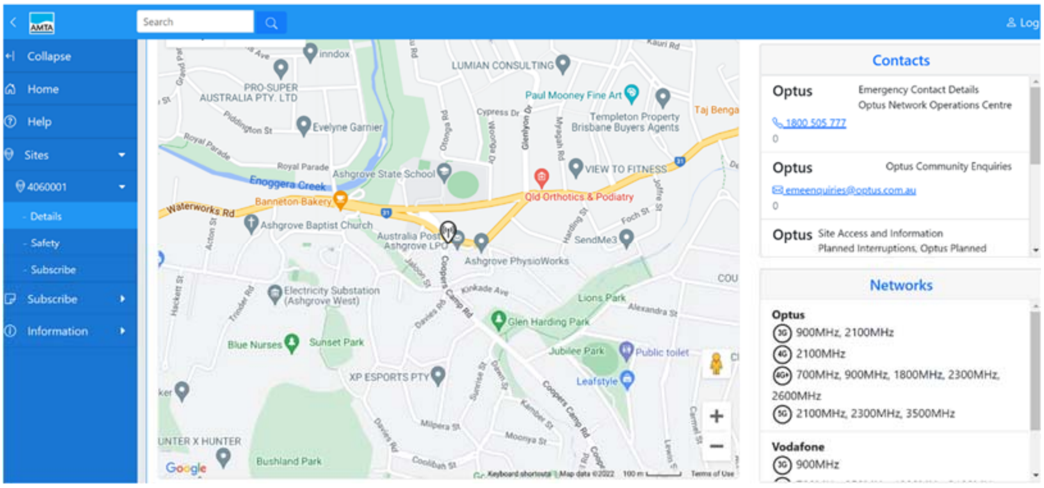


Figure 13: RFNSA Map of site and technologies used

According to the ACMA site location map this site has the following transmitter licenced at a bearing of 300 degrees (other bearings are also recorded).

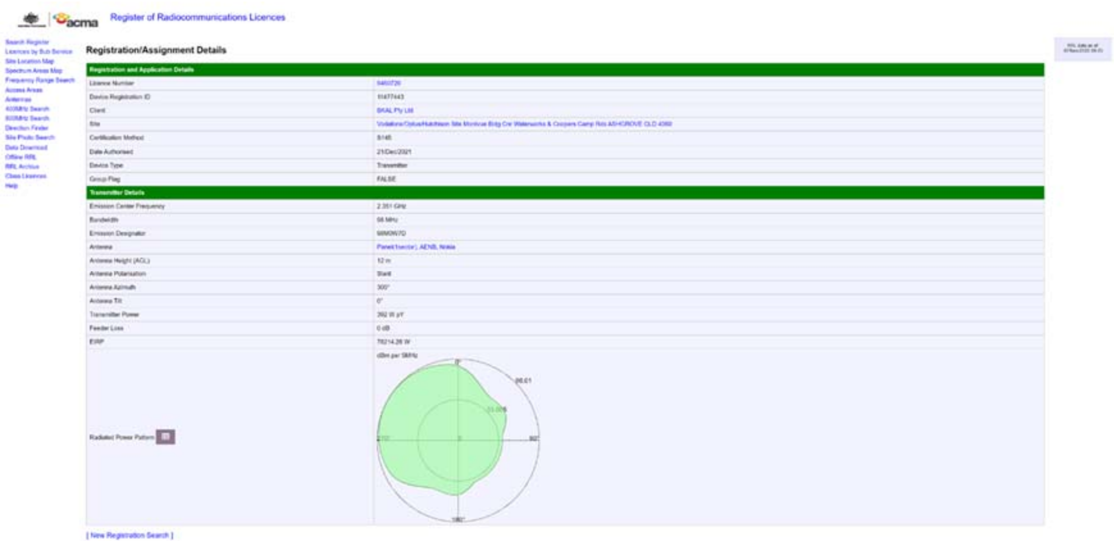


Figure 14: Image from ACMA site registration showing Nokia AENB radio hardware licenced at 300-degree sector bearing on 21 Dec 2021

