Vision 2030: Low-Band Spectrum for 5G

June 2022

About GSMA

The GSMA is a global organisation unifying the mobile ecosystem to discover, develop and deliver innovation foundational to positive business environments and societal change. Our vision is to unlock the full power of connectivity so that people, industry, and society thrive. Representing mobile operators and organisations across the mobile ecosystem and adjacent industries, the GSMA delivers for its members across three broad pillars: Connectivity for Good, Industry Services and Solutions, and Outreach. This activity includes advancing policy, tackling today's biggest societal challenges, underpinning the technology and interoperability that make mobile work, and providing the world's largest platform to convene the mobile ecosystem at the MWC and M360 series of events.

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About Coleago Consulting Ltd

Founded in 2001, Coleago is a specialist telecoms management consulting firm. Our expertise has been developed exclusively within the telecoms sector and delivers a rare combination of telecoms-related commercial, technical, and regulatory skills and experience. Since 2001 we have worked on over 110 spectrum related projects in developed and emerging markets. Since 2017 our spectrum projects included the transition to 5G, including valuing spectrum most relevant for 5G such as 600 MHz, 700 MHz, 3.5 GHz, and mmWave. We advise regulators on spectrum policy, spectrum roadmap, spectrum pricing, spectrum auctions and capacity building on the topic best practice

in spectrum auctions. For mobile operators Coleago delivers regulatory advocacy and responses to consultation, spectrum valuation, bid strategy development and live auction support. Coleago also authored complete bid books for spectrum licence awards by means of a beauty contest.

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In June 2022, Coleago Consulting and the GSMA published the paper on *Low-band spectrum for 5G*, highlighting the need for sub-1 GHz spectrum to deliver on the real vision of 5G connectivity. This GSMA report contains the core data and principal findings of the Coleago work.

For detailed analysis and assumptions, please refer to the full *Low-band spectrum for 5G* report.

https://www.gsma.com/spectrum/wp-content/uploads/2022/07/Low-Band-Spectrum-for-5G.pdf

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Summary

Low-band spectrum is the cornerstone of digital equality and a driver of broad and affordable connectivity. It is a crucial national asset that can build bridges towards digital inclusion and ensure the impact of mobile's economic and social benefits are felt in all communities.

Low band helps governments meet social goals and achieve digital parity between urban and rural areas. It allows networks to reach deeper in-buildings, cover wider areas with IoT and develop transport communications.

More spectrum in this range is vital to giving rural communities equitable access to the services available in urban areas and pushing towards digital inclusion goals. It can provide 5G speeds in rural areas and help to provide a consistent 5G user data rate at the edge of cells with less dense, less costly networks.

As connectivity, IoT, data, and insight permeate every aspect of organisations and enterprises become industrial data platforms, their access to connectivity is vital. Ensuring that the jobs and livelihoods that businesses provide are available in all parts of every market is crucial for balanced economic growth. The support that connectivity provides in the race to net zero must also be available to all.

Addressing the digital divide demands the provision of affordable connectivity to all users. Low-band capacity will be at the core of ensuring that 5G is available to everyone.

The additional capacity in the 600 MHz band leads to:

Improvements in rural and deep-indoors download speeds: **30 to 50%**

Reduction in the cost of extending 5G to rural populations: **33%**

Benefits of additional low-band spectrum for 5G

Thanks to its propagation characteristics, sub-1 GHz spectrum is essential to build coverage in thinly populated areas and provide indoor coverage in built-up areas. Data speeds are important for 4G (LTE-Advanced), but the International Telecommunication Union (ITU) IMT-2020 (5G) vision calls for a 10-fold increase in the user-experienced data rate[1].

To deliver sufficiently high data speeds in rural areas, as well as indoors in cities, the amount of sub-1 GHz spectrum matters as it is proportional to the user-experienced data rate. Today, regional assignments vary, but a maximum of 2x95 MHz of mobile spectrum is found at 700 MHz–1 GHz, with up to 20 MHz of SDL in some cases. Current proposals for more low-band spectrum in the 600 MHz band will allow for between 2x35 and 2x40 MHz of additional low-band capacity. This equals an improvement in speeds of 30-50% where low band is the only spectrum available.

Figure 1: Benefits of low-band spectrum

- Reduce cost of covering rural roads for 5G-connected vehicles
- Improve digital equality with 5G user-experienced speed in rural areas
- Consistent speed coverage deep-indoors and in hard to reach urban areas
- Improve the business case for 5G FWA to isolated rural buildings
- Enable smart agriculture, notably precision farming
- Cost-efficient 5G capacity solution for areas where mid-bands do not reach

1 Report ITU-R M.2441 "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)"

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Advantages of sub-1 GHz spectrum

