Mobile Evolution in 6 GHz

The impact of spectrum assignment options in 6.425–7.125 GHz

September 2024

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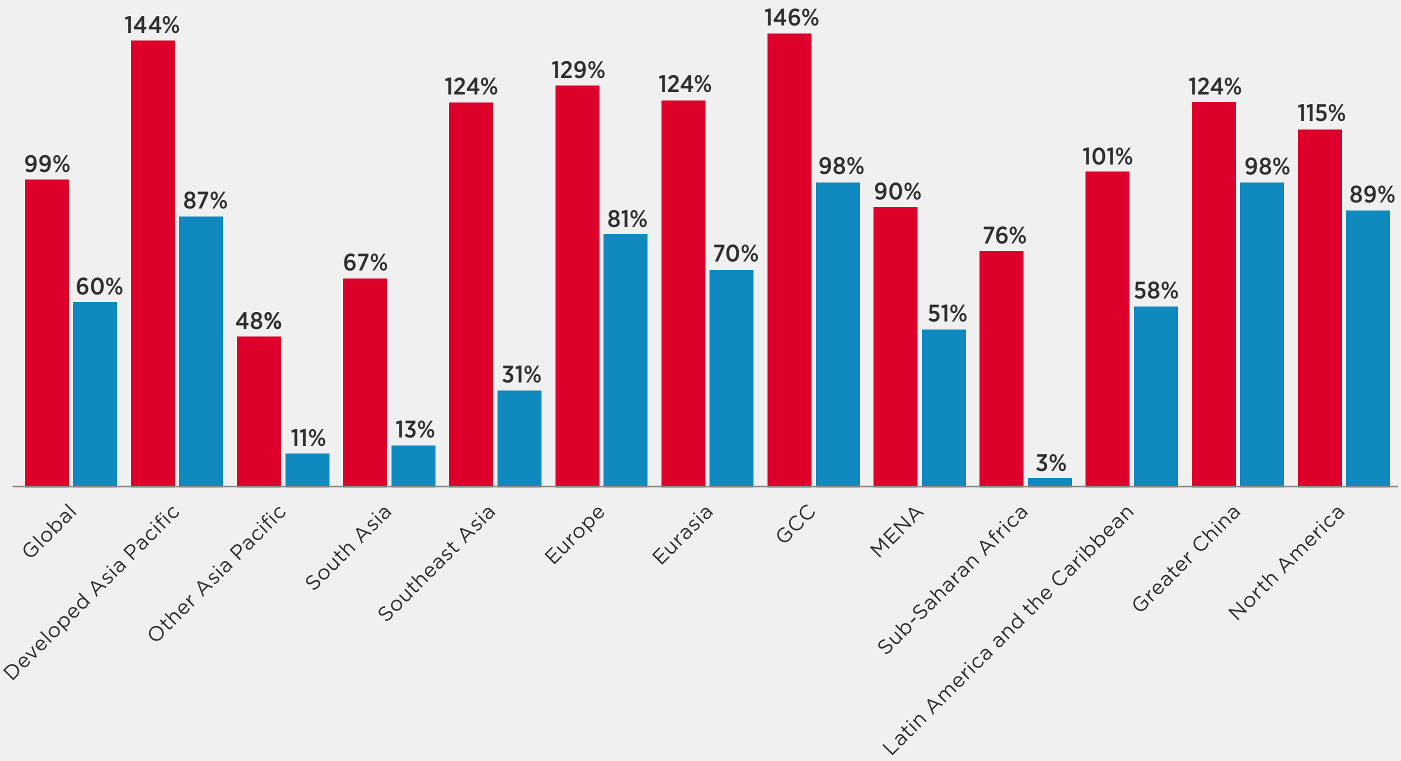
Executive summary

1. Introduction

The overwhelming majority of internet users rely on at least some form of wireless connectivity. This obviously applies to the 57% of the world's population that uses mobile internet,[10] while Wi-Fi provides the final link between a wireless-enabled device and a router or access point receiving a connection over fibre, cable, copper, fixed wireless or satellite.

The roles of the two types of connectivity vary by market. In countries with widespread fixed broadband infrastructure, mobile and Wi-Fi are complementary, with the latter used in places where a fixed connection is available (especially at home or in an office) and mobile used elsewhere. However, in many countries – especially low- and middle-income countries in Sub-Saharan Africa and South Asia – adoption of fixed broadband remains limited (see Figure 1). In these countries, most internet users rely entirely on mobile rather than Wi-Fi over a fixed connection.

Figure 1
Mobile and fixed broadband penetration, 2023



Source: GSMA Intelligence and ITU

Note: Mobile broadband penetration refers to 3G, 4G and 5G connections as a proportion of the population. A connection is a unique SIM card that has been registered on a mobile network. Connections differ from subscribers in that a unique subscriber can have multiple connections. Fixed broadband penetration refers to residential broadband subscriptions as a proportion of households. Appendix 2 provides the list of countries in each region.

Key findings

- Traffic growth is expected to continue increasing in absolute terms for both mobile and fixed broadband connections (and therefore also Wi-Fi).
- Mobile use is mostly indoors and delivered via mid-band frequencies. In the case of 5G, most indoor use is supported by the 3.5 GHz range.
- Mid-band frequencies provide good quality indoor coverage, with much faster speeds than low-band spectrum.
- While mobile operators have an incentive to be spectrally efficient, Wi-Fi could utilise spectrum more efficiently, including by upgrading legacy Wi-Fi 4 devices which remain in wide use.

10. State of Mobile Internet Connectivity Report 2023, GSMA, 2023

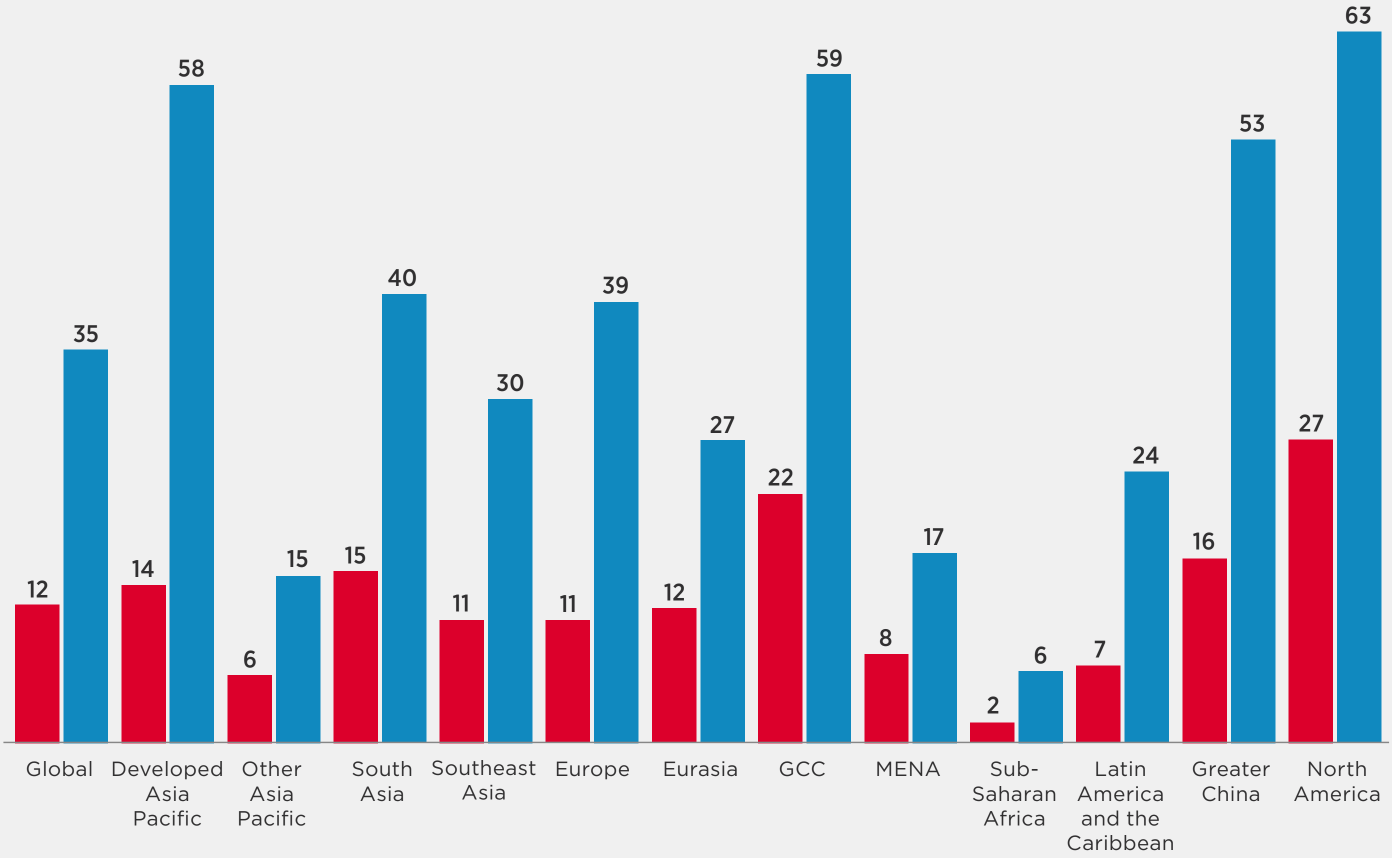
2.1 Traffic growth is expected to increase for both mobile and fixed broadband

Figure 2a shows the global level of mobile traffic (in exabytes, or EB, per month) since 2016. Some industry analysts have noted that growth in percentage terms is expected to decline. For example, between 2016 and 2017, there was a 78% increase in growth (from 9 to 16 EB per month) compared to a 31% increase between 2022 and 2023 (from 104 to 136 EB per month). However, this simply reflects the lower level of traffic in the initial years of 4G growth.

