IMT spectrum demand

Estimating the mid-band spectrum needs in the 2025-2030 time frame in Australia

A report by

Coleago Consulting Ltd

15 November, 2021

coleagoconsulting

Content

coleagoconsulting

Exhibits

Contact

Stefan Zehle, MBA
CEO,
Coleago Consulting Ltd

Tel: +44 7974 356 258
stefan.zehle@coleago.com

David Tanner, MA (Hons), MSc, MIET, CEng
Managing Consultant,
Coleago Consulting Ltd

Tel: +44 7976 415250
david.tanner@coleago.com

coleagoconsulting

1 Executive summary

Introduction

This report should be read in conjunction with the report "Estimating the mid-band spectrum needs in the 2025-2030 time frame, Global outlook", which contains a detailed description of the methodology used as well as evidence to support assumptions made.

The Australian Mobile Telecommunications Association (AMTA) seeks to quantify demand for mid-band IMT spectrum in Australia.

In July 2021, the GSMA published the report "Estimating the mid-band spectrum needs in the 2025-2030 time frame, Global outlook" (Global Report). The Global Report describes the methodology and provides estimates based on population density in 36 cities around the world, none of which are in Australia. This report is an extension of the Global Report with a focus on Australia. This report should be read in conjunction with the Global Report which contains a detailed description of the methodology as well as evidence to support it and the assumptions made.

The mid-band spectrum demand methodology is based on the need to deliver the requirements of 5G in an urban environment with significant population densities. Coleago carried out a population density analysis of Sydney, Melbourne and Brisbane all of which have a sizeable densely populated area.

Secondly, mid-band spectrum used to deliver 5G FWA is a highly cost effective means to deliver 100 Mbit/s broadband to small towns and villages. The cost per connected home for Australia can be up to 66% lower compared to FTTP.

Global analysis of the need for mid-band spectrum

The vision for 5G is to provide ubiquitous high-speed wireless mobile connectivity to support several use-cases: "*IMT-2020 is expected to provide a user experience matching, as far as possible, that of fixed networks*"[1]. The need for IMT spectrum is driven by the requirements for 5G as set out in the ITU-R requirements for IMT-2020[2].

5G must deliver a near guaranteed user experienced mobile data rate of 100 Mbit/s in the downlink and 50 Mbit/s in the uplink and accommodate 1 million connections per km^2. This poses a huge challenge in cities with a high traffic density. The Global Report focuses on cities with population densities of more than 8,000 per km^2. In these cities, 1,020 to 3,690 MHz of mid-band spectrum is needed to deliver the 5G vision in an economically feasible manner. The wide range of estimates reflects the different population densities of the cities analysed and the 5G traffic demand in the 2025-2030 time frame. The higher the population density and the more advanced an economy is, the greater the demand for mid-band spectrum.

The mid-band spectrum needs for city-wide speed coverage in Australia

Of all Australian cities, Sydney, Melbourne and Brisbane have the highest population densities over a relatively large area. Compared to the cities analysed in the Global report, population densities in those three cities are at the lower end of the scale, but still sufficiently high to require significant amounts of mid-band spectrum beyond that which is currently available.

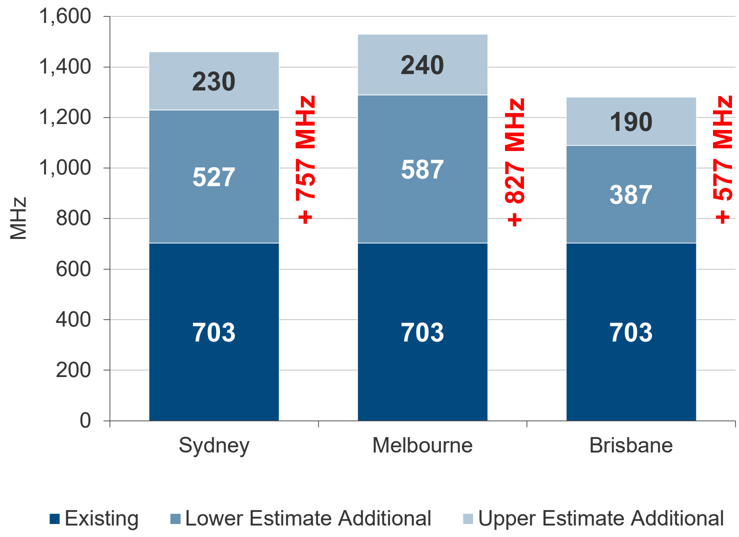
Our analysis shows that in Sydney there is a need for 1,230 to 1,440 MHz of mid-band spectrum compared to 703 MHz currently assigned to operators. Therefore, to deliver the city-wide 5G user experience in an economically and technically feasible manner in the 2025-2030 timeframe, an additional 527 to 757 MHz of mid-band spectrum is required.

For Melbourne an additional 587 to 827 MHz is needed and for Brisbane it is an additional 387 to 577 MHz.

[1] Report ITU-R M.2441-0 (11/2018), "Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT)"

[2] Report ITU-R M.2441-0 (11/2018), "Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT)" and Report ITU-R M.2410, "Minimum requirements related to technical performance for IMT-2020 radio interface(s)"

Exhibit 1: Mid-band spectrum requirement for Australian cities



Source: Coleago

These estimates for mid-band spectrum requirements have been made using the same methodology as for the Global Report. There are indications that the spectrum need and the benefit from additional mid-band spectrum is higher in Australia:

- Offload to mmWave in Australian cities is more likely to generally be less (5 % or under and only around 10-15% in very localised, high traffic areas such as stadiums, ferry terminals, train stations or public malls).
- In Australia the highest proportion of heavily loaded sites are in suburban residential areas which is not the case in European and Asian cities. Having additional mid-band spectrum would help to reduce the need for densification in Australian suburbs.
- Australia faces challenges around deployment. Given the trade-off between adequate spectrum and the need to deploy additional small cells to achieve the same performance, there is a strong preference for more spectrum as deploying that many cells across suburban environments is costly and impracticable given the regulatory constraints on deployment in Australia, particularly at local and State Government level.

If additional mid-band spectrum is not made available, this would require extreme cell site densification. For example, for Sydney 138 additional outdoor small cells per km^2 are required to deliver the same capacity as an additional 757 MHz. Considering the urban area of 110.3 km^2, 15,221 additional small cells would be needed for Sydney alone. This is unlikely to be feasible from an economic perspective and may not be feasible from a technical perspective due to the interference problem from the resulting extremely small inter-site distances.

The benefit of additional mid-band spectrum for 5G FWA

The cost of bringing 100 Mbit/s broadband connectivity to premises in rural small towns in Australia using Fibre to the Premises is substantial. Additional spectrum would deliver savings of to 66% in fulfilling Australia's rural connectivity goals, enable faster and scalable deployment, and ensure that 5G FWA is a long-term solution for small town broadband needs.

2 Spectrum need modelling approach and methodology

2.1 Spectrum to deliver the 5G vision

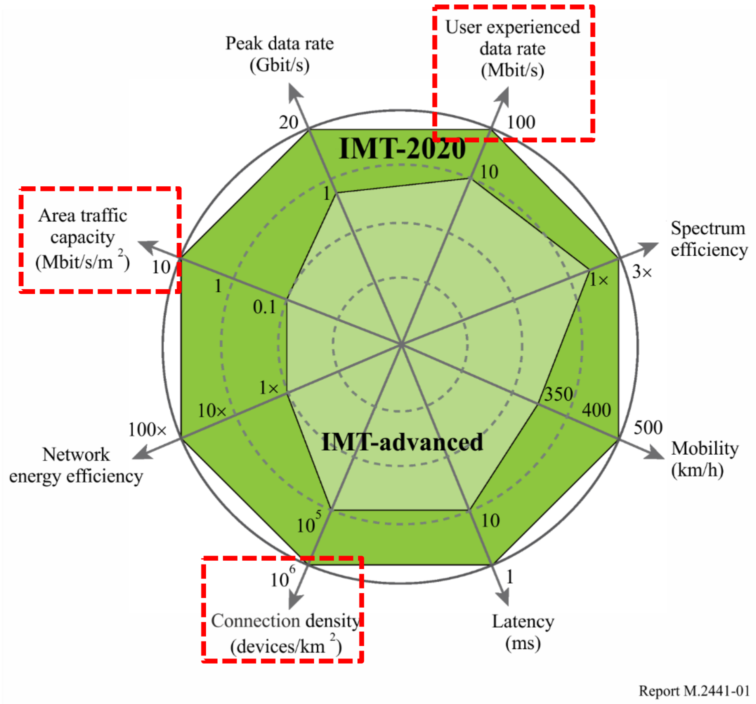
One of the pillars in the vision for 5G is to provide ubiquitous high-speed wireless connectivity to mobile and fixed users: "*IMT-2020 is expected to provide a user experience matching, as far as possible, that of fixed networks*"[3]. The need for IMT spectrum is driven by the requirements for 5G as set out in the ITU-R requirements for IMT-2020[4].

5G requirements focus on area traffic capacity, near guaranteed data rates, low latency and reliability, and this drives the need for spectrum.

Exhibit 2 shows the IMT-2020 (5G) requirements compared to LTE Advanced (LTE-A). The requirements are not just to deliver an incremental percentage improvement, but an improvement that amounts to a multiplier effect, i.e. a revolution rather than an evolution in its impact. In assessing the need for additional IMT spectrum we are focusing on three of these new 5G requirements:

- The user experienced data rate jumps from 10 Mbit/s to 100 Mbit/s - a factor of 10 increase;
- Area traffic capacity moves from 0.1 Mbit/s/m^2 to 10 Mbit/s/m^2 – a 100-fold increase; and
- The connection density increases 10-fold to 10 million devices per km^2.