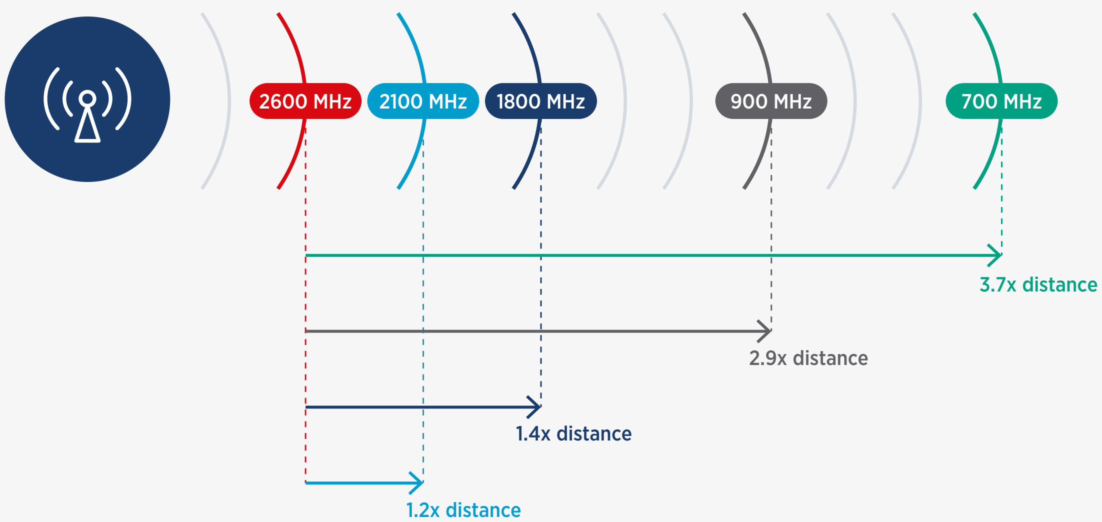
Lower frequencies have superior propagation characteristics, determining how far a signal can travel and how well it can penetrate buildings. For example, using 700 MHz instead of 1800 MHz produces a path loss gain of 13.4 dB, thus creating better indoor and wide-area coverage. The higher the path loss gain, the wider the coverage range and the better the in-building penetration.

In rural areas, the cell range advantage makes it possible for operators to cover wide areas cost-effectively. In an open environment, 700 MHz, for example, reaches 2.6 times further than 1800 MHz.

To provide equivalent geographic 5G speed coverage with 1800 MHz spectrum as 700 MHz spectrum, around three to four times the number of cell sites would be required.[2] This considers differences in path loss and the fact that there is more 1800 MHz spectrum available than 700 MHz, which affects cell edge speed.

Meanwhile, in built-up areas, including cities, small towns and villages, the propagation advantages of sub-1 GHz spectrum are essential to provide in-building coverage where mid-band spectrum cannot penetrate sufficiently.

Figure 2: Coverage comparison by band



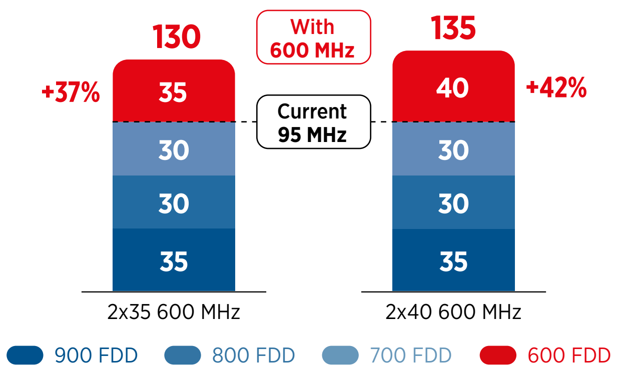
2 Theoretically, over four times the number of sites are needed to cover the same area with 1800 MHz. However, the real-world figure is lower. The precise figure depends on local propagation conditions, the amount of spectrum available in 700 MHz versus 1800 MHz, MIMO configurations in each band and the distribution of demand over the area covered by a site.

Increased speed: rural areas

There is a direct relationship between the amount of spectrum and the downlink and uplink 5G speeds which users experience. Availability of sub-1 GHz spectrum varies between countries: in ITU Region 1 (EMEA), there is potentially 210 MHz of sub-1 GHz spectrum, of which 115 MHz is DL, in Region 3 (APAC) there is typically 2x80 MHz of low-band mobile spectrum available, while Asia-Pacific Telecommunity (APT) is currently considering a new 2x40 MHz band plan in 600 MHz. We outline several scenarios in the graphs below.

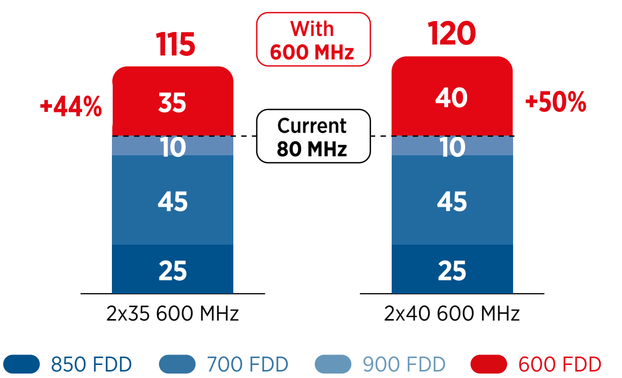
Increased throughput by Region

Figure 3: Region 1 (EMEA)



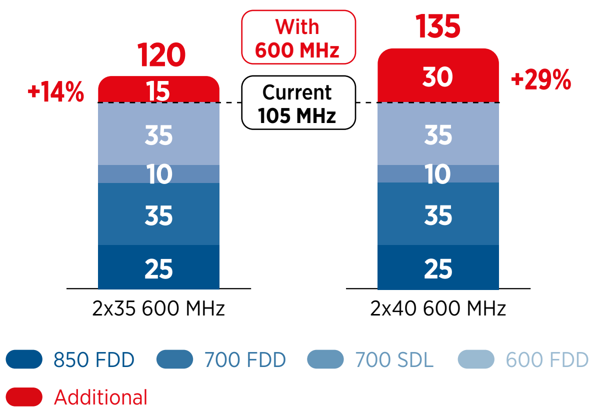
The first scenario for Region 1 shows the potential downlink speed increase for 2x35 and 2x40 additional 600 MHz spectrum without the use of the 20 MHz of SDL spectrum in the 700 MHz band.

Figure 4: Region 2 (LatAm) and Region 3 (APAC)



The scenario for both LatAm and Region 3 countries includes the 2x35 and 2x40 options in 600 MHz.