Mobile networks need to manage the absolute increases in traffic. Figure 2b shows this has been increasing over time and is expected to continue to 2030. For example, growth in global traffic in 2023 was greater than absolute traffic levels five years earlier in 2018 – even though the percentage growth in 2023 was lower.

Growth in mobile traffic is expected to occur across all regions. Figure 2c shows that while there are significant differences across regions, growth in traffic per mobile connection during 2023–2030 is expected to be 2–4× greater than in the previous seven years, depending on the region.

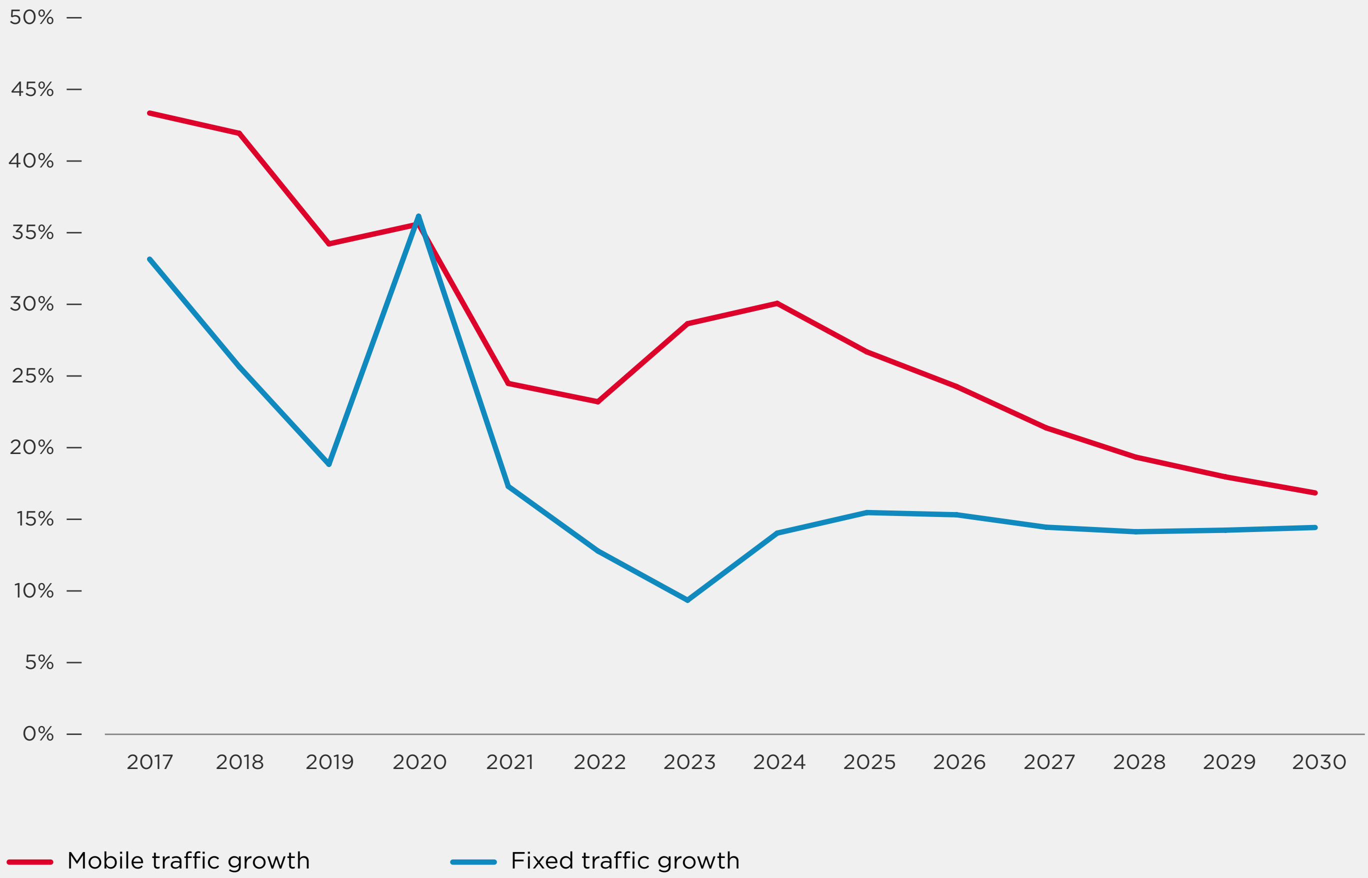
Figure 2c
Increase in traffic per mobile connection
GB per month



Source: GSMA Intelligence
Note: FWA and cellular IoT traffic are not included in the analysis.

It is therefore important that regulators and policymakers consider the absolute levels and increases in network traffic, rather than the percentage growth. When considering the latter only, we do, in fact, observe similar trends in fixed and mobile traffic. Figure 3 shows historic and forecast annual growth in mobile and fixed traffic in Europe, highlighting that in percentage terms both are declining – though are still significant by 2030, at 15–20%. This means both types of traffic will continue increasing in absolute terms.