Exhibit 2: IMT 2020 requirements



Source: Report ITU-R M.2441-0 (11/2018)

[3] Report ITU-R M.2441-0 (11/2018), "Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT)"

[4] Report ITU-R M.2441-0 (11/2018), "Emerging usage of the terrestrial component of International Mobile Telecommunication (IMT)" and Report ITU-R M.2410, "Minimum requirements related to technical performance for IMT-2020 radio interface(s)"

Radio frequencies are the key ingredient to deliver these requirements. Therefore, there is also a step change in the need for IMT spectrum. Clearly, improved spectral efficiency associated with higher orders of MIMO, the 5G radio interface and densification will enable mobile operators to squeeze more capacity out of existing spectrum resources, but this is not remotely sufficient to deliver the capacity requirements of 5G in a dense urban environment.

2.2 Low, mid, and high frequency bands

Spectrum in the range of 450 MHz to 50 GHz is used today for IMT and band plans exist in many frequency ranges. Depending on the frequency range and the amount of spectrum in the range, different frequency bands serve different purposes and cannot, therefore, be used as substitutes for each other. Therefore, we need to assess the demand for additional IMT spectrum depending on the frequency range. The large number of frequency bands can be categorised into four groups: sub-1 GHz, lower mid-bands, upper mid-bands, and high bands.

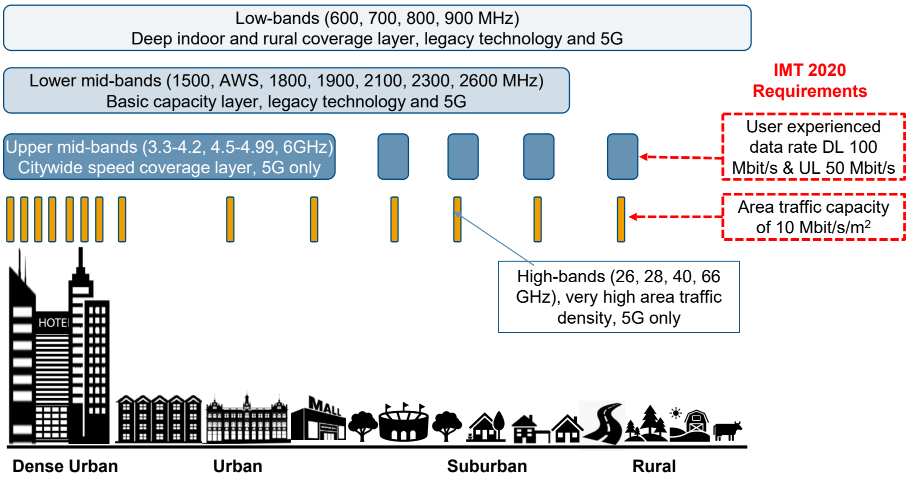
- Low bands (e.g. 600, 700, 800, 900 MHz) are effective at addressing very wide area coverage and deep indoor coverage given their good propagation characteristics. However, there is little spectrum available and hence the channel bandwidth does not provide much capacity.
- Lower mid-bands (e.g. 1500, AWS,[5] 1800, 1900, 2100, 2300, 2600 MHz) are already used for IMT for 2G, 3G, 4G and 5G. The lower mid-bands have been the capacity layer for 4G data traffic and in most countries the spectrum is used in FDD mode. China and the US are notable exceptions to this, with extensive 5G deployments in the 2600 MHz band with a TDD band plan. The use of this band for 5G will certainly grow over time.
- Upper mid-bands (e.g., 3.3-4.2, 4.5-5, 5.925-7.125 GHz[6]) are newer to 5G and offer much wider bandwidths. This is a key 5G capacity resource. As of mid-2020, upper mid-band spectrum used in most countries is in the range of 3300 to 3800 MHz. Upper mid-bands offer a good combination of propagation and capacity for cities. 3GPP standards currently support 100 MHz wide channels and a maximum bandwidth of 400 MHz in carrier aggregation mode.
- High bands (e.g. 26, 28, 40, 50, 66 GHz, also referred to as mmWaves) are effective at addressing areas with very high traffic density and extreme peak data rates.

Upper mid-bands (e.g. 3.3-4.2 GHz, 4.5-5 GHz, 5.925-7.125 GHz) are newer to 5G and offer a much wider bandwidth. This is a key 5G capacity resource because they offer a good combination of propagation and capacity for cities.

The exhibit below shows the capabilities of each spectrum range and relates to their mix of coverage and capacity. The wider the rectangle, the higher the coverage. The shorter the rectangle, the higher the capacity.

[5] Advanced Wireless Services, 90 MHz of spectrum within the 1.7-2.1 GHz range in Region 2.
[6] 5.925-7.125 GHz has not yet been defined in 3GPP for 5G NR but is in development (RP-202114) and expected by Dec 2022

Exhibit 3: Mix of spectrum for 5G



Source: Coleago Consulting

5G is not simply a continuation as we know it. The 5G vision is for a ubiquitous fibre-like speed user experience and connectivity for a wide range of new uses coupled with new features.

5G is much more than providing smartphone connectivity. 5G also enables the Internet of Things (IoT) with Massive Machine Type Communications (mMTC) and Ultra Reliable and Low Latency Communications (uRLLC). 5G end to end features such as making available a slice of the network for specific use cases bring a new dimension to how wireless communications can be used.

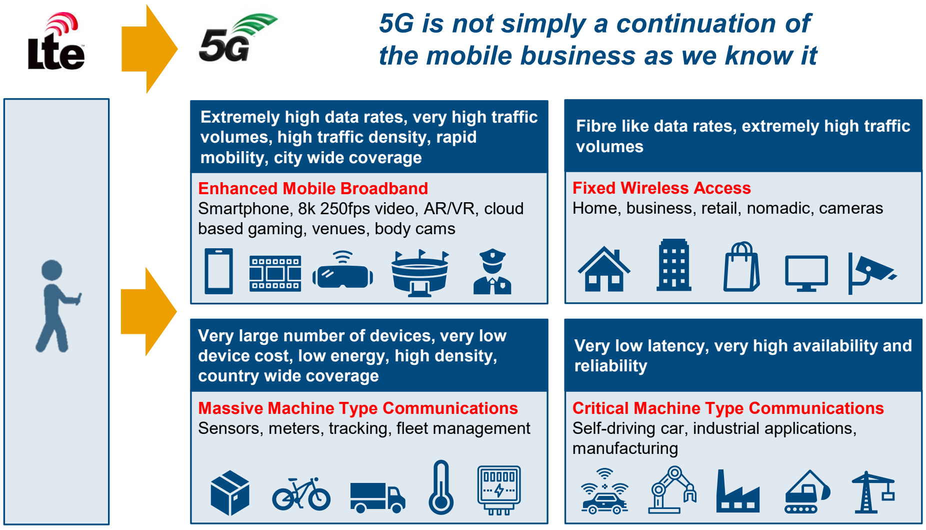
Exhibit 4 illustrates the 5G set of applications and use cases, all enabled by the enhanced capabilities of 5G compared to 4G. With these capabilities 5G is an enabling platform for what has been described as the “4th industrial revolution”[7]. While appearing futuristic today, connected vehicles, smart deliveries with drones and robots and smart cities will generate traffic volumes far higher than todays’ smartphone driven data usage rates.

5G envisions many use cases in the cities of the future, the so called “smart cities”. These will be crucial for our environment, enabling industries to control their energy consumption, and use intelligent tracking and traffic management to optimise the most efficient delivery routes.

Driven by these requirements, we have based our analysis on the need for additional upper mid-band spectrum to deliver near guaranteed user experienced data rates of 100 Mbit/s on the DL and 50 Mbit/s on the UL, anytime, anywhere in cities while “on the move”.

[7] Klaus Schwab, The Fourth Industrial Revolution, Magazine of Foreign Affairs, 12 Dec 2015

Exhibit 4: New use cases and applications drive 5G spectrum needs



Source: Coleago Consulting

2.3 Mid-band spectrum requirement for city-wide speed coverage

Our model focuses on the user experienced mobile data rate of 100 Mbit/s on the downlink and 50 Mbit/s on the uplink in a city, i.e. ensuring citywide speed coverage. A detailed description of the approach to modelling is contained in the report "Estimating the mid-band spectrum needs in the 2025-2030 timeframe, Global outlook". In this chapter we provide a summary of the methodology.

The relevant metrics are: (i) area traffic density demand, and (ii) area traffic capacity supply in terms of Gbit/s/km^2. We examine the area traffic capacity requirement against the background of increased concurrent bandwidth demand from human users and other use cases.

We have developed a concise and easily verifiable model to examine the need for mid-band spectrum in an urban environment to deliver the 100 Mbit/s user experienced data rate in downlink and 50 Mbit/s in the uplink ITU-R requirement for IMT-2020.