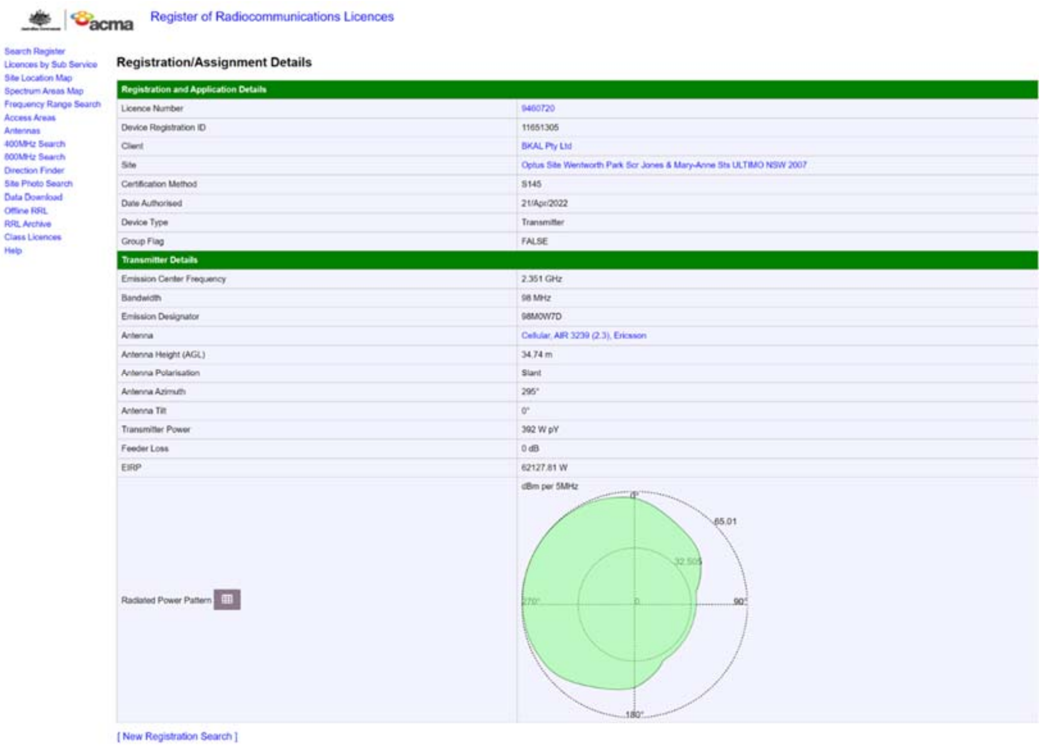
4.3.2 Ericsson AIR3239

4.3.2.1 Example Sydney : Site ID 134993

Optus Site Wentworth Park Scr Jones & Mary-Anne Sts SYDNEY

According to the ACMA site location map this site has the following transmitter allocations at the bearing of 295 degrees (other bearings are also recorded).

[redacted]



Register of Radiocommunications Licences

Search Register
Licences by Sub Service
Site Location Map
Spectrum Areas Map
Frequency Range Search
Access Areas
Antennas
400MHz Search
800MHz Search
Direction Finder
Site Photo Search
Data Download
Offline RRL
RRL Archive
Class Licences
Help

Registration/Assignment Details

Registration and Application Details	
Licence Number	9460720
Device Registration ID	11651305
Client	BKAL Pty Ltd
Site	Optus Site Wentworth Park Scr Jones & Mary-Anne Sts ULTIMO NSW 2007
Certification Method	S145
Date Authorised	21/Apr/2022
Device Type	Transmitter
Group Flag	FALSE
Transmitter Details	
Emission Center Frequency	2.351 GHz
Bandwidth	98 MHz
Emission Designator	98M0W7D
Antenna	Cellular, AIR 3239 (2.3), Ericsson
Antenna Height (AGL)	34.74 m
Antenna Polarisation	Slant
Antenna Azimuth	295°
Antenna Tilt	0°
Transmitter Power	392 W pY
Feeder Loss	0 dB
EIRP	62127.81 W
Radiated Power Pattern	dBm per 5MHz