Figure 3
Mobile and fixed traffic: percentage growth in Europe

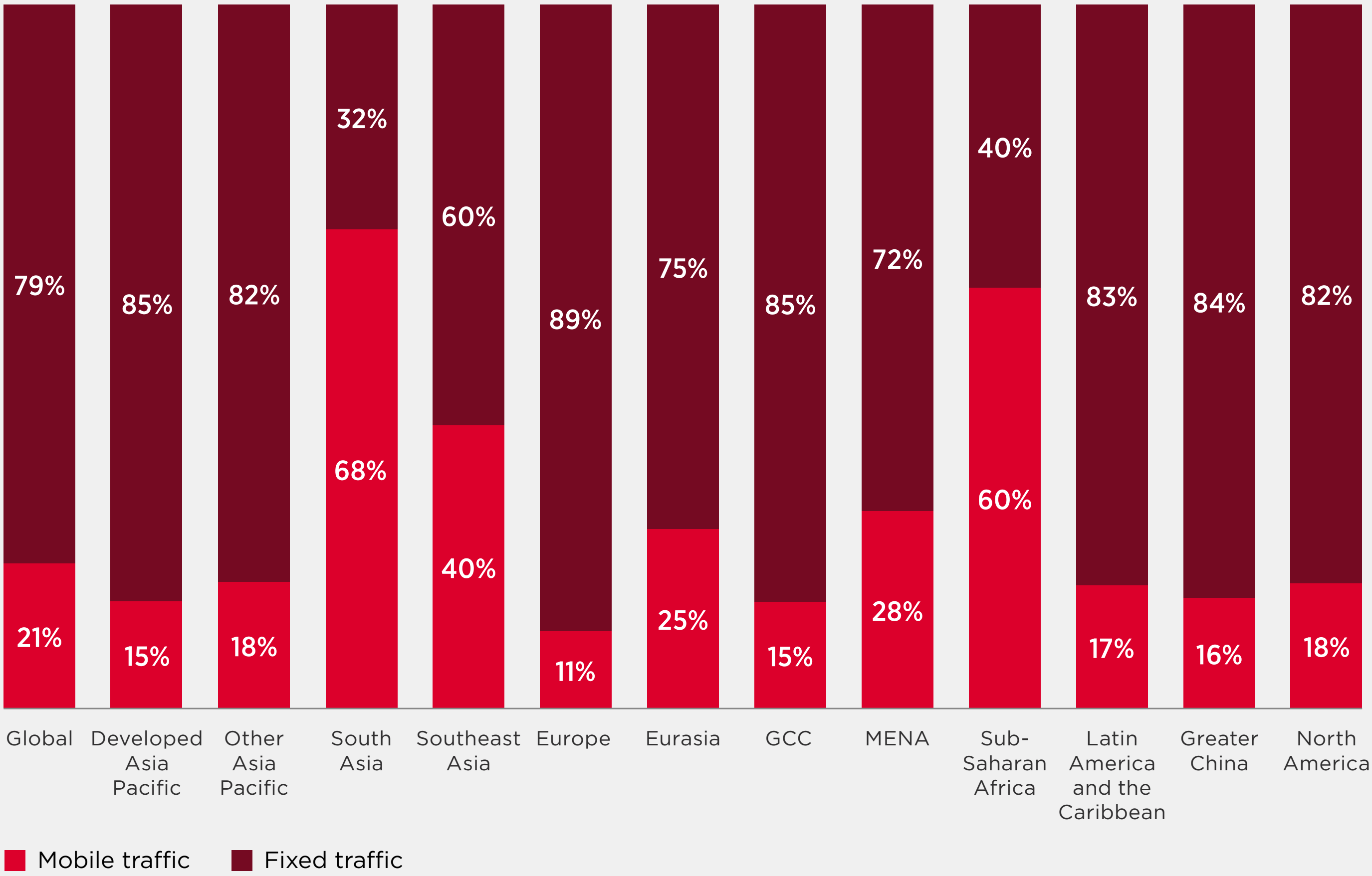


Source: GSMA Intelligence

It is important that regulators do not just take total traffic into consideration when deciding the optimal use of spectrum. Assumptions are sometimes incorrectly made that since global fixed traffic is around four times greater than mobile (see Figure 4), there is a greater need for unlicensed spectrum to support the delivery of fixed traffic via Wi-Fi. However, a simple comparison of traffic delivered over mobile and Wi-Fi is not like-for-like. Mobile technology provides wide area coverage from sites to thousands of end users who can be either indoors or outdoors, and macro cell sites can provide coverage up to 15–20 kilometres. Wi-Fi and other unlicensed RLAN technologies typically provide indoor, short-range coverage (up to 50 metres) to offer best-efforts connectivity for a single household of 1–5 people, with most data delivered by the underlying copper, fibre, wireless or satellite connection.

While most traffic globally is carried by fixed networks, this is not the case in every country and region. In particular, mobile traffic significantly exceeds fixed traffic in South Asia and Sub-Saharan Africa (see Figure 4). The two regions account for almost 40% of the global population. The traffic reflects the low levels of fixed broadband penetration in the two regions.

Figure 4
Distribution of mobile and fixed traffic by region, 2023

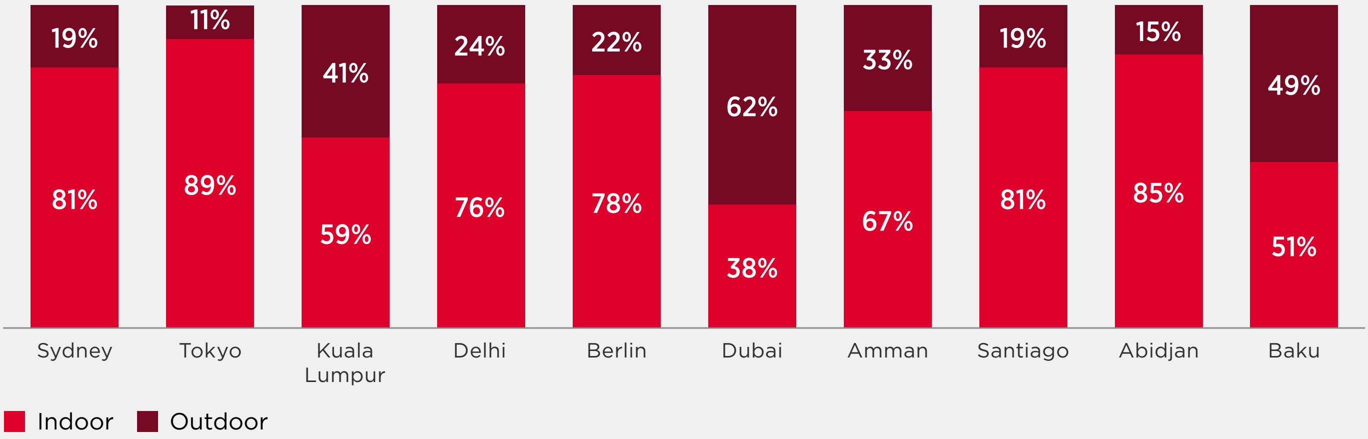


Source: GSMA Intelligence and ITU
Note: FWA and cellular IoT traffic are not included in the analysis.

In many countries, mobile operators are converged providers offering fixed and mobile. For example, mobile operators account for more than a third of fixed broadband subscriptions in Brazil and Mexico, around 70% in France and Germany, 80% in Indonesia and Colombia, and more than 90% in China and South Korea.[11] Their customers use both licensed mobile and unlicensed WAS/RLAN connectivity as part of the suite of services offered to them. As such, mobile operators focus on the best means of getting localised connectivity to the end user. This makes them well-placed to determine which technology has the greatest need for additional spectrum.

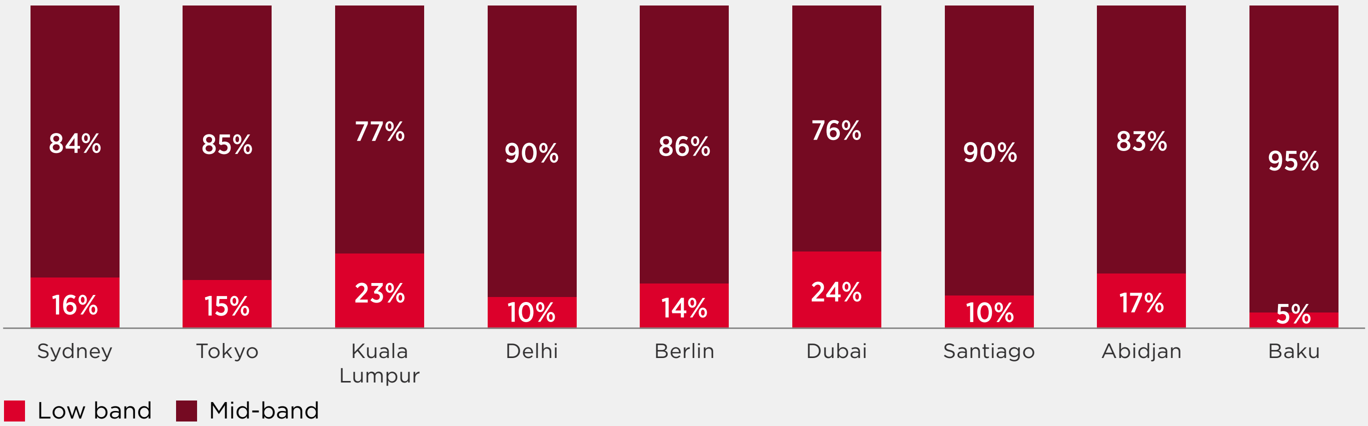
11. Harnessing Spectrum Diversity, GSMA

Figure 5a
Distribution of mobile scans based on indoor/outdoor locations



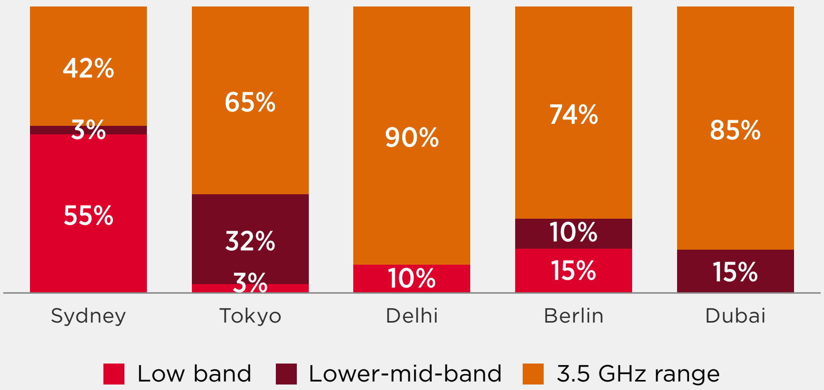
Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