On the demand side, we look at mobile area traffic demand density in cities in the 2025-2030 timeframe:

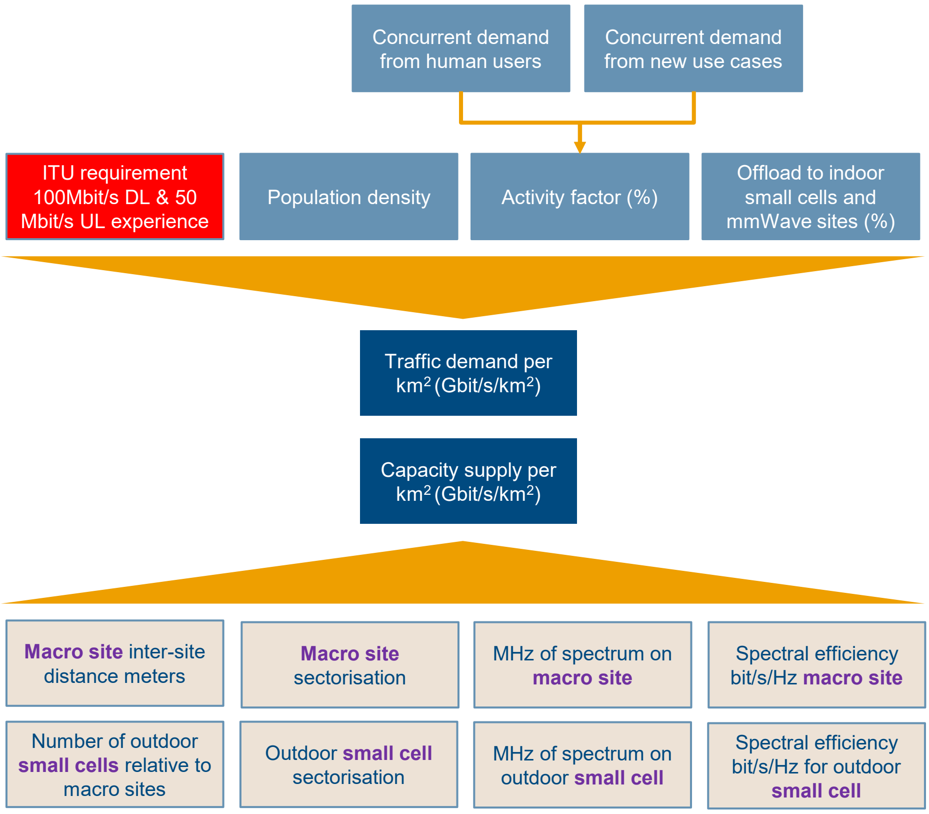
- We use the resident population density in cities as a proxy for mobile area traffic demand density that is triggered by both human and non-human users. This is appropriate because traffic generated by, for example, connected vehicles, cameras or video-based sensors occurs where people are located, and is in addition to the traffic generated by human users. Hence, tying traffic demand per capita to the 100 Mbit/s downlink and 50 Mbit/s uplink requirements generates a realistic estimate for future area traffic demand which takes account of all use cases.
- We make an assumption for concurrent bandwidth demand from both human users and other use cases. This is presented in the form of an activity factor ranging from 10% to 25%. The activity factor represents the proportion of the population which demand 100 Mbit/s in the downlink and the proportion of the population which demand 50 Mbit/s in the uplink concurrently in a cell during the busy period. For Australian cities a factor of 20-25% is relevant in the 2030 timeframe.

On the supply side, we begin by considering the network evolution in the 2025-2030 timeframe. Aiming for a realistic estimate of spectrum needs from 2025 to 2030, we make the following conservative assumptions in respect of area traffic capacity supply:

- The “baseline spectrum” includes spectrum already in use by mobile operators in low and mid-bands. The baseline spectrum in Melbourne, Sydney and Brisbane is around 830 to 840 MHz (see Exhibit 6).
- We assume that, depending on the country, within the 2025 to 2030 timeframe, mobile operators will have made the necessary investment to use all “baseline spectrum” for 5G.
- We also assume that each operator will deploy 3 outdoor small cells per each of its macro sites[8], invest in MIMO upgrades, install indoor small cells, and deploy high-bands (mmWave) spectrum on outdoor and indoor sites.
- We assume that cells can be 85% loaded, i.e. we apply a 15% design margin.
- Other parameters in the model are the number of macro cell sites per km^2, driven by the inter-site distance, base station sectorisation, and spectral efficiencies as detailed in Exhibit 7.

The excess demand over supply drives the forecast of the need for additional upper mid-band spectrum. Exhibit 5 summarises the variables in the model.

Exhibit 5: Area traffic demand and capacity supply model



Source: Coleago Consulting

[8] As noted in the Executive Summary, Australia faces challenges in deployment and this assumption may not be realistic in the Australian context except in dense urban areas with high demand.

Exhibit 6: Mobile operator spectrum holdings

Band	Category	Duplex	Sydney	Melbourne	Brisbane
700 MHz	Low Band	FDD	90	90	90
850 MHz	Low Band	FDD	40	40	40
1800 MHz	Mid Band	FDD	120	120	120
2100 MHz	Mid Band	FDD	120	120	120
2300 MHz	Mid Band	TDD	98	98	98
2600 FDD	Mid Band	FDD	140	140	140
3.4-3.7 GHz	Mid Band	TDD	225	225	225
26GHz	High Band	TDD	2,400	2,400	2,400
	Low Band		130	130	130
	Mid Band		703	703	703
	High band		2,400	2,400	2,400

Source: AMTA

Exhibit 7: Key 5G modelling assumptions for future urban environment

Band	Category	Average inter-site distance (m)	No of sectors	Average DL/UL spectral efficiency (bit/s/Hz)
700 & 850 MHz	Macro site; Low bands	400	3	1.8 / 1.8
1.500-2.600 GHz	Macro site; Lower mid-bands	400	3	2.2 / 2.5
3.3- 7.125 GHz	Macro site; Upper mid-bands	400	3	6.0 / 4.1
3.3-7.125 GHz	Macro site; Additional upper mid-bands	400	3	6.0 / 4.1
3.3-7.125 GHz	Outdoor small cell; Upper mid-bands	n/a*	1	3.7 / 2.6
3.3-7.125 GHz	Outdoor small cell; Additional upper mid-bands	n/a*	1	3.7 / 2.6

* For outdoor small cells this does not assume contiguous coverage because outdoor small cells are deployed to fill in speed coverage holes rather than providing contiguous coverage. Hence the inter-site distance is irrelevant

Source: Coleago Consulting

3 Population density analysis

3.1 Population density in Sydney, Melbourne and Brisbane

Our approach is to use population density in cities as a proxy for traffic density to estimate the minimum or floor capacity requirement.

Our approach is to use population density in cities as a *proxy* for traffic density to estimate the minimum or floor capacity requirement. The population is the resident population and in many areas the day-time population density is materially higher. Traffic generated by connected vehicles and video based sensors could be a multiple of traffic generated by human users and therefore tying traffic demand per capita to the user experience data rate generates a conservative estimate for future spectrum needs. In principle, *other things being equal*, the higher the density, the greater the demand per km^2 and consequently the higher the population density the greater the need for additional mid-band spectrum.

The population density is the average resident population in a dense area of a city. In the Global report we focused on cities which have an area of at least 40 km^2 with a population density of at least 8,000 per km^2. On average, population densities in major Australian cities are at the lower end of the scale but they tend to cover a larger area. Therefore we examined the population density using contour lines starting at 4,000 people per km^2 to 9,000 people per km^2 in steps of 1,000. The resident population density analysis uses 1 km grid cells sourced from the Australian Bureau of Statistics, Reference period 2019-20 financial year. The 4,000 people per km^2 contour line is the area of a city where the population density is at least 4,000 in each 1 km^2 grid cell.

Exhibit 8 below shows the population density analysis for Sydney, Melbourne and Brisbane. Within the 9,000 pops contour lines are areas with a higher density. The most densely populated areas are inner-city Melbourne (22,400 people per km^2), Sydney Potts Point - Woolloomooloo (16,700) and Pyrmont - Ultimo (16,500).