[New Registration Search]

Figure 15: Image from ACMA site registration showing Ericsson AIR3239 radio hardware licenced at 295-degree sector bearing on 21 Apr 2021

Observation 6: The 2300 MHz band is already supported with RAN equipment from at least the top 3 vendors in the world representing over 74% of the global base station market and 5G hardware from both Nokia and Ericsson is already operational in the Optus network. These factors indicate that 2300 MHz is an established 5G band for the RAN vendor market.

5 Chipset and device support for 5G in the 2300 MHz band

5.1 Overview

This section looks at the level of device ecosystem support for 2300 MHz that would enable the widespread availability of 5G devices such as smartphones, tablets, modems and other types of connected things.

This includes reviewing the availability of 5G chipsets that support the 2300 MHz band as these are a key component required by device vendors to develop 5G devices.

5.2 Chipset support for 5G in the 2300 MHz band

Chipset suppliers design the underlying 5G radio technologies in accordance with the 3GPP standards and have these fabricated in silicon.

Some of the key chipset suppliers to phone OEMs include Qualcomm, MediaTek, Samsung (Exynos), HiSilicon (Huawei).

The majority of chips supplied for 5G to the major handset manufacturers Apple and Samsung have to date been a combination of Qualcomm and Exynos.

5.2.1 Qualcomm:

Qualcomm releases yearly models of chipsets for devices such as smartphones. The first chipset to support 5G was the X50 followed by X55, X60 and the upcoming X70 is expected in devices from

[redacted]

2023. All of these chipsets support the 5G n40 band and each iteration has progressively added features such as carrier aggregation for more carriers and carrier combinations of FDD and TDD as well as Stand Alone (SA) support.

Qualcomm has been the 5G chip used in Apple devices since 2020.

Qualcomm is also used in some markets of the world in Samsung devices. Samsung uses chipsets from both Exynos and Qualcomm by geography.

Qualcomm chipsets are expected to be used uniquely in the Galaxy 23[16] models in 2023.

5.2.2 Samsung (Exynos)

Exynos is a division of Samsung that develops Large-Scale Integration (LSI) chips. Exynos chips are used by Samsung in a range of their own brand device models in various geographies of the world. Samsung also uses Qualcomm chips in some geographies. Like Qualcomm the Exynos chipset ranges have progressively supported 5G in the n40 2300 MHz band and iterated support for added features over recent years.

5.2.3 MediaTek

MediaTek design chipset for a variety of electronic goods including smartphones. MediaTek tend to follow the other mainstream chipsets into the market by a number of years and is used in smartphones, gateways, tablets.

MediaTek have recently announced[17] a new model chipset for 5G use.

5.3 Device support for 5G in the 2300 MHz band

5.3.1 Overview

The rate of availability of 5G enabled devices has grown rapidly since the launch of the first 5G networks around 2019/2020.

The Global Suppliers Association (GSA) 5G-Ecosystem October 2022 Member Report[18] indicates that there were 1,227 commercially available 5G devices as of September 2022 across 202 manufacturers and 24 form factors.

The form factors available include smartphones, wireless gateways, FWA and IoT based devices. The majority however will comprise smartphones from the world's largest suppliers.

5.3.2 Market share of devices in Australia by brand

The website GlobalStats[19] shows the market share per mobile brand in Australia over 2021/2022.