Figure 5: Region 2 (North America)



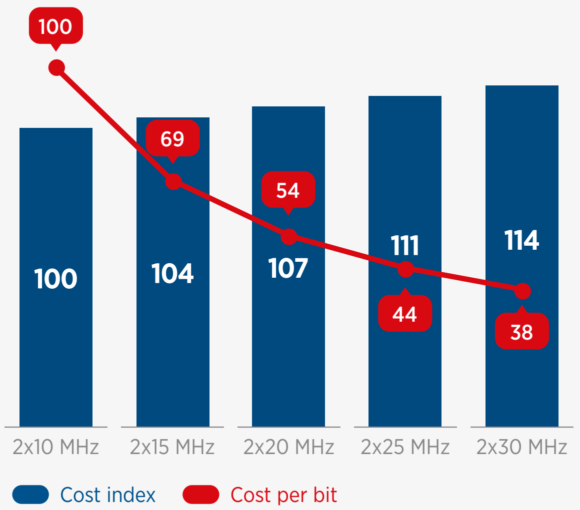
As the 600 MHz band is already used in the US and Canada with 2x35 MHz, the calculations for this region are hypothetical. The amount of spectrum in band n71 resulted from an auction that matched the willingness of broadcasters to relinquish spectrum at prices mobile operators were prepared to pay. According to FCC documents[3] for the 600 MHz auction, an auction outcome with 2x50 MHz would have been possible, extending the band further downwards. In the hypothetical scenarios for an additional 15 MHz and 30 MHz of DL spectrum being made available below 617 MHz, DL speeds could increase by 14% or 29%, respectively.

3 Expanding the Economic and Innovation Opportunities of Spectrum Through Incentive Auctions, DA/FCC #: FCC-14-50, Docket/RM: 12-268, 2014

03

Cost impact of low-band capacity

Figure 7: Cost efficiency of wider bands



Increasing sub-1 GHz spectrum capacity affects the cost-efficiency of 5G. This relates to the amount of spectrum deployed in a single band and the number of sub-1 GHz bands available.

Increasing spectrum can impact costs in four ways:

- Deployment of multiple sub-1 GHz frequency bands in a single radio and antenna reduces the cost per band deployed
- Deployment in a wide channel reduces the cost per MHz deployed and increases bandwidth utilisation
- 4T4R MIMO (Multiple-Input, Multiple-Output) deployment in a wider band can improve efficiency and reduce costs
- A single cell tower can serve more fixed wireless access (FWA) connections with additional bandwidth, thus lowering the cost per FWA connection

Spectral efficiency of wider channels

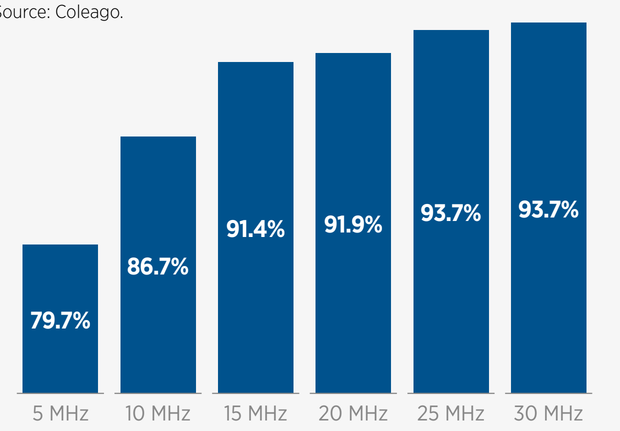
Sub-1 GHz spectrum is scarce when compared to mid-bands, making it vital to maximising spectral efficiency. The wider the channel, the greater the bandwidth utilisation.

4G and 5G transmission technology is structured into resource blocks. These resource blocks have fixed widths which may not fit exactly into a 5 MHz wide channel, and thus some bandwidth is not used. This unused portion of bandwidth declines with wider channels. In a 2x10 MHz deployment, only 86.7% of bandwidth is used for data throughput, but in a 2x30 MHz wide deployment channel, this increases to 93.7%, a gain of 8.1%.

In addition, performance gains in larger bandwidths come from better performance of frequency selective scheduling, larger resource pool with better optimisation potential, and less relative signalling overhead in wider carriers. These additional gains are in the order of 5 - 10% for a 20 MHz wide channel compared to a 10 MHz wide channel. This therefore brings overall efficiency gains for a 2x20 MHz wide channel compared to 2x10 MHz to 10 - 15%.

Figure 8: Channel bandwidth impact on utilisation

Source: Coleago.



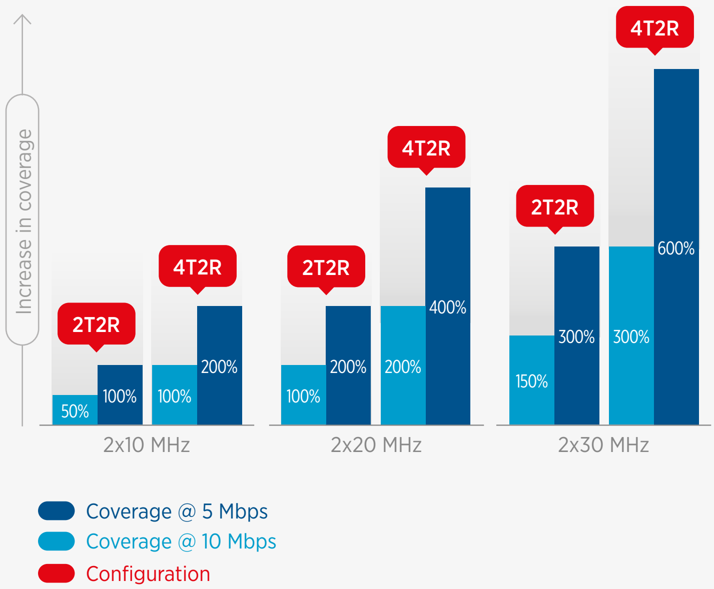
Wider channels for MIMO implementation

Larger channel bandwidths enhance the business case for MIMO. Deploying 4T4R MIMO technology in sub-1 GHz spectrum allows MNOs to dramatically increase cell-edge capacity and performance. However, deploying MIMO in small channels can be prohibitively expensive and impact consumer affordability. The more MHz that are available, the more cost-efficiency will improve.