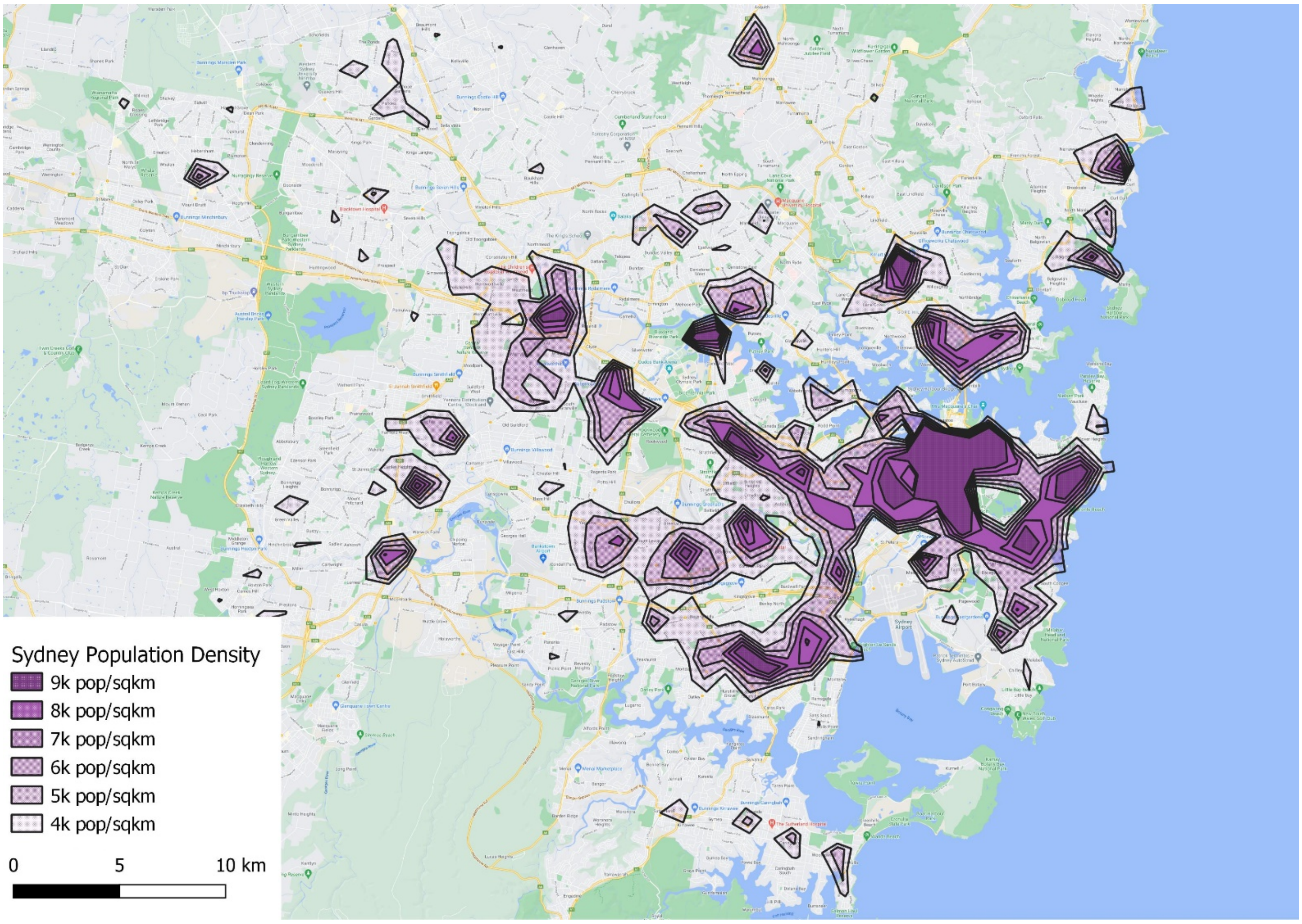
For the purposes of spectrum demand modelling (see chapter 4 below) we used the 6,000 people per km^2 contour line. This includes an area 110 km^2 for Sydney and 38 km^2 for Melbourne with a population density respectively of 8,428 per km^2 and 8,979. For Brisbane the densities are lower and the area is smaller, but additional mid-band spectrum is also required to deliver 5G.

Exhibit 8: Population density analysis

City	Contour line pops / km^2	Area km^2	Population per km^2	Resident population
Sydney	4,000	297	6,190	1,838,418
Sydney	5,000	175	7,403	1,296,780
Sydney	6,000	110	8,428	929,536
Sydney	7,000	67	9,403	629,087
Sydney	8,000	38	10,338	388,907
Sydney	9,000	21	11,261	241,465
Melbourne	4,000	145	5,710	826,191
Melbourne	5,000	67	7,401	498,567
Melbourne	6,000	38	8,979	339,973
Melbourne	7,000	25	10,229	257,763
Melbourne	8,000	14	11,994	169,734
Melbourne	9,000	9	13,487	125,505
Brisbane	4,000	35	5,210	183,543
Brisbane	5,000	13	6,336	81,080
Brisbane	6,000	5	7,147	33,290
Brisbane	7,000	2	8,352	20,346
Brisbane	8,000	1	9,043	5,693

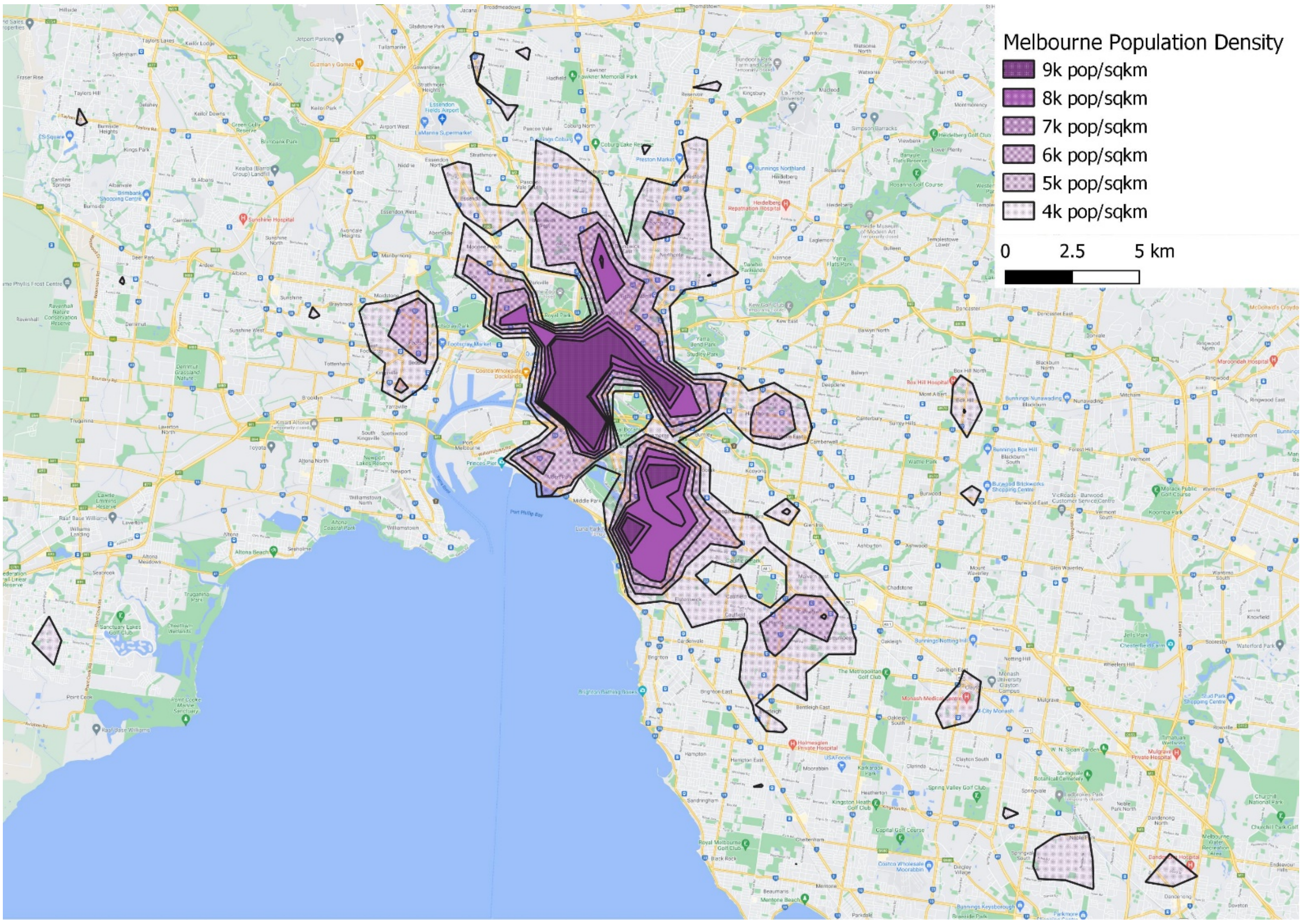
Source: Coleago analysis based on data from the Australian Bureau of Statistics

Exhibit 9: Population density map for Sydney



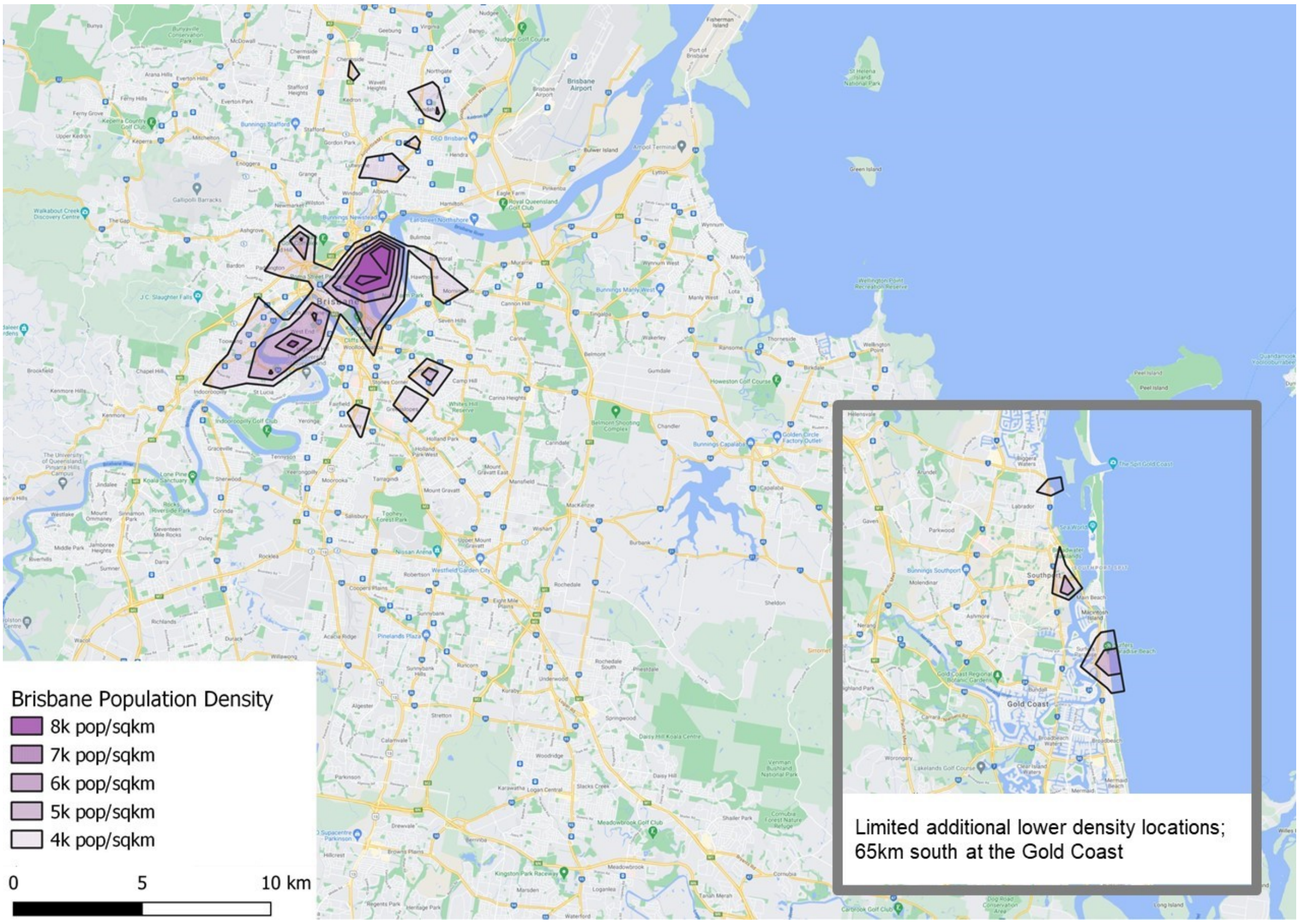
Source: Coleago based on 1 km^2 grid cell data from Australian Bureau of Statistics