Figure 5b
Distribution of 4G and 5G indoor mobile scans by spectrum band



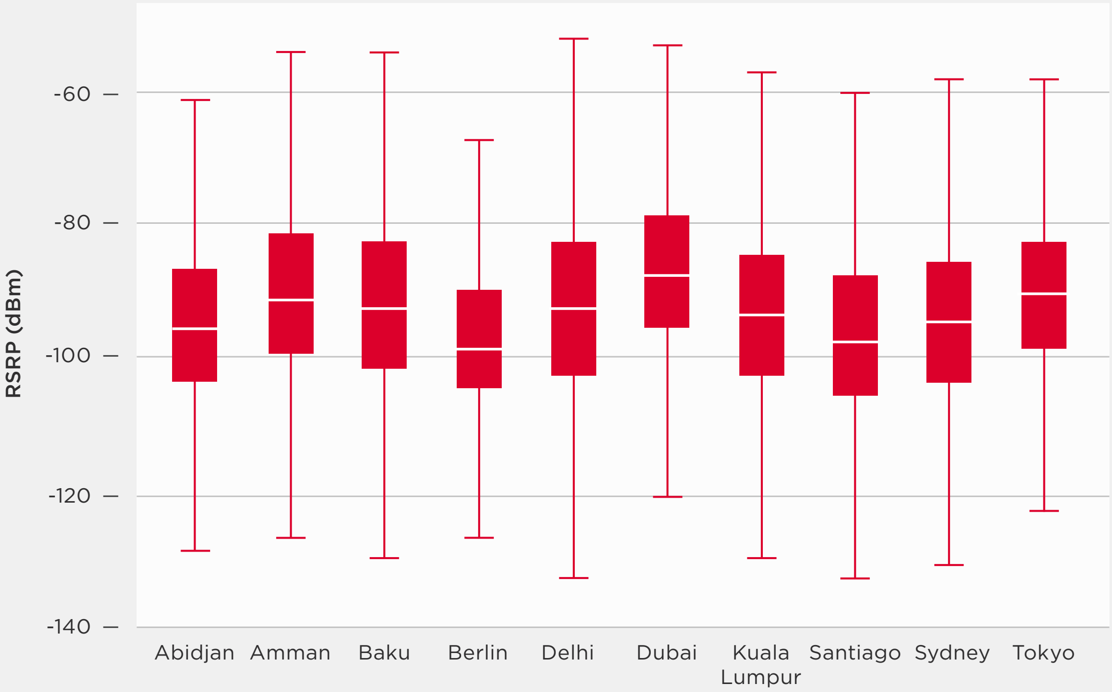
Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla
Note: Low bands refer to frequencies below 1 GHz, while mid-bands refer to frequencies above 1 GHz excluding mmWave bands. Insufficient data on low bands in Amman.

Figure 5c
Distribution of 5G indoor mobile scans by spectrum band



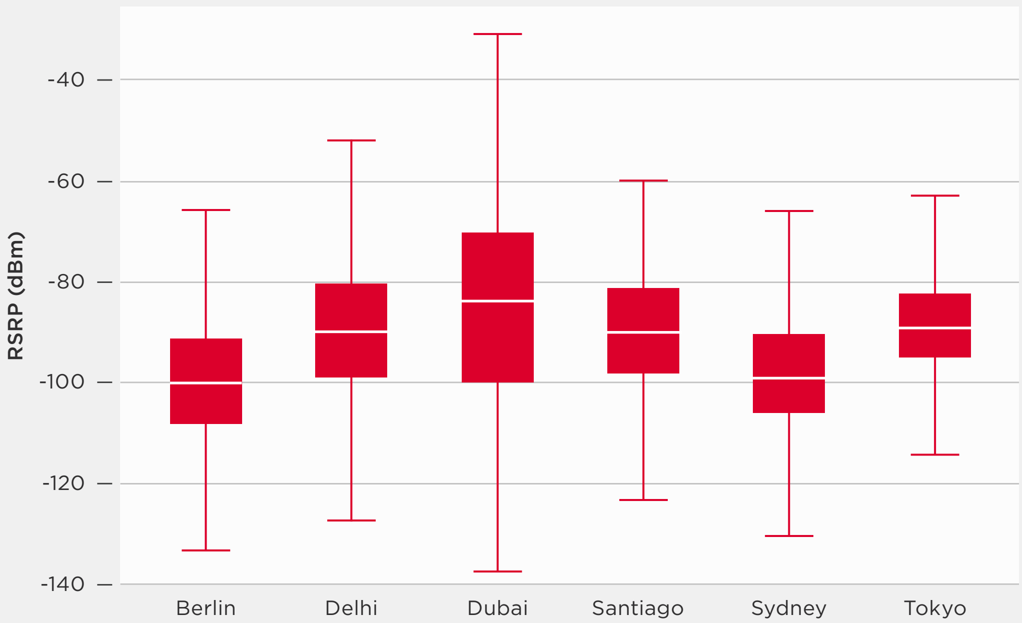
Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla
Note: Low bands refer to frequencies below 1 GHz, while lower mid-bands refer to frequencies between 1 and 3 GHz. The 3.5 GHz range refers to frequencies in the 3.3–4.2 GHz range and excludes mmWave bands.

Figure 6a
Distribution of 4G/5G indoor signal strength delivered by mid-bands



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla
Note: Mid-bands refer to frequencies above 1 GHz and exclude mmWave bands.

Figure 6b
Distribution of 5G indoor signal strength delivered by 3.5 GHz range

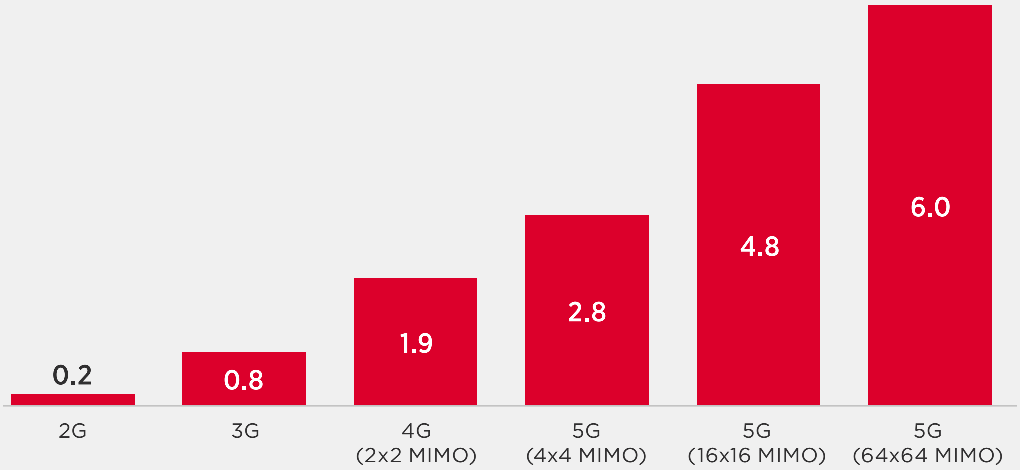


Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla
Note: The 3.5 GHz range refers to frequencies in the 3.3–4.2 GHz range

2.5 How efficiently do mobile and Wi-Fi utilise spectrum?

Almost all governments and policymakers aim to ensure spectrum is used efficiently.[18] With each technology cycle, mobile has made more efficient use of spectrum, as shown in Figure 8, with the spectral efficiencies of 5G more than seven times greater than that of 3G. Operators also have an incentive to utilise spectrum efficiently, because in almost all countries they face a pricing signal to do so – whether they purchase spectrum in an auction and/or pay renewal or annual fees (or have a licence obligation). This means that in addition to improving spectral efficiencies, they also reuse spectrum where possible by densifying networks.

Figure 8
Mobile spectral efficiencies by generation
Bps/Hz



Source: GSMA Intelligence

By contrast, where a spectrum user does not face a pricing signal, there is less incentive to deploy it as efficiently as possible. Figure 9a shows how Wi-Fi theoretical spectral efficiencies have evolved by generation, with the spectral efficiencies of Wi-Fi 6 around twice that of Wi-Fi 4. However, these headline rates are rarely achieved due to co-channel and non-co-channel interference, especially in densely populated, urban apartment buildings. Given this challenge, several studies have sought to assess actual Wi-Fi spectrum needs to deliver certain speed requirements (for example, 1 Gbps) in dense urban apartment blocks. This includes analysis by Qualcomm (2016 and 2023),[19] Analysys Mason and Huawei,[20] and Plum Consulting.[21]

More recently, Comtel published the results of a series of field tests on Wi-Fi connectivity in a high-density urban residential environment, with the aim of evaluating the ability of Wi-Fi access points to effectively handle high traffic volumes while subjected to significant interference.[22]

The results of these studies vary considerably according to the following assumptions and inputs:

- frequency bands and channels used
- number of access points
- backhaul between access points (Ethernet or WLAN)
- number of devices (or STAs)
- number of antenna, per access point and per STA
- coverage
- frequency reuse
- access point channels
- use of unlicensed mmWave in the 57–71 GHz range.