The relative coverage that can be achieved with spectrum depends on:

- The amount of spectrum
- The configuration of MIMO (on network base stations and UE)
- The speed target

Figure 9: Impact of bandwidth and MIMO on 700 MHz band[4]



Impact of bandwidth and MIMO configuration on cell-edge speed coverage compared to a base (100%) of 2x10 MHz with a 2T2R configuration with a 5 Mbit/s speed target.

4 5 Mbps and 10 Mbps given as examples to show impact of speed target on coverage area. These are not actual target speeds for any particular technology generation.

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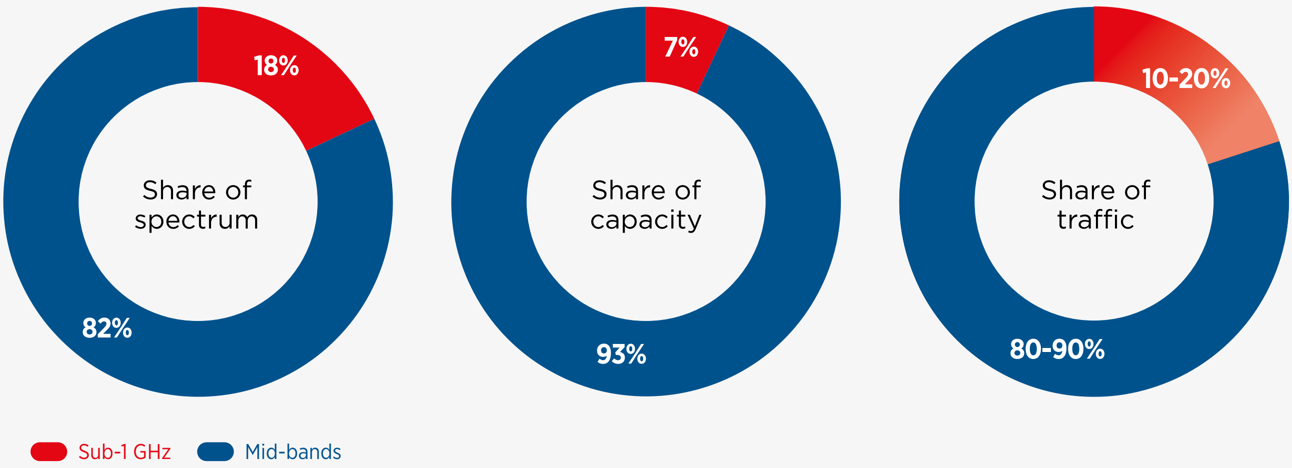
Low-band capacity gap

Figure 10: Sub-1 GHz share of spectrum, capacity and traffic

Source: Coleago.



Low-band spectrum is limited. Comparing the MHz volume of spectrum with mid-band, low band typically accounts for around 18% of spectrum and mid-bands for 82%, depending on the country. This calculation includes spectrum on spectrum assignment roadmaps that is not yet assigned to mobile operators.

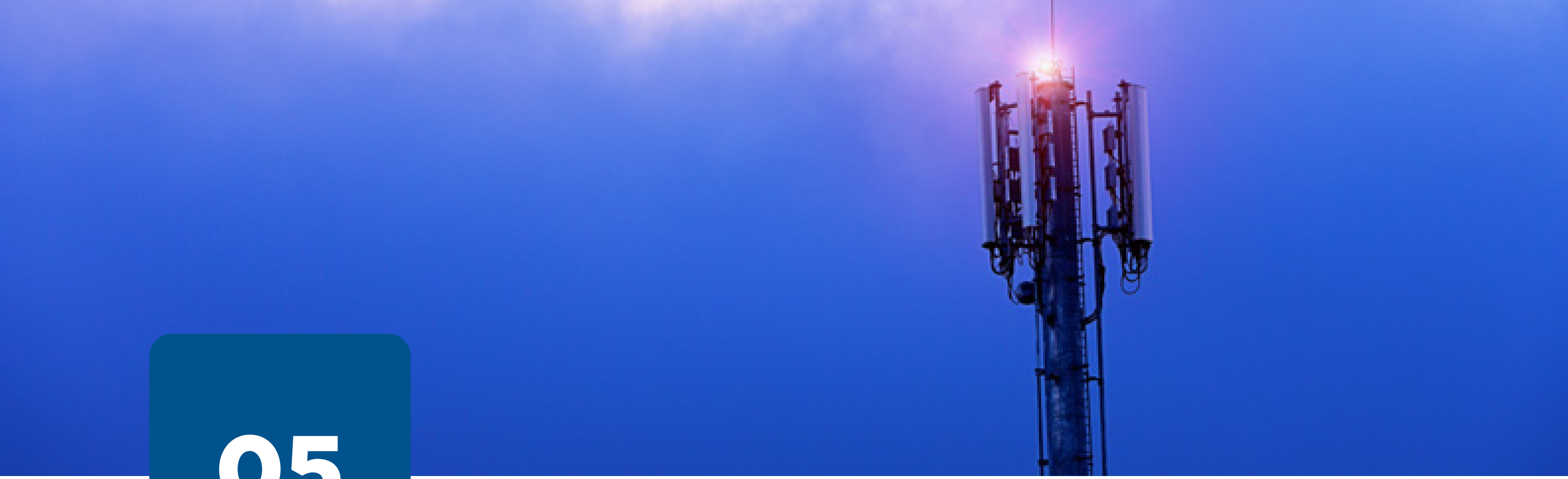
However, the MHz volume of spectrum does not represent how much network capacity is offered. The larger antennas required for low-band spectrum limit the opportunity to increase spectral efficiency using MIMO and beamforming. This matters both in urban areas where traffic density (Gbit/s/km2) is higher and in rural areas with low traffic density and low site density.