Exhibit 10: Population density map for Melbourne



Source: Coleago based on 1 km^2 grid cell data from Australian Bureau of Statistics

Exhibit 11: Population density map for Brisbane



Source: Coleago based on 1 km^2 grid cell data from Australian Bureau of Statistics

3.2 Population growth and implications for density

According to projections by the Australian Government Centre for Population, Australia will continue to experience significant population growth particularly in its capital cities. By the end of 2030, the population of Sydney is projected to grow by 9.9%, while Melbourne is expected to be 16.9% larger, and Brisbane 13.3%.

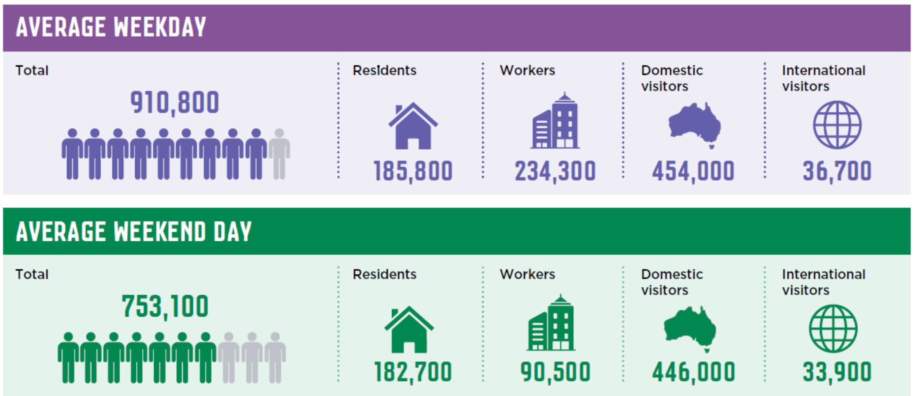
The increase in population is likely to increase population density rather than increasing the sprawl of the city. This trend has been apparent in the recent years. Given that the three cites still have a population density below the 15,000 per km^2 mark recommended by UN-Habitat, population density is likely to increase at least in line with the figures for urban population growth.

UN-Habitat recommendations[9] address urbanisation challenges such as population growth, urban sprawl, poverty, inequality, pollution and congestion, as well as urban biodiversity, urban mobility and energy. One of the five principles of urban planning is to aim at what is termed "high density" with 15,000 people per km^2.

3.3 Daily population variations

Our estimates are based on resident population. In many areas of cities, daily populations are significantly higher than resident populations. For example, in the City of Melbourne in 2019 the resident week-day population was estimated at 185,800 but if workers and visitors are added 910,800 people are present in the City of Melbourne area. This means our estimate for spectrum need is conservative.

Exhibit 12: City of Melbourne Daily Population Estimates 2019



Source: City of Melbourne, Daily Population Estimates 2019

[9] A new strategy of sustainable neighbourhood planning: Five Principles. Discussion Note 3, Urban Planning. UN-Habitat (2014)

4 Spectrum demand in Australia

4.1 Introduction

Using the methodology and parameters outlined above in combination with the population densities shown in chapter 3 we modelled the needs for additional mid-band spectrum to meet the downlink and uplink area traffic demand in Sydney, Melbourne and Brisbane in the 2025-2030 timeframe.

The key variables that explain the demand for spectrum are:

- population density;
- the activity factor; and
- the percentage of traffic offloaded to high bands.

4.2 Example: Sydney

We calculated the area traffic demand for the downlink and the uplink depending on the activity factor and the percentage of traffic that is offloaded to high bands. The result is shown in Exhibit 13 below. Australia is a high-income country and hence there is a reasonable expectation that by 2030 100% of smartphone users are 5G and that there will be a high-density of other 5G use cases. This would mean a 25% activity factor is relevant for Sydney. Given the high activity factor, it is reasonable to assume that 35% of traffic will be offloaded to high bands. With those assumptions the area traffic demand density is forecast to be 93 Gbit/s/km^2 for the downlink traffic. Adding the uplink traffic produces a total area traffic demand density of 139 Gbit/s/km^2.

To put the average downlink area traffic demand density of 139 Gbit/s/km^2 into perspective we can compare it to the ITU-R IMT-2020 area traffic requirement of 10 Mbit/s/m^2. 10 Mbit/s/m^2 equates to 10,000 Gbit/s/km^2. The 139 Gbit/s/km^2 on average across the whole city is less than 1.5% of the hotspot peak. This illustrates that our estimates are modest by comparison to localised traffic density peaks.

Exhibit 13: Area traffic demand in the Sydney area

	Dowlink Traffic Demand (Gbit/s/km^2)					Uplink Traffic Demand (Gbit/s/km^2)					DL + UL Traffic Demand (Gbit/s/km^2)				
	Activity Factor					Activity Factor					Activity Factor				
Offload to High-Band	5%	10%	15%	20%	25%	5%	10%	15%	20%	25%	5%	10%	15%	20%	25%
10%	34	67	101	135	169	17	34	51	67	84	51	101	152	202	253
15%	32	63	95	126	158	16	32	47	63	79	47	95	142	190	237
20%	29	59	88	118	147	15	29	44	59	74	44	88	133	177	221
25%	27	55	82	110	137	14	27	41	55	68	41	82	123	164	205
30%	25	51	76	101	126	13	25	38	51	63	38	76	114	152	190
35%	23	46	70	93	116	12	23	35	46	58	35	70	104	139	174
40%	21	42	63	84	105	11	21	32	42	53	32	63	95	126	158
45%	19	38	57	76	95	9	19	28	38	47	28	57	85	114	142

Source: Coleago

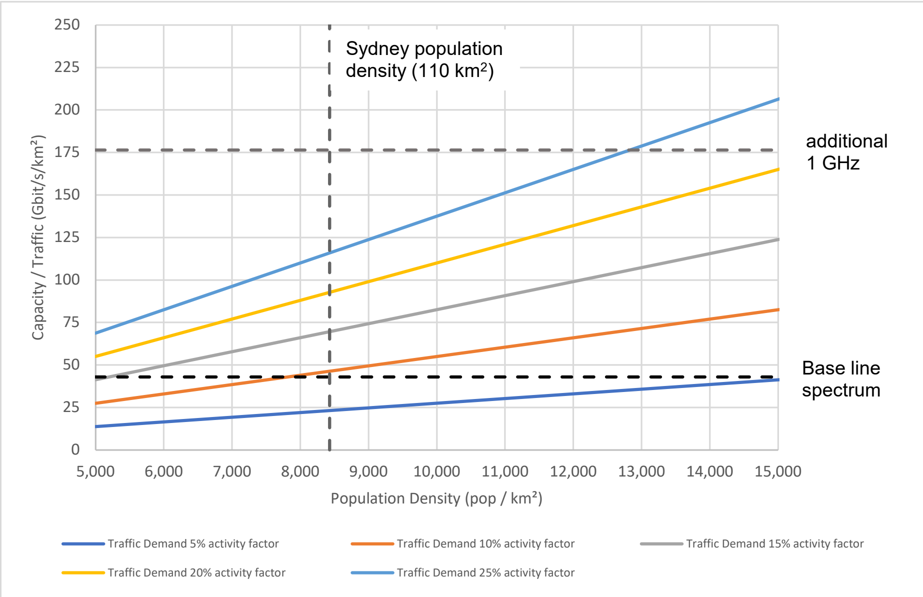
Having calculated the area traffic demand density, we can compare this with the area traffic capacity using the assumptions stated above and different availability levels of upper mid-band spectrum in addition to the baseline spectrum. Exhibit 14 shows the downlink spectrum need for Sydney. The population density is plotted on the horizontal axis. The dense urban area includes 110.3 km^2 with a population of 929,536 and an average population of 8,428 per km^2. This population density for the Sydney dense urban area is indicated by the vertical line.

The upward sloping coloured lines are the area traffic demand at various activity factors. The lines are upward sloping because area traffic demand increases in proportion to population density. The area traffic demand and capacity in Gbit/s/km^2 is shown on the left-hand vertical axis. In this chart we only show the downlink traffic.