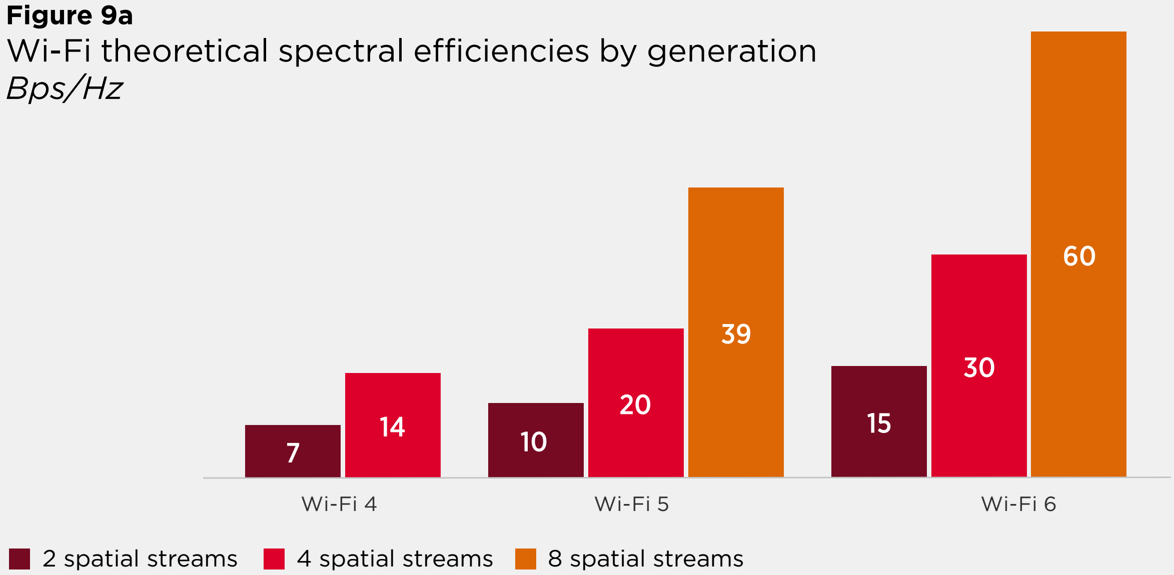
18. For example, Decision No 676/2002/EC of the European Parliament and of the Council, Article 1 states, *"The aim of this Decision is to establish a policy and legal framework in the Community in order to ensure the coordination of policy approaches and, where appropriate, harmonised conditions with regard to the availability and efficient use of the radio spectrum necessary for the establishment and functioning of the internal market in Community policy areas such as electronic communications, transport and research and development (R&D)".*
19. A Quantification of 5 GHz Unlicensed Band Spectrum Needs, Qualcomm 2026; Presentation for the UK Spectrum Policy Forum On Future Demand for Unlicensed Spectrum, Qualcomm, 2023
20. Impact of additional mid-band spectrum on the carbon footprint of 5G mobile networks: the case of the upper 6GHz band, Analysys Mason, 2023
21. Wi-Fi Spectrum Requirements, Plum Consulting, 2024
22. See https://www.comtelitalia.it/indoor_connectivity_test_en/

Figure 9b shows the range of spectral efficiencies implied from each study, based on the spectrum required to deliver 1 Gbps. The lower range typically assumes one access point, one end user device (or STA), 99% coverage, minimal frequency reuse, no utilisation of mmWave and that STAs will have two antennas even in the long term. The upper range adjusts one or two of these assumptions – for example, 2–4 access points, 90% coverage, greater frequency reuse or assuming STAs will have four antennas in the long term. This is important, as when deciding how to assign spectrum outside of a market-based mechanism, policymakers should incentivise the efficient use of spectrum and avoid assigning spectrum to compensate for inefficient use.

Figure 9a

Wi-Fi theoretical spectral efficiencies by generation

Bps/Hz

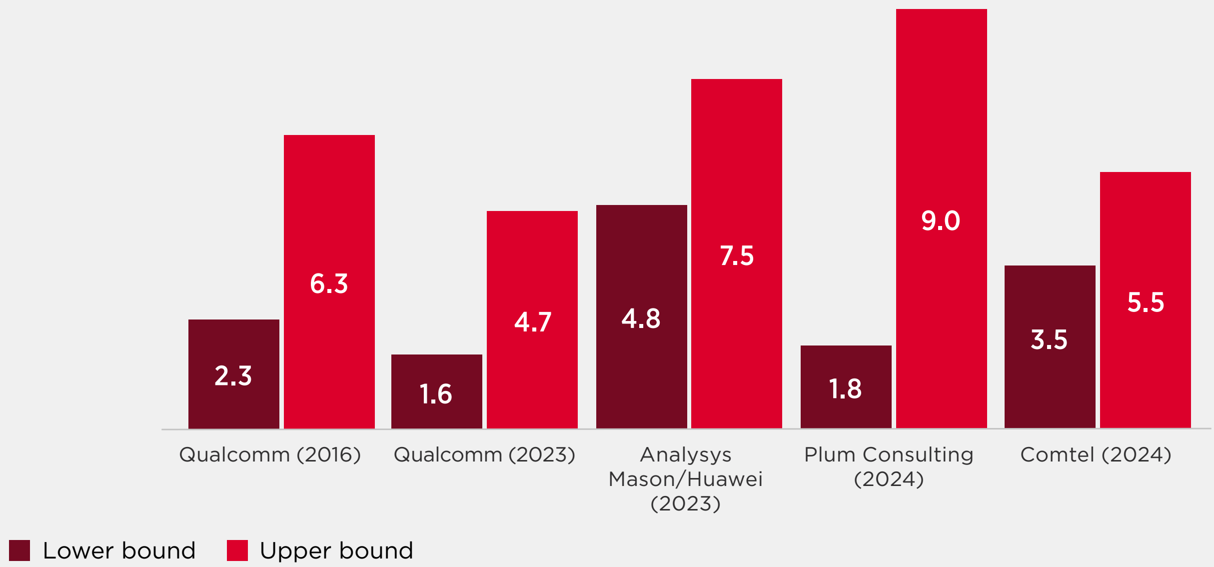


Source: GSMA Intelligence calculations based on the MCS Index table

Figure 9b

Wi-Fi spectral efficiencies to deliver 1 Gbps

Bps/Hz



Source: GSMA Intelligence calculations based on the respective studies

Wi-Fi performance can be significantly improved by upgrading Wi-Fi 4 devices

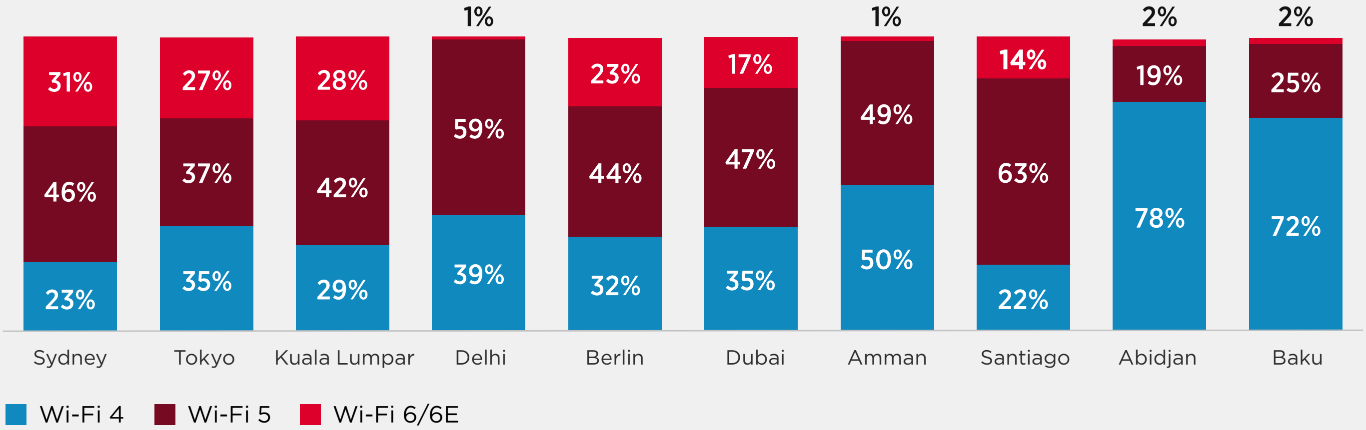
A related point regarding the efficient deployment of unlicensed networks is whether they utilise the most efficient technology. In the 10 cities considered in this study, Figure 10a shows a significant proportion of Wi-Fi scans were on Wi-Fi 4, ranging from 22% in Santiago to 78% in Abidjan.[23]

As demonstrated in Figure 10b, the type of Wi-Fi technology has a significant impact on user experience. Download speeds on Wi-Fi 6/6E were up to 15× faster than Wi-Fi 4. This shows that Wi-Fi performance could be significantly enhanced by upgrading users to the latest technology, as well as more efficient deployments indoors. It is also worth emphasising that the fast speeds observed on Wi-Fi 6/6E in this analysis have not been dependent on access to the lower 6 GHz band. Figure 10c shows that when looking at Wi-Fi 6/6E scans, less than 1% have utilised the lower 6 GHz band, with the exception of Tokyo. This includes cities such as Berlin, Sydney and Santiago, where the lower 6 GHz band has been available to use for unlicensed RLAN technologies.