Thus, while the low band share of spectrum against mid-band is 18%, the share of capacity provided by low-band spectrum – once more efficient MIMO and beamforming are introduced in mid-bands – falls to 7%.

Against these two figures, where both mid- and low-band spectrum are available, data taken from mobile networks shows that low band typically carries between 10-20% of the traffic, showing a wide gap between sub-1 GHz area traffic capacity and area traffic demand. Additional low-band assignment can alleviate this capacity gap.

While mid-band spectrum availability grows (for example, via 3.8–4.2 GHz, 4.8 GHz or 6 GHz), the capacity gap between sub-1 GHz spectrum and mid-bands widens. Given the projected growth in mobile data traffic density, sub-1 GHz bands will face severe congestion compared to mid- and high-band capacity unless additional low-band spectrum is made available.

Ensuring that additional low-band spectrum accompanies expansion of mid-band and high band (i.e., mmWave) is crucial for maintaining digital equality.



05

Digital equality through low-band spectrum

Figure 11: Reduction in cell sites with 600 MHz

2x10 of 600 MHz	Reduction in sites 21%
2x20 of 600 MHz	Reduction in sites 33%

Reduction in rural cell sites

Additional low-band spectrum will help connect rural areas to better quality services by reducing the number of cell sites needed to reach the same level of performance. Today, operators typically aim to deliver at least 5 Mbit/s to 10 Mbit/s at the cell edge in rural areas, but this is expected to increase to 10 to 20 Mbps for 5G. Even with existing spectrum assets in other low bands, an additional 600 MHz spectrum will reduce the sites needed to provide 20 Mbps consistent coverage.

To reach rural connectivity goals, policies must address both the coverage gap (percentage of population not covered) and the usage gap (percentage of population covered but not using mobile broadband). In all countries, the usage gap is wider than the coverage gap.

While lack of knowledge, skills and relevance partially explain this gap, affordability is a major factor, especially in low and middle-income countries (LMICs). Importantly, these account for more than 90% of the world's unconnected population and 98% of the uncovered population.

As population coverage nears 100%, more area will need to be covered for each incremental coverage percentage as networks reach more and more sparsely populated areas. This general principle applies to virtually all countries: every additional per cent of population coverage is more expensive than the preceding per cent.

Consumers and businesses in newly covered areas will not benefit from high volume data at high speeds unless mobile operators can reduce the cost per bit. Having more sub-1 GHz spectrum is essential to improve investment efficiency and thus reduce the cost per bit.

Connected

93% of the world's population is covered by mobile internet

51% World's population are connected

Coverage gap

Global coverage gap: **7%**

Usage gap

Global usage gap: **43%**

Table 1: Rural coverage cost reductions

Source: Coleago.

	No additional spectrum	Plus 2x10 MHz of 600 MHz	Plus 2x20 MHz of 600 MHz
Spectrum	900 MHz – 2x10 MHz 800 MHz – 2x10 MHz 700 MHz – 2x10 MHz	900 MHz – 2x10 MHz 800 MHz – 2x10 MHz 700 MHz – 2x10 MHz 600 MHz – 2x10 MHz	900 MHz – 2x10 MHz 800 MHz – 2x10 MHz 700 MHz – 2x10 MHz 600 MHz – 2x20 MHz
Cell-edge downlink speed	20 Mbit/s	20 Mbit/s	20 Mbit/s
Single-user cell range[5]	27.0 km	30.5 km	33.1 km
Single-user cell area	1,897 km^2	2,412 km^2	2,843 km^2
Typical cell range[6]	9.0 km	10.2 km	11.0 km
Typical cell area	210 km^2	269 km^2	316 km^2
Reduction in cell sites	–	21%	33%

5 Simulation assumes a single cell-edge user per site; rural near line of sight, 50m 40W base station and using the Okumura-Hata propagation model; SINR performance simulations for 4x2 MIMO 64 QAM.

6 The typical cell range is how operators design their network, taking into account non-line of sight, terrain and cell loading.

06

Low-bands in urban environments

Data taken from mobile networks provides evidence that the relative lack of sub-1 GHz spectrum is the cause of the speed challenge indoors and in other hard-to-reach places.

Figure 12: Percentage of urban traffic per MHz

Source: Measurements in several mobile networks.

	Low bands	Mid-bands
of traffic	30%	70%
% of traffic per MHz	3%	2%

Real world data from MNOs using 2x10 MHz in low band and 2x35 MHz in mid-band.

In areas where both mid- and low-band spectrum are used, real-world data from operators consistently shows low-band capacity as a network bottleneck. Low-band capacity is lower and does not support high MIMO configurations but is still used in many urban environments, including deep indoors.

Although in cities, mobile networks provide continuous coverage and inter-site distances are short, 10-20% of traffic flows through sub-1 GHz spectrum. Sub-1 GHz spectrum is essential to provide eMBB speed coverage in hard-to-reach places, such as deep indoors or narrow alleys. Low band is not expected to offer the same speeds as mid-band but spectrum capacity can improve performance and bring them closer.