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16 https://www.gsmarena.com/qualcomm_confirms_samsung_galaxy_s23_series_will_use_snapdragon_chipsets_globally_-news-56405.php

17 https://www.gsmarena.com/qualcomm_confirms_samsung_galaxy_s23_series_will_use_snapdragon_chipsets_globally_-news-56405.php

18 https://gsacom.com/technology/5g/

19 https://gs.statcounter.com/vendor-market-share/mobile/australia

[redacted]

Figure 16: Image from Globalstats site showing relative market share of device vendors

From Figure 16 above it is clear that just two device manufacturers control over 85% of market share for smartphones in Australia. In many respects if these devices support a feature or band, it reflects the market in Australia.

5.3.3 Support for 2300MHz in commercial handsets

A Subset of typical models for the two most popular brands sourced from their websites is shown in the tables below.

iPhone Standard Models[20,21]

Model/year	Model ID	Band 40 LTE	Band n40 5G
iPhone 14/2022	A2649, A2632	Yes	Yes
iPhone 13/2021	A2481, A2482	Yes	Yes
iPhone 12/2020	A2172	Yes	Yes
iPhone 11/2019	A2111	Yes	No

Samsung S20 5G models[22]

Model/year	Model ID	Band 40 LTE	Band n40 5G
S22/2022	S22, S22+, Ultra	Yes	Yes
S21/2021	Ultra5G, 5G, +5G, FE 5G	Yes	Yes

[20] https://support.apple.com/kb/SP873?viewlocale=en_AU&locale=en_AU
[21] https://www.apple.com/au/iphone/cellular/
[22] https://www.samsung.com/au/smartphones/galaxy-s22/specs/

S20/2020	Ultra5G, 5G, +5G, FE 5G	Yes	Yes
S10/2019	S10, S10E, S10+	Yes	Some models

Additional model smartphones such as the OPPO Find X5 Pro, Google Pixel7, Pixel 6 are recorded online to support 5G the n40 band (2300 MHz).

With the top two smartphone brands in Australia representing over 85% of the market share supporting 5G in band n40 (2300 Mhz) for the past 3 years it is probable that the majority of all existing Australian 5G enabled devices also support the n40 band.

This analysis is supported by the statistics provided by TPG Telecom which shows that of over [C-I-C begins] [redacted]
[C-I-C ends] i.e. Over 91% of all 5G handsets on the TPG Telecom network are 2300 MHz capable, there is no reason to believe that this ratio varies greatly across other operators.

It should be noted that some device vendors might support a band or a network feature in certain models but will not enable it in their devices until they are satisfied that the features and related performance on each network operator will deliver a high level of user experience.

Whilst this might delay or prevent availability for some device models, it does not prevent the widespread deployment of these capabilities over time. [C-I-C begins]

[redacted]

[C-I-C ends] *Figure 17: TPG Telecom provided table showing number of 5G n40 and n78 capable handsets on their network*

Observation 7: The information available indicates that there is widespread support for 5G in the 2300 MHz band across the majority of 5G devices on networks in Australia.

6 Current and future maturity of the 2300 MHz 5G ecosystem

This report has shown there is support and availability for the 2300 MHz 5G n40 band across 3GPP standards, Network RAN vendors, chipset and handsets.

When considering the overall maturity of the 2300 MHz ecosystem it is useful to take into account the worldwide support and implementation of the band as this will have some influence on the extent to which network and device vendors maintain the latest roadmaps and support for the band.

[redacted]

As outlined in the in the July 2020 Coleago[23] consulting report into the 2300 MHz band:

- "As of June 2020, 2300MHz TD-LTE had been deployed in 39 countries by 61 operators and 5,827 devices including smartphones and routers are available." Meaning there was already a broad base of 4G use of the 2300 MHz band for LTE; and

And a number of operators were already pushing into 5G use of this band.

- "The commercial deployment of 5G in 2300MHz already started in Australia with Optus, and TDC Denmark and STC Saudi Arabia have started N40 trials." Meaning that a number of operators across the world were already pushing into 5G use of this band.

The momentum created by these operators and information in this report shows that important standards-based roadmap features are being supported by network, chipset and handset vendors.