Wi-Fi speeds will be constrained by the maximum speed of the underlying copper, fibre or cable connection. Around half or more fixed broadband subscriptions cannot deliver speeds greater than 100 Mbps in Europe, Latin America & the Caribbean, South Asia, Southeast Asia, Sub-Saharan Africa and MENA (outside of the GCC).[24] In such cases, Wi-Fi and the amount of unlicensed spectrum will never be a capacity bottleneck.

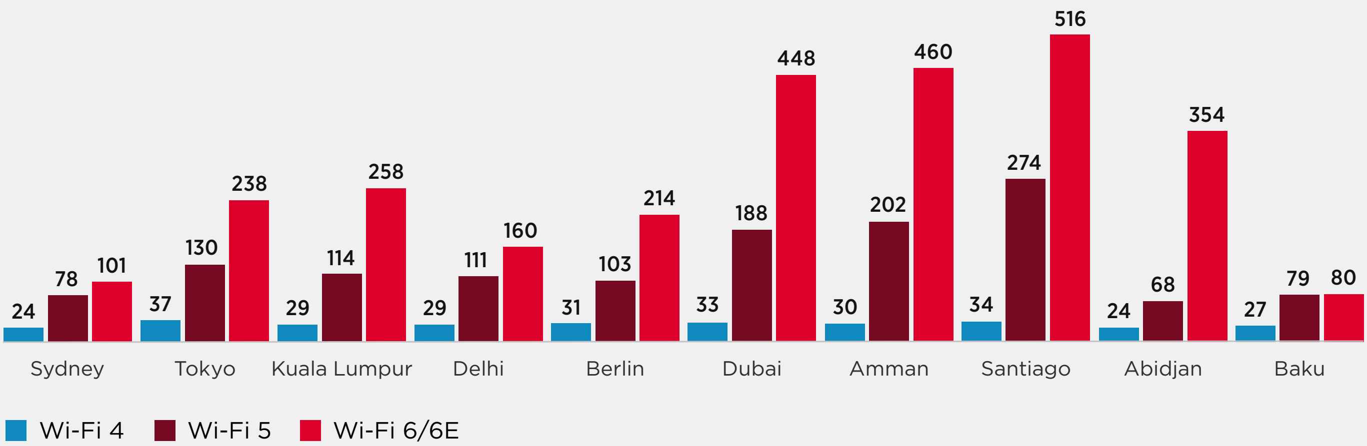
23. This is further supported by analysis in other cities and countries. See for example "ISPs Need to Do More to Improve Wi-Fi Performance in the Home", Ookla, May 2023; "Gulf ISPs should help fiber customers upgrade and configure their Wi-Fi routers to deliver faster speeds", Ookla, October 2023.
24. GSMA Intelligence analysis of ITU data

Figure 10a
Distribution of Wi-Fi scans by technology



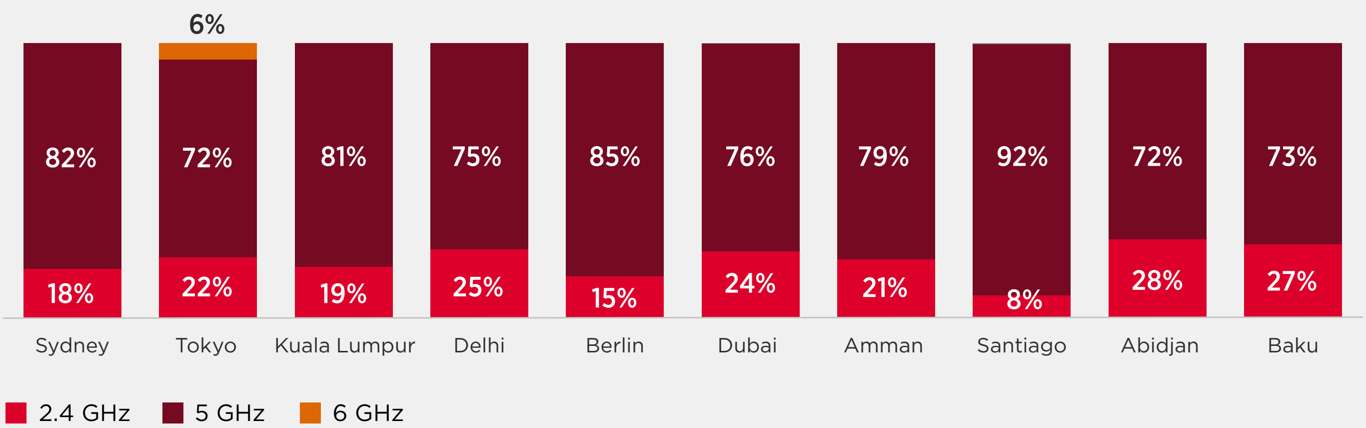
Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

Figure 10b
Median Wi-Fi download speeds by technology (Mbps)



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

Figure 10c
Distribution of Wi-Fi 6/6E scans by band



Source: GSMA Intelligence analysis, based on Speedtest Intelligence data provided by Ookla

3. Economic assessment of policy options in the upper 6 GHz band

For this study, it has not been feasible to assess each option being discussed in relation to sharing the upper 6 GHz band between licensed and unlicensed use, as there is not yet sufficient clarity on how each approach would be implemented. For example, geographic sharing would depend on how the relevant geographic segments for shared use are defined (i.e. where are mobile and Wi-Fi permitted to use the band?). Dynamic sharing would depend on which parts of the band are prioritised for each use (and whether this varies based on the time or location) as well as the sharing mechanism used (for example, managed databases, spectrum sensing or a combination of both). It is also currently unclear what the costs of these solutions would be, and their impact on mobile and Wi-Fi deployments in the upper 6 GHz band (in terms of capacity loss, for example).

However, using the framework developed for Scenarios 1 and 2, we can consider the impact of reducing the power of mobile deployments, as there is initial evidence on the implications for mobile spectral efficiency and capacity[31] (though there may still also be a requirement for additional mitigation to ensure no interference with Wi-Fi, which is not captured). While the impact depends on the level of power restriction put in place, we have modelled one scenario based on a 50% reduction in capacity offered by the upper 6 GHz band for mobile (see Appendix 1 for further details). As more details are developed on other sharing approaches and further analysis and evidence is gathered, the framework developed in this study can be applied to carry out an economic assessment of those options.

31. See Ericsson submission, ECC PT1(24)110, Vodafone submission, ECC PT1(23)033 and Huawei submission ECC PT1(24)_CG6GHz022.