Real-world operator data demonstrates that:

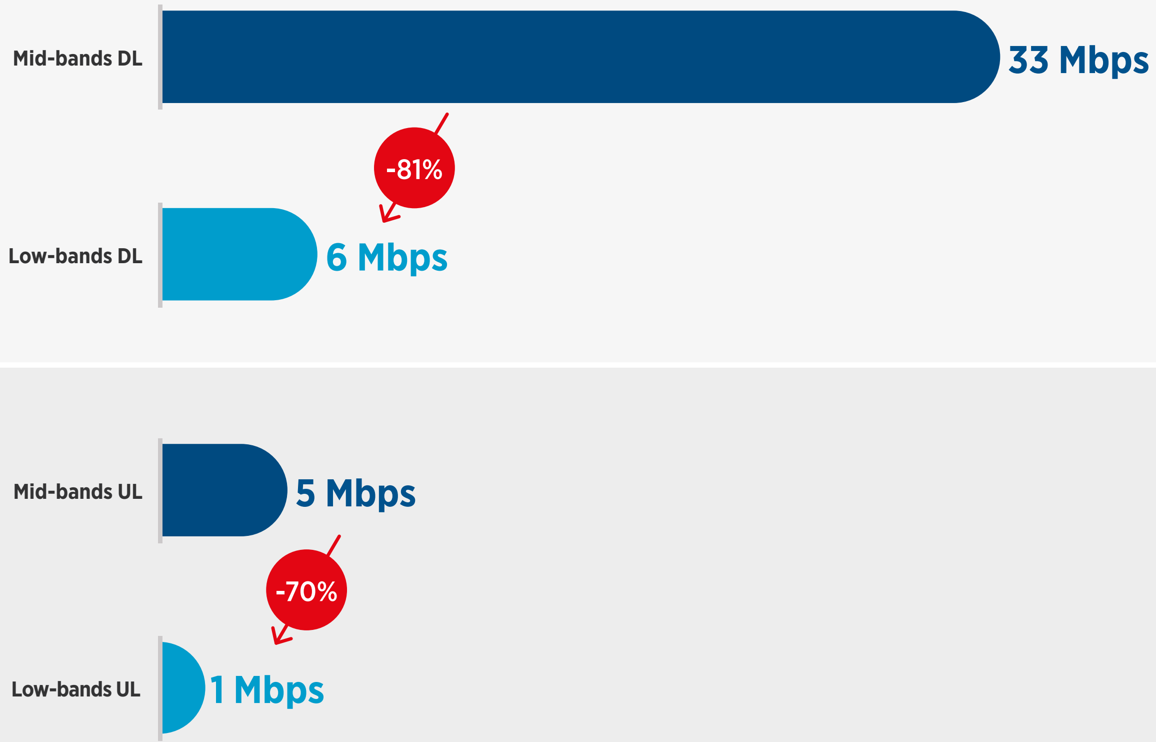
- 80% of network congestion in urban areas is in low band
- Low band carries 10-20% average of traffic in cities
- The user-experienced data rate in the busiest hours of the day using low band can be 80% slower (DL) and 70% slower (UL) than mid-band

Operator data also shows that traffic per MHz of spectrum in a 4G environment was 50% higher in low-bands than mid-bands, with 2x10 MHz in low band and 2x35 MHz in lower-mid bands.

In this context, the growth of 5G data traffic is a problem. While network densification and additional indoor cells will help address this, demand will grow for capacity beyond the reach of the mid-bands. For these deep indoor spaces, additional sub-1 GHz spectrum is vital to consistently meet the ITU-2020 requirements[7].

Figure 13: Busy hour low-band vs. mid-band speeds

Source: European mobile network operator.



The user-experienced data rate in the busiest hours of the day using low band can be 80% slower (DL) and 70% slower (UL) than mid-band

"Lower frequency spectrum (2x10 MHz of 700 MHz) allows operators to provide a given level of customer experience to a larger share of indoor locations than a network based on 1800 MHz (2x20 MHz of 1800 MHz), particularly in deep indoor locations... in the case of deep indoor locations, a network based on 2x10 MHz of 700 MHz can outperform a network with 2x20 of 1800 MHz (i.e. with twice the bandwidth)." **Ofcom UK[8]**

7 Report ITU-R M.2441-0 (11/2018)
8 Ofcom, "Award of the 700 MHz and 3.6-3.8 GHz spectrum bands", Annexes 5-18 – supporting information , p. 121