The dashed horizontal lines indicate the area traffic capacity depending on the amount of spectrum available. The lower line shows the area traffic capacity if no additional upper mid-band spectrum is available. The upper line shows the area traffic capacity if 1,000 MHz of additional mid-band spectrum is made available.

The point at which the upward sloping demand lines crosses the Sydney area population density line shows the required area traffic capacity. For example, the yellow line which represents the 20% traffic demand activity factor crosses the Sydney population density line at halfway to the 1 GHz of additional spectrum line, where the area traffic capacity / demand shown on the vertical axis is 93 Gbit/s/m^2. This figure can also be seen in Exhibit 13 in the first table, which shows the downlink demand in the cell 20% activity factor and 35% offload to high bands.

Exhibit 14: Downlink spectrum need in Sydney urban area



Note: This chart is based assuming 35% offload to high bands.

Source: Coleago Consulting

4.3 Total mid-band spectrum needs in Australian cities

We have calculated the IMT spectrum demand for Sydney, Melbourne, and Brisbane and Exhibit 15 shows the total mid band spectrum needs, including the baseline mid-band spectrum and considering a range of activity factors and high bands offload factors.

- The table takes account of downlink and uplink traffic.
- Resident population density in urban areas is the key driver for additional upper mid-band spectrum needs.
- Looking at the table horizontally, the data shows that a) with higher activity factors the need for upper mid-band spectrum increases and b) the lower the offload to high bands, the higher the need for upper mid-band spectrum.
- We modelled the spectrum need depending on the percentage of traffic offload to high bands with a range from 10% to 45%. The higher the activity factor the higher the traffic density. With high traffic densities operators will increasingly resort to upper mid-band small cells to provide area traffic capacity. Therefore, the higher the percentage of traffic that is likely to be offloaded to high bands.

Our analysis leads to the conclusion that the use of significant amounts of additional mid-band spectrum would enable the 5G NR experienced 100/50 Mbit/s data rate to be delivered in an economically feasible manner in the cities we examined, anytime, anywhere, citywide thus delivering not only the 5G experience for smartphone users but also enabling the smart city.

Exhibit 15: Total (incl. base line) mid-band spectrum needs (MHz)

DL and UL total (including baseline) mid-bands spectrum need [MHz]														
	Popn density	Dense Area	Activity factor 10%			Activity factor 15%			Activity factor 20%			Activity factor 25%		
			High bands offload			High bands offload			High bands offload			High bands offload		
City	per km^2	km^2	30%	20%	10%	35%	25%	15%	40%	30%	20%	45%	35%	25%
Sydney	8,428	110	800	890	970	990	1110	1230	1130	1290	1460	1230	1440	1640
Melbourne	8,979	38	840	920	1010	1030	1160	1290	1180	1360	1530	1290	1510	1730
Brisbane	7,147	5	740	800	870	890	990	1090	1010	1150	1280	1090	1270	1440

Spectrum need					
	< 10 MHz	10 to 500 MHz	500 - 1000 MHz	1000-2000 MHz	> 2000 MHz

Source: Coleago

Note: Figures are rounded down to the nearest 10 MHz. The figures exclude low-band spectrum.

4.4 Interpreting the findings

The results of our modelling show a wide range of spectrum needs for the three cities and this requires some interpretation. As explained above, the key variables driving differences in the need for additional upper mid-band spectrum are population density, the activity factor and offload to the high bands.

- The population density is a property of a particular city, but the activity factor is an assumption. The activity factor will increase over time. A 15% activity factor may be a realistic assumption for 2025 in a high-income country whereas higher activity factors will be representative of the situation in 2030, the key reason being that over the next 10 years 5G adoption will increase. Mobile operators in High Income countries such as Australia, expect that by 2030, 100% of their smartphone customer base is likely to be 5G enabled.
- The activity factor is likely to be different around the world, sometimes based on countries' income levels. For example, it is expected that Australia will have fast adoption of 5G smartphones and other use cases. Therefore, when looking at the table which shows the spectrum demand, a 20-25% activity factor for Australian cities is likely to be relevant in the 2030 timeframe.

- Offloading to high bands is expected to increase with increased activity factor. For countries with higher activity factors such as Australia, 30-45% of traffic may be offloaded to high bands However, due to the topology of the cities in Australia, offload to high bands may be much less, i.e. only 10%.

The table in Exhibit 16 below highlights the cells corresponding to the activity factors that are likely to be reached in the 2025-2030 timeframe in the three cities, which in turn leads to the total spectrum needs in these cities (including the baseline spectrum).

Exhibit 16: Likely range for the total (incl. base line) mid-band spectrum needs (MHz) in 2025-2030

DL and UL total (including baseline) mid-bands spectrum need [MHz]															
	Base line	Base Line	Base Line	Activity factor 10%			Activity factor 15%			Activity factor 20%			Activity factor 25%		
	Low Band	Mid Band	Total	High bands offload			High bands offload			High bands offload			High bands offload		
City	MHz	MHz	MHz	30%	20%	10%	35%	25%	15%	40%	30%	20%	45%	35%	25%
Sydney	130	703	833	800	890	970	990	1110	1230	1130	1290	1460	1230	1440	1640
Melbourne	130	703	833	840	920	1010	1030	1160	1290	1180	1360	1530	1290	1510	1730
Brisbane	130	703	833	730	800	870	890	990	1090	1010	1140	1280	1090	1270	1440

Spectrum need	< 10 MHz	10 to 500 MHz	500 - 1000 MHz	1000-2000 MHz	> 2000 MHz

Source: Coleago

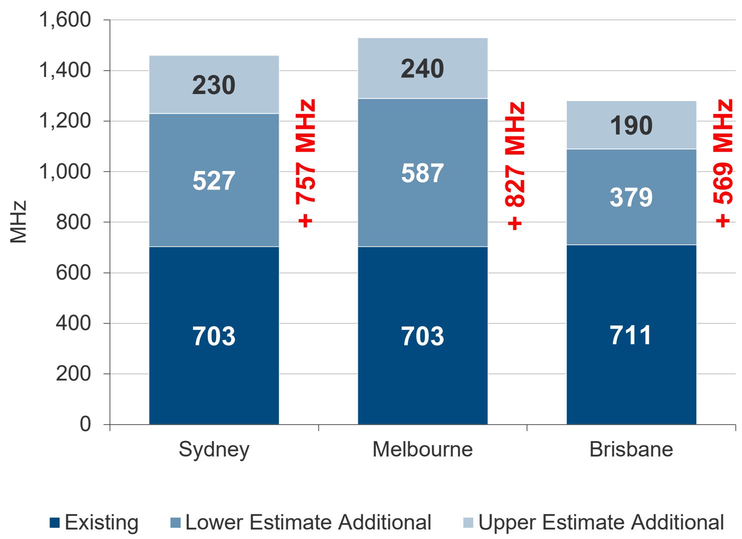
4.5 Additional mid-band spectrum requirements

Exhibit 16 shows the base line spectrum included in our model, i.e. the spectrum already assigned to mobile operators in Australia and also the total mid-band spectrum need. The additional mid-band spectrum needed is the difference between the existing mid-band spectrum and the need.

- In Sydney, a total 1,230 to 1,440 MHz of mid-band spectrum is required in the 2025-2030 timeframe.
- 703 MHz is already assigned to operators in Sydney.
- To deliver the city-wide 5G user experience in an economically and technically feasible manner in the 2025-2030 timeframe, an additional 527 to 757 MHz of mid-band spectrum is required in Sydney

For Melbourne an additional 587 to 827 MHz is needed and for Brisbane an additional 379 to 569 MHz needs to be assigned to mobile operators to deliver 5G, city-wide.

Exhibit 17: Mid-band spectrum need



Source: Coleago

4.6 Reasonableness check

In assessing the reasonableness of the findings, the assumption as to the level of concurrent area traffic demand in Gbit/s/km^2 is the key determinant which drives spectrum need. In most cities in our sample, with a 20% activity factor, these results show an area traffic density of less than 300 Gbit/s/km^2. This can be compared to the ITU-R IMT-2020 area traffic requirement of 10 Mbit/s/m^2. 10 Mbit/s/m^2 equates to 10,000 Gbit/s/km^2. 300 Gbit/s/km^2 on average across the whole city is 3% of the hotspot peak, showing a reasonable averaged traffic across the city.

To illustrate the requirement for high traffic density in a mobile environment, we examined a public transport scenario using London Route Master bus which is similar to Sydney's B-Line double decker bus. The bus has an area of 25 m^2 (2.5x10 meters) and a capacity of 80 passengers. If only 10% of the passengers use 4k video requiring 20 Mbit/s DL speed, this results in an area traffic demand of 6.4 Mbit/s/m^2. This is close to the 10 Mbit/s/m^2 requirement and well above the average area traffic capacity calculated for the sample cities.

5 Alternatives to additional mid-band spectrum

5.1 Trade-off between additional spectrum and network densification

We examined whether small cell densification could be a substitute for more upper mid-band spectrum available. For example, for Sydney with a population density of 8,428 per km^2, 138 additional outdoor small cells per km^2 are required to deliver the same capacity as an additional 757 MHz. These sites would be needed across the entire city area. Considering the urban area of 110.3 km^2, 15,221 additional small cells would be required in the absence of an additional 757 MHz of mid-band spectrum.