4. Economic assessment: results and key findings

4.1 Scenario 1 – the greatest economic benefit in all countries studied

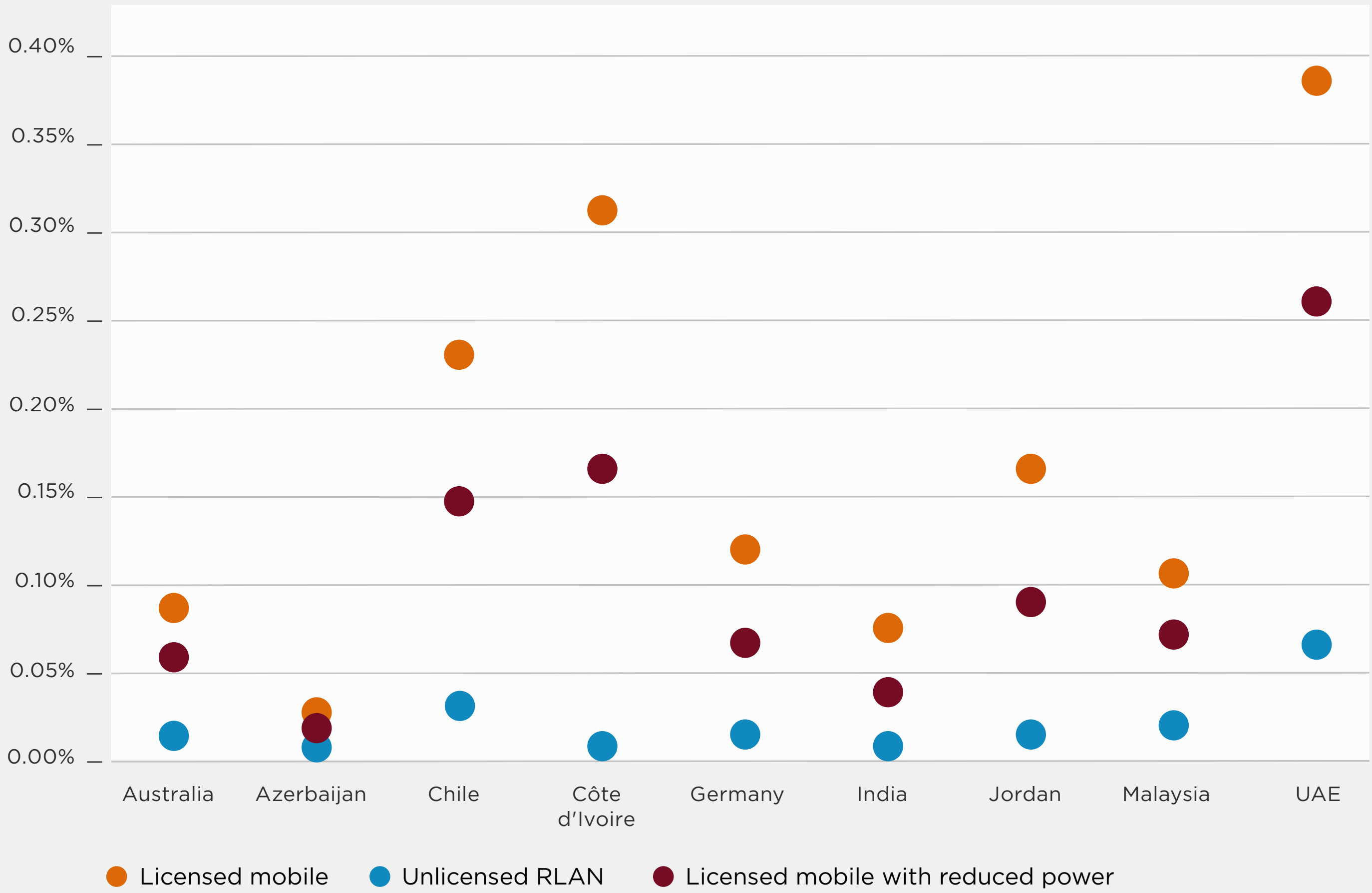
The results of our assessment, presented in Figure 12, show that across the nine countries studied, the greatest economic benefit in all countries is for Scenario 1, where the upper 6 GHz is assigned for full-power, macro-cell licensed use. This is followed by Scenario 3, enabling shared use via lower IMT power levels, and then Scenario 2 (assigning the band for unlicensed use).

The benefits of Scenario 1 are 3–20× greater than Scenario 2, with the exception of India and Côte d'Ivoire, where they are even greater due to the limited adoption of FTTH/B and cable broadband compared to mobile broadband. The benefits for Scenario 3 represent an upper bound as they do not include potential mitigation costs to manage interference between low-power mobile deployments and Wi-Fi.

The main reasons for these consistent results are as follows:

1. Mobile is more likely to be capacity-constrained than Wi-Fi in each country.
2. There remains scope to increase Wi-Fi capacity by improving Wi-Fi spectral efficiency.
3. In lower income countries, mobile broadband adoption is generally higher than fixed broadband adoption, and there is limited use of FTTH/B and cable broadband.

Figure 12
Economic benefits of the three scenarios in nine countries
Proportion of expected GDP in 2035



Source: GSMA Intelligence

Note: The results represent the net present value (NPV) of economic benefits over 2023–2035, expressed as a proportion of expected GDP in 2035 for each country. Appendix 1 includes details of the methodology and key assumptions, as well as a sensitivity analysis based on a data traffic approach to measuring demand.

Scenario 1 drives the greatest benefit because mobile is much more likely than Wi-Fi to be capacity constrained in each country over the period to 2035. This either means demand exceeds supply, or the extent of excess capacity is much lower for mobile than for Wi-Fi. Our assessment is based on mobile operators and Wi-Fi providers being efficient in the long term, which is the best-practice approach when deciding how to allocate spectrum because it ensures it is not assigned for a service being delivered inefficiently or using older technologies, or because the existing bands that have been assigned are not being fully utilised.

By assuming that, in the long term, all licensed spectrum uses 5G technology and all unlicensed spectrum uses Wi-Fi 6 technology[32] and by assuming efficient utilisation of spectrum, the analysis shows that unlicensed assignments in the 2.4, 5 and lower 6 GHz bands are more than sufficient to meet expected demand for fixed traffic. This is the case whether we assume that all fixed broadband connections should provide speeds of 1 Gbps (shown in Figure 12) or if we consider the expected growth in fixed traffic (see Appendix 1 for these results).

The analysis also does not assume any use of unlicensed high-band spectrum in the 57–71 GHz range, but does assume mmWave bands will be used by mobile operators. These unlicensed high-band frequencies provide propagation properties that allow short-range coverage (e.g. within a room) while easing coordination in terms of interference between adjacent access points. High bands can therefore be used for Wi-Fi to support connectivity for certain high-capacity use cases, such as AR/VR, and a variety of short-range devices.

With regard to Scenario 3, the benefits are subject to some uncertainty. The main modification was to reduce the capacity that mobile networks can provide when transmitting in the upper 6 GHz frequency range at a lower power limit (see Appendix 1). It is possible that operators do not utilise the band at lower power levels if they do not provide the necessary capacity and coverage, especially for indoor use.

In Scenario 3, we also assume that, with lower IMT power levels, Wi-Fi would be able to utilise the upper 6 GHz band without interference indoors. In practice, this may not be the case depending on the power restriction, especially in 'shallow' indoor locations. This would potentially involve additional mitigation costs, as well as potential impacts on how the upper 6 GHz band is used by Wi-Fi. The benefits in Scenario 3 should therefore be considered as an upper bound.

32. Over the next 12 years, it is expected that new standards will be developed for RLAN (Wi-Fi 7) and mobile (6G). However, given the uncertainty over timing and the specifications, we only model Wi-Fi 6 and 5G in this study.

4.2 Shared use of upper 6 GHz

With regard to the options for shared use, while it has not been possible to carry out an assessment of all approaches in the upper 6 GHz band, there are some important implications from the analysis.

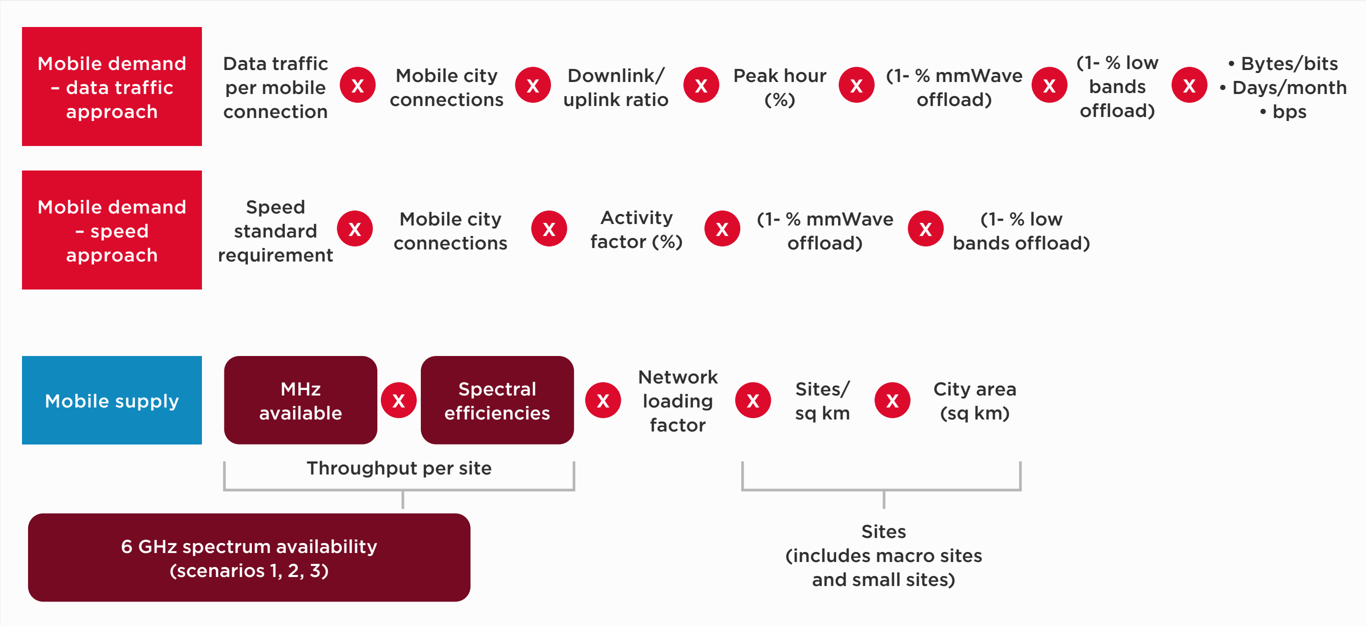
First, restricting the power levels that mobile base stations can emit in the band will significantly reduce the additional capacity that can be provided, meaning the economic benefits are lower than a policy of having a fully licensed band. Furthermore, given that the majority of mobile traffic originates indoors, there is no clear rationale for attempting to enforce an indoor/outdoor split of the band, and it is unlikely that a reduction in mobile power levels would achieve that. More generally, if the technical conditions for sharing are too stringent and costly for one of the technologies, the sharing framework will lose value.