07

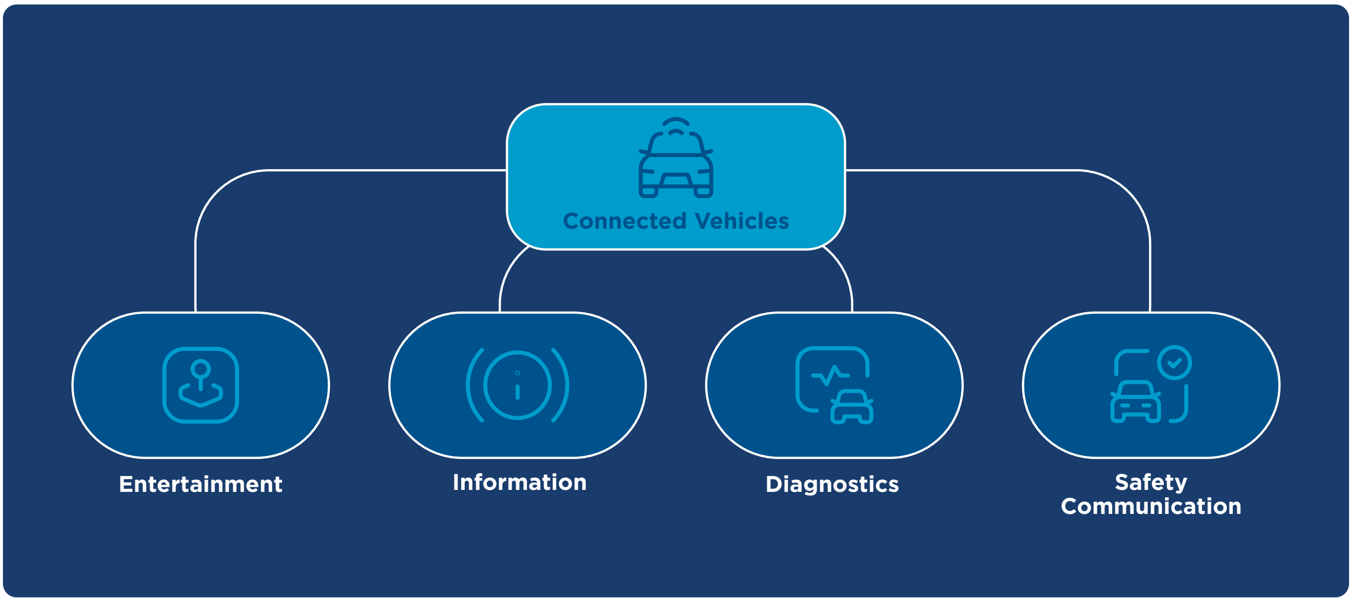
Transport and agriculture

5G on transport routes

5G coverage along roads and other transport links is an important policy goal. Inter-site distances along roads in non-populated areas are largely determined by the range of sub-1 GHz spectrum for a given cell-edge and cell-average speed target. Building additional sites along roads through rural areas is very costly. Depending on the country, these sites, including power and backhaul, can cost between US$400,000 and $700,000 each. Adding another sub-1 GHz radio to an existing site, including civil works, might cost $30,000 to $60,000.

The need for 5G capacity along roads will increase sharply to serve the connected vehicle use case. This spectrum need is driven by general eMBB use cases, including information, entertainment and diagnostics, as well as road safety-related communication.

On long stretches of rural highways, it is not economically feasible to provide continuous coverage with mid-bands, and that sub-1 GHz spectrum must provide sufficient bandwidth for connected vehicles. In a 5G environment, traffic demand from connected vehicles and passengers in those vehicles will increase substantially.



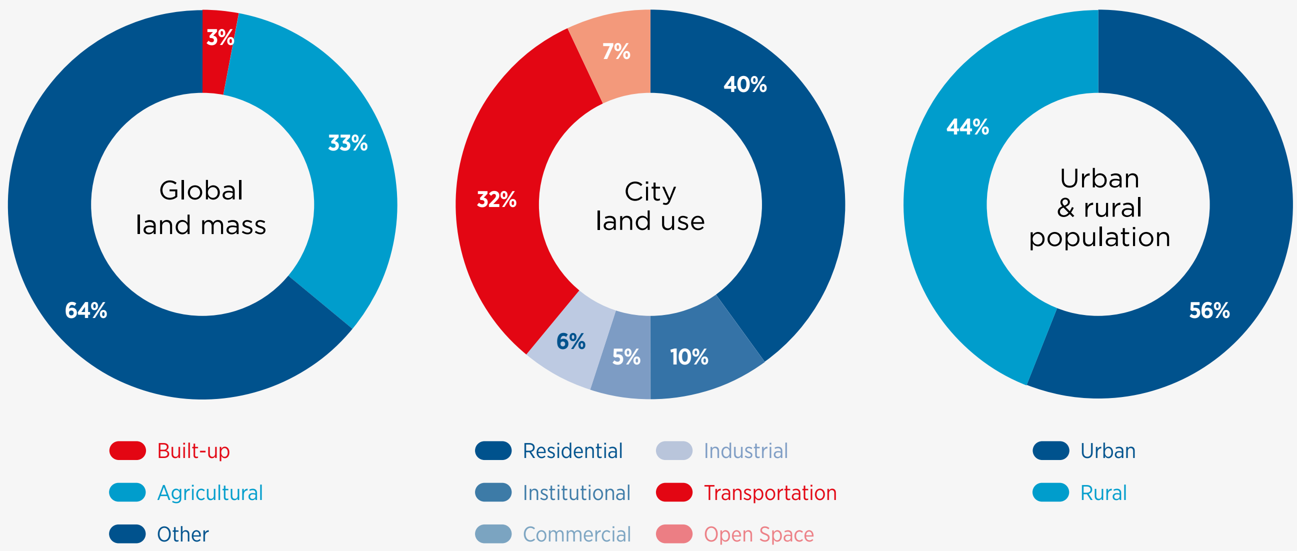
Agricultural coverage

At the end of 2020, 56.2%[9] of the world's population lived in cities.[10] The remaining 43.8% of the world's population lives in other built-up areas, such as rural small towns and villages, and a very small proportion in isolated houses.

For this population in LMICs, mobile is often the only source of connectivity, with much of it provided by sub-1 GHz spectrum. Therefore, an additional sub-1 GHz spectrum is essential to provide 5G mobile broadband connectivity and eliminate the urban-rural digital divide.

However, agricultural areas (rural areas where people live and work) make up around 33% of global landmass, and some of this area is intensively farmed. Covering such areas is challenging and is often achieved through base stations covering rural villages and roads.