These are significant numbers of outdoor small cells with relatively short inter-site distances, particularly when it is noted that this average spacing must be maintained across the entirety of the large city areas involved. This is an unrealistic prospect and, if it were technically feasible, would have negative consequences because:

- such densification would push against the technical limits of network densification and such small inter-site distances, over such large areas, may also not be practically possible from an interference point of view;
- It would clearly have a negative impact on the city environment from an aesthetics point of view and would be very costly; and
- the larger number of cells sites would substantially increase power consumption.

5.2 City-wide speed coverage with High bands (mmWave)

A reasonable question is whether it is feasible to provide city-wide speed coverage through densification using high bands (mmWave) macro/small cells rather than with mid-band small cells. Given the different options for mmWave densification (e.g. densifying using only mmWave small cells or adding mmWaves to the existing macro mid-bands grid in conjunction with mmWave small cells) and considering the different sizes of cities and their propagation environments (influenced by street design, building characteristics, etc.), estimating the exact number of mmWave sites needed requires a case-by-case analysis. However, all options for such a densification would require new mmWave macro sites and/or new mmWave small cells over large areas (i.e. not only locally).

We also know that relatively small inter-site distances are required by the mmWaves. The average spacing that would need to be maintained across the entirety of the large city areas involved would not be feasible. A densification approach using mmWave spectrum is therefore not a viable option because it would be both too costly and undesirable from an environmental and aesthetic perspective.

5.3 Further detail

The report "Estimating the mid-band spectrum needs in the 2025-2030 time frame, Global outlook" contains a more detailed analysis showing that small densification and / or the use of high-bands are not substitutes for making additional mid-band spectrum available to provide city-wide 5G speed coverage.

6 Mid-band spectrum for 5G "fibre-like speed" FWA

6.1 100 Mbit/s rural broadband

The benefits of making available additional upper mid-band spectrum extends beyond cities. 5G FWA relying on additional mid-band spectrum would make it possible to overcome the urban-rural digital divide by connecting new places and, more importantly for Australia, additional spectrum would provide sufficient bandwidth to ensure that FWA will be able to address the needs for fixed connectivity with 100 Mbit/s as a long-term solution for rural areas.

Using additional mid-band spectrum for 5G FWA would reduce the cost of delivering future proof "fibre-like" fixed wireless access services to households and enterprises.

In Australia, there is a lack of 100 Mbit/s DL broadband in rural small towns and villages. The Australian Government declared that the NBN rollout was complete and should be considered "built and fully operational" in late 2020. However, not all premises are connected, a mix of technology has been deployed, and it remains costly and requires substantial funding. The availability of additional mid-band spectrum would enable mobile operators to provide 5G FWA solutions, reducing the average cost of bringing 100 Mbit/s connectivity to rural towns/villages and provide much needed infrastructure competition to regional Australia.

6.2 Improving the FWA economics with additional mid-band spectrum

Closing the rural broadband connectivity gap using 5G FWA requires far less investment compared to FTTP. However, the 5G FWA business case is highly dependent on the number of connections that can be supported per cell tower. In turn, this is a function of the amount of spectrum that can be deployed on a cell tower to deliver fibre like broadband using 5G NR technology.

We have modelled how the availability of additional upper mid-band spectrum impacts on the number of homes that can be supported from a cell tower to deliver "fibre-like speed". The following assumptions differ from those used for 5G mobile.

- Outdoor customer premises equipment (CPE) may be used which results in an uplift to spectral efficiency. In addition, radios adapted for use in a flat rural area may be added, further enhancing cell radius for rural FWA. However, in a rural environment with a low building height 16-element MIMO would be deployed for FWA compared to 64-element MIMO for eMBB in a dense urban environment. Hence, we assume a lower downlink spectral efficiency of 5 bit/s/Hz.
- We assume a higher activity factor of 50% compared to 10-25% for mobile because fixed broadband monthly data usage in terms of the duration of streaming media is assumed to remain higher than mobile broadband usage as illustrated by the following examples:
  - In Australia in June 2020, the average monthly broadband usage per connected premises was 297 Gbytes downlink and 29 Gbytes uplink[10]. For subscribers with a 100 Mbit/s+ connection usage was 333 Gbytes/month in Europe and 398 Gbytes in the US.
  - A further reference point is the service definition in the Connect America Fund Phase II Auction (Auction 903) rural broadband funding programme. The 100 Mbit/s broadband service must include a 2 Terabyte monthly usage allowance.
  - Fixed broadband is used over longer continuous periods thus pushing up concurrent use (i.e. the longer the usage, the higher the activity factor).
  - Streaming media, such as watching IP TV by household tends to occur at the same hours of the day, i.e. it tends to be concurrent.

[10] NBN Corporate Plan 2021

In rural small towns and villages there will also be demand for 5G NR mobile. However, due to the lower population density compared to cities, this demand can be served with existing IMT spectrum. This means if additional upper mid-band spectrum is assigned to mobile operators, this could be used to provide 100 Mbit/s service to a significant number of premises in a rural small town using existing cell towers.

5G FWA with additional upper mid-band spectrum provides an opportunity for a sustainable 5G FWA business case delivering user experienced DL data rate of 100 Mbit/s.

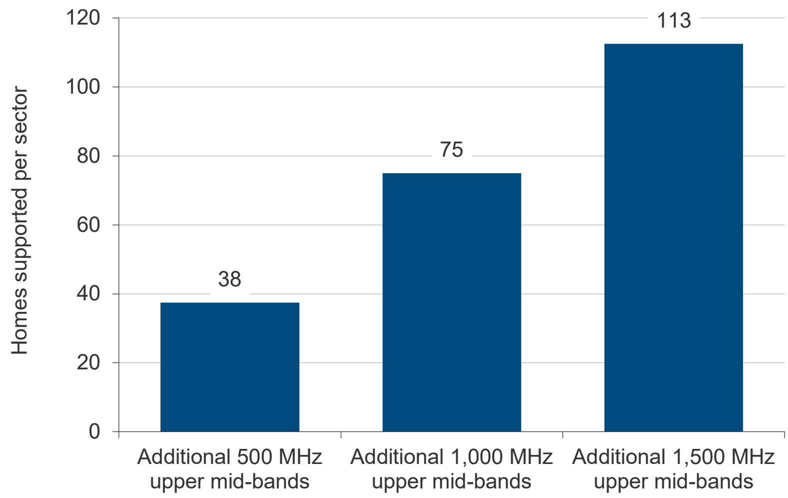
Exhibit 18 shows the assumptions used to calculate the number of premises that could be supported. Exhibit 19 shows the number of households that can be served by one sector depending on the amount of additional spectrum. The more households that can be served per sector and hence per site, the lower the cost per home served with a 100 Mbit/s speed on the downlink.

Exhibit 18: FWA premises per sector depending on amount of spectrum

	500 MHz	1,000 MHz	1,500 MHz
TDD DL:UL ratio	3	3	3
Spectral efficiency - bit/s/Hz	5	5	5
DL capacity per sector - Mbit/s	1,875	3,750	5,625
Number of households supported	38	75	113

Source: Coleago

Exhibit 19: FWA premises per sector depending on amount of spectrum



Source: Coleago Consulting

6.3 Leveraging existing mobile infrastructure for rural FWA

In rural areas, mobile networks can supply to a greater proportion of villages and small towns compared to FTTP coverage. The cost of bringing 100 Mbit/s broadband connectivity to these rural population clusters can be significantly reduced if the existing cell towers are also used for 5G FWA. It is of course also much quicker to leverage the existing mobile infrastructure rather than laying fibre in every street.

A sustainable 5G FWA business case in rural small towns and villages will require a significant amount of spectrum with reasonable propagation characteristics which can be found in upper mid-bands. While the range of upper mid-band spectrum is much smaller compared to low-bands spectrum, the radio range of 5G in 3.5 to 7 GHz is not a limiting factor when assessing the number of rural premises which could be covered with a 100 Mbit/s service.

6.4 5G FWA in Australian small towns

To illustrate the benefit of 5G FWA for small town Australia, we selected three small towns with different characteristics in terms of the number of premises, size of the area, and number of existing cell towers.

Roxby Downs

Roxby Downs has a population of 4,500 and around 1,700 premises. The population density is no more than 3,000 per km^2 and 5G mobile capacity could be provided with the existing spectrum holdings.

Mobile operators serve the town from three base station sites, two of which (indicated by the red dot on the map) are in close proximity. From these sites the entire town as well as the nearby facilities of Motorsport Park and Roxby Downs Quarry could be served with 5G FWA using upper mid-band spectrum. These three sites could accommodate four sectors covering the town. With an additional 500 MHz of mid-band spectrum, 150 premises could be served while an additional 1,000 MHz would double this to 300 premises.