Looking ahead there is ongoing activity in the market with the first of the devices and networks are already evolving from 5G-NSA configurations to 5G-SA (Stand Alone).

The 3GPP continues to add new bands and feature support including more support for lower FDD bands and wider bandwidth support.

As this evolves to encompass the lower bands such as the larger 900 MHz bandwidths now held by Optus there is potential for wider and deeper deployment of 5G, likely in the SA configuration over time.

Optus now has access to spectrum capable of creating a powerful 'wedding cake' architecture using a SA combination of 900 MHz carrier aggregated with 2300 MHz and 3.5 GHz band(s) in the key and most populated metropolitan markets.

7 Comments and conclusions

From the analysis above the following comments are provided in relation to each of the key ACCC points highlighted in the introduction.

a. The ACCC considers that holdings in the 3.4, 3.6 and 3.7 GHz bands are substitutable due to their similar technical characteristics and device availability, as well as international harmonisation of the wider band.

   I agree, these bands offer similar coverage and bandwidth for network use as well as standards support and device availability as each other.

b. Other potentially relevant spectrum bands canvassed in our consultation paper included other mid-band spectrum, and 2.3 GHz band spectrum in particular. We do not consider 1800 MHz, 2100 MHz, and 2.6 GHz band spectrum substitutable because they do not offer the same large bandwidths available as 3.4-3.8 GHz spectrum.

   I agree in relation to the 1800 MHz, 2100 MHz, and 2.6 GHz band spectrum with respect to not having as large bandwidths available. Further, other considerations such as those outlined in section 2.7 show that Frequency Division Duplex (FDD) configuration of these spectrum bands limits capacity and performance compared to other TDD band configurations.

[23] https://www.coleago.com/app/uploads/2020/09/2300MHz-spectrum-for-5G-30-July-2020.pdf

[redacted]

c. The 2.3 GHz band has similar propagation characteristics, vendor availability and technical frameworks as the 3.4–3.8 GHz band.

   I agree, however the propagation range of 2300 MHz is superior to the 3.4-3.8 GHz bands and therefore leads to a number of other advantages in terms of coverage range, depth and capacity per unit of spectrum.

d. However, the 5G equipment ecosystem is not as developed for 2.3 GHz as it is for the 3.4–3.8 GHz band.

   I disagree, facts in the sections above in relation to 3GPP standards and roadmap support, RAN vendor hardware and roadmap support, chipset and device support for 2300 MHz makes this band's ecosystem support about the same as the 3.4-3.8 GHz band for 5G.

e. Additionally, due to existing geographic asymmetries of holdings, including 2300 MHz as substitutable in this allocation may prevent affected operators from acquiring geographically contiguous spectrum in the 3.4 and 3.7 GHz bands. Where there are different licensees in two adjacent areas at the same frequency, the effective licence area may be smaller due to coordination.

   I agree on the statement in general, but I do not agree that this is necessarily a material impact nor one that cannot be mitigated to a large extent, in particular given the implications of excluding a material and impactful bandwidth of 2300 MHz TDD spectrum from consideration in the ACCC's recommendations.

7.1 Conclusions

Given the ACCC determined that allocation limits are required on page 3 of the Allocation Limits Advice[24] , it is incongruous that the ACCC would then exclude the 2300 MHz TDD spectrum in that same consideration.

Given the level of maturity of the 2300 MHz 5G ecosystem shown in this report, it appears that the ACCC are working on outdated or flawed assumptions about the 2300 MHz TDD band, particularly given the quantum of coverage, speed and capacity that can be delivered using the existing 2300 MHz spectrum.

On this basis, the ACCC's own allocations limit objectives will be ineffective in this instance if its advice to the ACMA were to be adopted.

[24] https://www.accc.gov.au/system/files/ACCC%20advice%20to%20ACMA%20on%20allocation%20limits%20for%203.4%20and%203.7%20GHz%20spectrum%20allocation.pdf

[redacted]