Figure 14: Population and land use

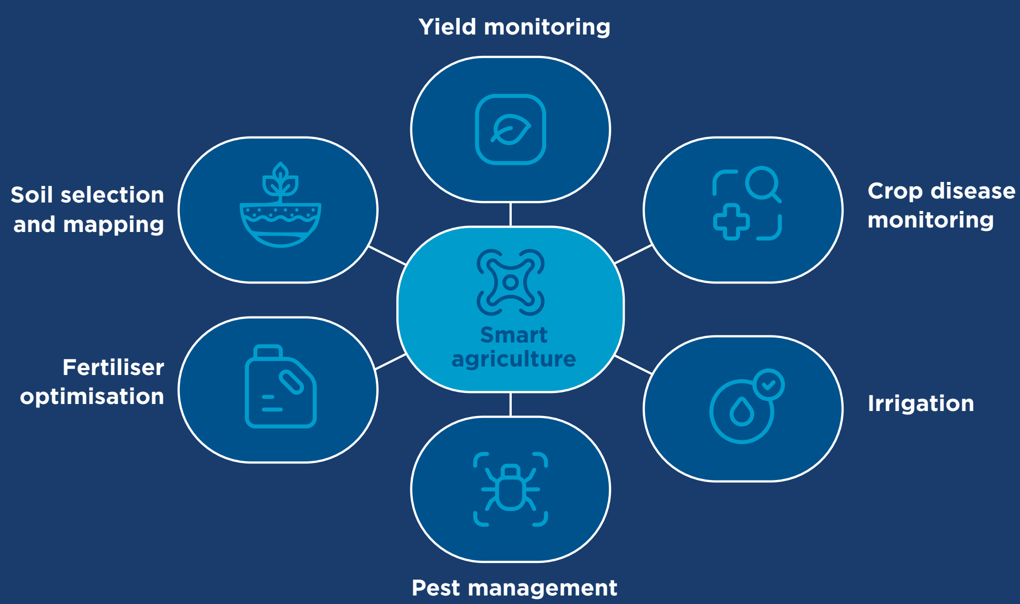


9 World Bank. (n.d.) "Population, total". World Bank Data.
10 UN Department of Economic and Social Affairs. (2018). World Urbanisation Prospects.

Smart agriculture solutions have an important role in optimising resources, reducing emissions, and averting a food shortage. The deployment of such solutions makes it crucial to cover large areas with mobile networks cost-effectively. Smart agriculture applications that rely on higher data rates, such as video-based crop analysis using drones, can only be deployed effectively if additional sub-1 GHz spectrum is made available.

Mobile regulatory policy tends to focus on coverage that delivers the greatest socio-economic benefit: population, road and railways and transport hubs. As a result, the percentage of agricultural area covered in most countries is significantly lower than the percentage of population covered.

Figure 15: Drone-enabled precision farming

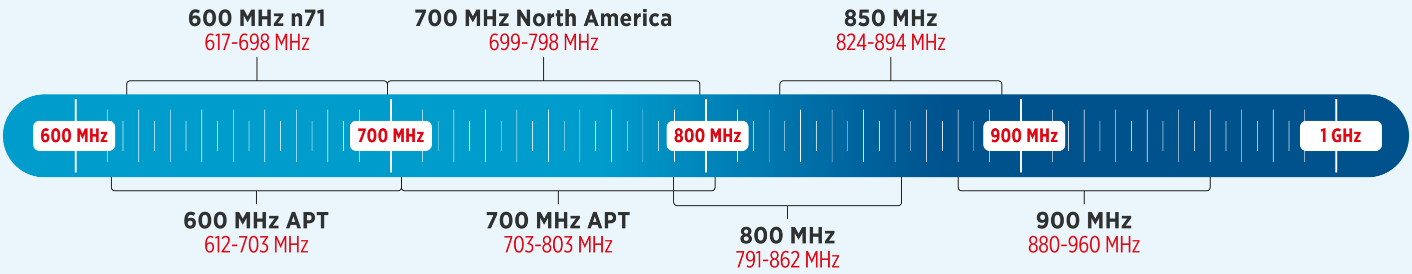


Smart agriculture requires on-ground and vertical coverage over large areas for drone connectivity. This is much more challenging than providing coverage along roads. As road coverage needs to be linear, building one additional mid-band site between existing cell sites is sufficient to compensate for the lack of capacity provided by sub-1 GHz spectrum. However, three additional sites would be required to cover an area of landmass rather than simply providing coverage along a line.

In addition, the cost of roadside in-fill sites is much lower than for sites away from the road where there is unlikely to be fibre or power.

While agricultural applications such as sensors require only a low data rate, video-based monitoring applications require data rates as high as 6 Mbit/s for HD streaming. The larger the area over which this speed can be provided, the more useful the applications for smart agriculture.

Appendix: Low-band spectrum



Source: 3GPP, Coleago.

Regional low-band variations

- **900 MHz** (Band 8, 2x35 MHz) is the original GSM band deployed in Regions 1, 2 (Latin America) and 3. In Regions 2 and 3, some countries mixed 900 MHz (Band 8) and 850 MHz (Band 5) assignments, but this does not significantly alter total sub-1 GHz availability.
- **850 MHz** (Band 5, 2x25 MHz) is the first cellular band for North America and used in other Region 2 countries and Region 3.
- **800 MHz** (Band 20, 2x30 MHz) is the EU Digital Dividend band used as the first LTE (4G) coverage band in Region 1.
- **700 MHz APT** (Band 28, 2x45 MHz) is the LTE (4G) coverage band for Asia Pacific and it has also been adopted in Latin America. However, in Region 1, where the band is used as the 5G coverage band, only 2x30 MHz is available. There is also 20 MHz of supplementary DL spectrum (Band 67) specified in the Band 28 centre gap, but it has only been assigned in a few countries.
- **700 MHz North America** consists of a total of 80 MHz, including 10 MHz of supplementary downlink (SDL) spectrum.
- **600 MHz US DD** (Band n71, 2x35 MHz) has been assigned and is used in the US and Canada. It is in the 5G coverage band.
- **600 MHz APT** (3GPP 2x40 MHz) is being considered by APAC and is still under development.

For more information, please visit the
GSMA website at www.gsma.com