Exhibit 20: 5G FWA potential Roxby Downs

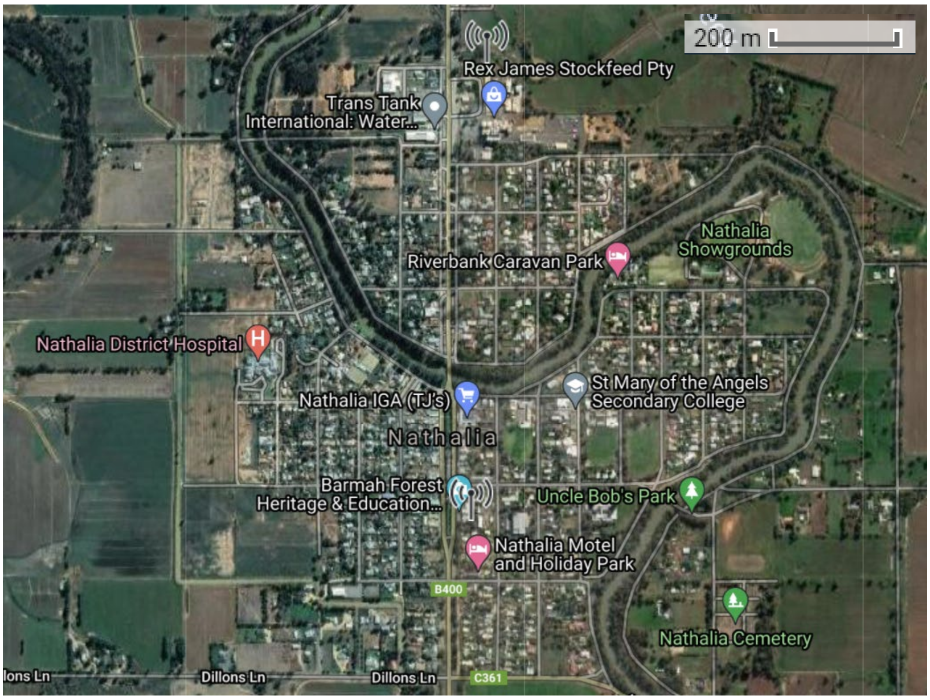
Source: Coleago

Nathalia

Nathalia has a population of 1,900 and an estimated 750 premises. The population density is no more than 2,000 per km^2 and 5G mobile capacity could be provided with the existing spectrum holdings.

Mobile operators serve the town from two base station sites which are ideally located. From these sites the entire town could be served with 5G FWA using upper mid-band spectrum. The two sites could accommodate five sectors covering the town. With an additional 500 MHz of mid-band spectrum, 188 premises could be served increasing to 375 premises with an additional 1,000 MHz.

Exhibit 21: 5G FWA potential Nathalia



Source: Coleago

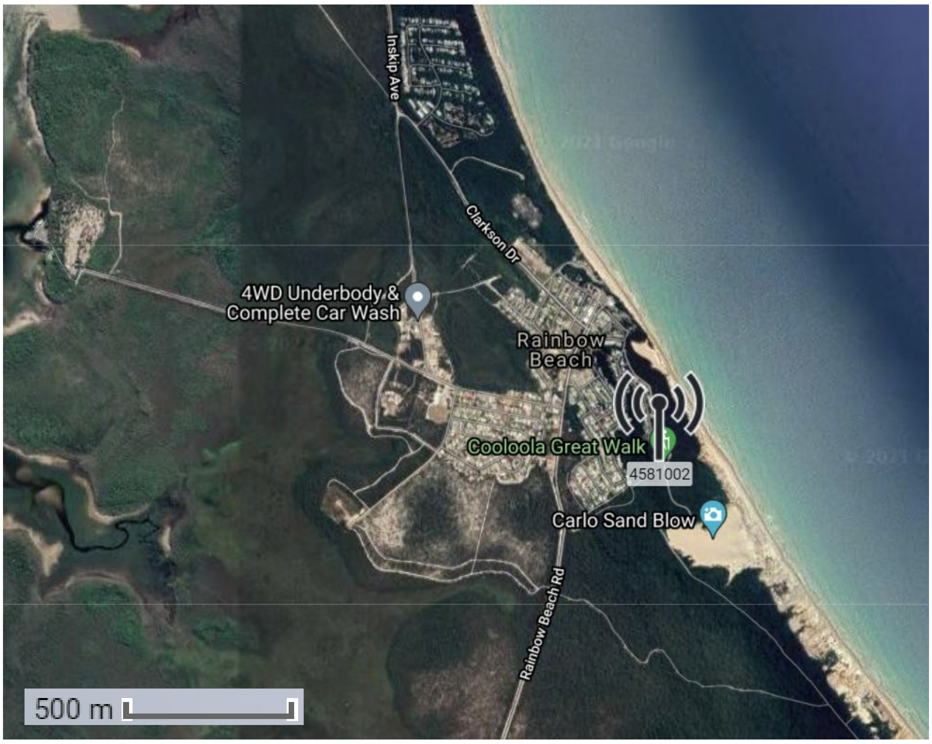
Rainbow Beach

Rainbow Beach has a resident population of 1,250 and around 500 premises. The population density is less than 1,000 per km^2. The town sees a substantial influx of visitors during the beach holiday season. The capacity for 5G mobile capacity could be provided with the existing spectrum holdings.

Mobile operators serve the town from one base station site from which the entire town could be served with 5G FWA using upper mid-band spectrum. The site could accommodate three sectors. With an additional 500 MHz of mid-band spectrum, 113 premises could be served and with an additional 1,000 MHz 255 premises could be served.

5G FWA would be particularly useful for Rainbow Beach camping grounds, where FTTP may not offer a suitable form of connectivity. 5G FWA would be a more flexible solution which can easily adapt to changing locations.

Exhibit 22: 5G FWA potential Rainbow Beach



Source: Coleago

6.5 5G FWA vs. FTTP to provide rural broadband connectivity

The economics of using "fibre like speed" 5G FWA in upper mid-bands to close the rural connectivity gap are significantly better compared to fibre and using 5G FWA will reduce the funding and time it takes to fulfil rural connectivity targets.

NBN Co indicated that the average cost per FTTP connection in a brownfield area is $4,395[11]. This average covers a wide range. The lower the density of premises connected, the higher the cost per FTTP connection. The cost per premises connected using 5G FWA is much lower. Exhibit 23 show the calculations for the cost per premises using 5G FWA, depending on whether an additional 500MHz or 1,000 MHz of upper mid-band spectrum is made available.

- Where mobile coverage already exists, incremental investment is required for the 5G radio but not the mast. We estimate the cost of adding mid-band radios to existing sites in rural areas at around AU$ 40,000 for three sectors. The number of radios required will depend on the instantaneous bandwidth (IBW) accommodated by the radio (typ. 300-400 MHz) as well as the possibility to access contiguous spectrum. For example, in the event that 1,000 MHz of additional spectrum is made available and assuming an IBW of 200 MHz, then five radios may be required on the cell tower.
- Civil works may amount to AU$31,000 per site.
- Given that the site has to cater for 5G mobile traffic, we assume that a fibre connection is required but there may be some incremental cost if the same fibre links has to accommodate a higher capacity. We have allowed AU$ 20,000 for this.
- The cost per home connected using a self-installed CPE is in the order of AU$400.
- The number of households that can be supported at different speeds is a function of the amount of spectrum deployed on an FWA site.

The cost per premises connected is AU$ 1,900 if 500 MHz of additional spectrum is available and AU$ 1,501 if an additional 1,000 MHz is available. This is considerably lower than the AU$ 4,395 cost per premises cited by NBN.

Exhibit 23: Cost per 5G FWA connection

Additional spectrum	500 MHz	1,000 MHz
Cost per radio - AU$	40,000	40,000
Number of radios per site	3	5
MHz of spectrum for FWA	500	1,000
MHz per radio	167	200
Radio cost per site AU$	120,000	200,000
Civil works cost AU$	31,000	31,000
Incremental fibre cost per site AU$	20,000	20000
Total cost per site AU$	171,000	251,000
Cost per CPA AU$	400	400
Number of premises supported	114	228
Cost per premises AU$	1,900	1,501

Source: Coleago

[11] Source: NBN Co 2021 Corporate Plan, page 55, "Cost per Premises".

There are substantial benefits to using 5G FWA to provide broadband connectivity in rural small towns and villages instead of FTTP:

- Leverage mobile coverage obligations: Many countries attached coverage obligations to low-bands spectrum licences. This means many rural small towns and villages which do not have any fixed network access have a mobile cell tower in or near the settlement. While the available low bands will be used for mobile connectivity, the same mast can be used to add “fibre-like” 5G FWA. If sufficient upper mid-band spectrum is available to deliver 100 Mbit/s broadband to home and businesses, then mobile operators are likely to have a business case to upgrade the cell tower and bring fibre to the cell towers instead of wireless backhaul.
- Scalability: Initially only some households may have terminals to make use of broadband while others may not be able to afford it. Demand will grow over time. FWA has a large advantage over Fibre to the Premises (FTTP) in terms of cost per home connected. The key metric for FTTP is homes passed and homes connected. Even if only one home in a street wants FTTP, fibre still has to pass all the other homes in the street thus pushing up the FTTP operator’s cost per home connected. In contrast, a mobile operator can install, for example, a two-sector radio which covers the whole settlement.
- Avoiding duplication: In rural areas, mobile coverage is ahead of fixed network coverage. This existing mobile network can serve both 5G NR mobile and fixed broadband needs provided sufficient spectrum is available. Bringing FTTP into a rural small town is in effect a duplication of infrastructure, network operations expenditure, and customer administration.

7 Conclusions

Conservatively, an additional 587 to 827 MHz of mid-band spectrum is required to realise the IMT-2020 5G vision of providing a fibre like user experienced data rate of 100 Mbit/s DL and 50 Mbit/s UL, city-wide, in Melbourne, Sydney, and Brisbane. This is a conservative estimate. Specific factors for Australia indicate that the spectrum requirement may be 20 to 30% higher.

In the suburbs of these and other Australian cities, cell sites are very heavily loaded and operators face densification challenges. The additional mid-band spectrum would help to overcome these challenges and reduce the number of sites that would otherwise have to be built in sub-urban Australia.

In Australian rural small towns, the additional mid-band spectrum could be used for 5G FWA, when deployed on existing mobile operator cell towers. This would result in savings of up to 66% compared to an FTTP solution and speed up the progress to bringing 100 Mbit/s connectivity to premises in Australia’s small towns.