Second, the results of the economic analysis show that if Wi-Fi is deployed in an efficient manner, there is no capacity constraint in the cities considered. By contrast, demand is much more likely to exceed capacity for mobile. Mobile operators also have an incentive to utilise spectrum efficiently as they face a pricing signal, whereas Wi-Fi deployments do not have such an incentive. Any approach to spectrum sharing should incentivise efficient spectrum use by both technologies. This means the burden of sharing and limitations on use should not be entirely placed on mobile operators.

Any approach to sharing the band should reflect these considerations by ensuring licensed mobile has priority to the band using standard power where (and when) needed and that any requirements and additional costs to share spectrum are not just solely imposed on mobile operators but also place responsibility on Wi-Fi providers. Such solutions are currently being explored in Europe – around cross-technology signalling, for example. This will allow fixed ISPs to determine the most suitable option to increase capacity where needed, rather than relying on additional spectrum to compensate for inefficient spectrum utilisation. This could involve upgrading to the latest technologies, optimising indoor deployments (for example, with additional access points, mesh network solutions, using Wi-Fi boosters, utilising unlicensed mmWave bands) or accessing the upper 6 GHz band when not being used by mobile.

Appendix 1: Methodology

Figure A1
Mobile traffic demand and capacity supply model



Source: GSMA Intelligence

Table A1
Mobile model data inputs

Input	Data	Source
5G spectral efficiencies DL/UL (bps/Hz)	Lower mid-band: 2.2/2.5 for macro sites Upper mid-band: 6.0/4.1 for macro sites 3.7/2.6 for small sites	Coleago (2021)[39]
Number of sites	City-specific assumptions The number of sites is calculated based on: – city square kilometres – an inter-site distance of 400 metres – three small sites installed for each macro site	City square km: GHS Urban Centre Database Inter-site distance: Coleago (2021) Small sites per macro site: Coleago (2021)
Spectrum available	Country-specific assumptions Existing and planned mid-band spectrum assignments by country	GSMA Intelligence and national regulators
mmWave offload	30%	GSMA Intelligence
Low-bands offload	15%	GSMA Intelligence
DL/UL ratio	Downlink traffic: 75% Uplink traffic: 25% This refers to the amount of data or traffic downloaded/uploaded by the user	GSMA Intelligence
Peak hour	Mobile peak hour: 8.5% FWA peak hour: 20% This refers to proportion of daily traffic delivered in the hour when the demand for data usage is at its highest	GSMA Intelligence
Network loading factor	85%	GSMA Intelligence
Mobile connections in the city and other urban areas	Country- and city-specific assumptions Expected take-up of 4G and 5G services combined with urban adoption produces the number of mobile city connections over time	GSMA Intelligence and Gallup World Poll
Data traffic per connection (traffic approach)	Country- and city-specific assumptions	GSMA Intelligence
Performance requirements (speed approach)	100 Mbps download speeds 50 Mbps upload speeds	IMT-2020 requirements. Report ITU-R M.2441-0 (11/2018)
Activity factor (speed approach)	5% This reflects the concurrent demand from connected 5G users during the busy period. For example, a share of 5% means that up to 5% of all 5G users will be using their devices simultaneously.	GSMA Intelligence

Source: GSMA Intelligence

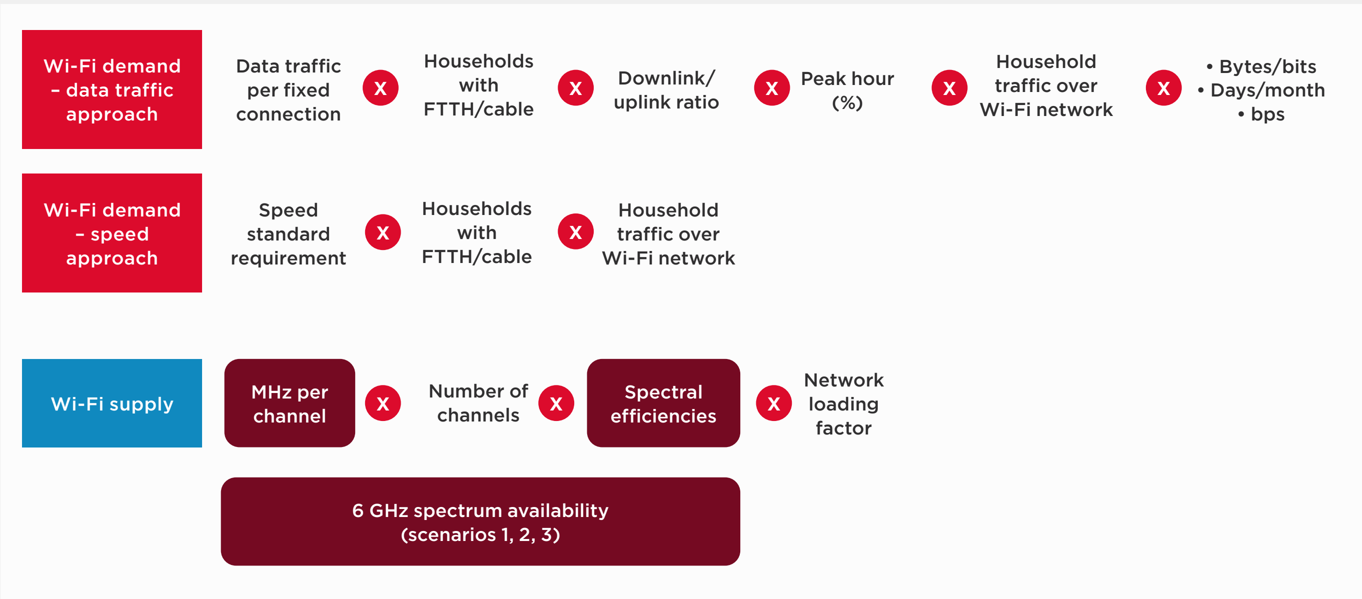
39. Estimating the mid-band spectrum in the 2025–2030 time frame, Coleago, 2021

A1.2 Wi-Fi demand and supply model

Figure A2 shows the structure of the Wi-Fi model. It is based on demand in residential premises and works as follows:

- In a similar way to mobile, demand is based on either a 'traffic approach' or 'speed approach'. The traffic approach takes the latest ITU fixed broadband traffic data and applies forecasts to 2035.[40] As with mobile, we adjust demand to reflect traffic in each city, which is higher than the country average due to higher fixed broadband adoption and greater use per consumer. Demand is then converted into Mbps units based on the proportion of traffic delivered during the busy hour.
- The speed approach assumes operators must deliver 1 Gbps of connectivity to each household that has a broadband connection to support those speeds (i.e. FTTH/B and cable), which is in line with targets set by some governments and policymakers.[41]
- Wi-Fi supply (or capacity) is driven by the amount of spectrum available, spectral efficiencies and a network loading factor. We include 2.4, 5 and lower 6 GHz frequencies but not unlicensed high bands. However, the latter represents a solution to address potential Wi-Fi capacity constraints within households.[42]
- We then compare the baseline where no additional upper 6 GHz spectrum is available and where 700 MHz in the upper 6 GHz band is made available in Scenarios 2 and 3. In the case of Scenario 3, we assume that with lower IMT power levels, Wi-Fi would be able to utilise the upper 6 GHz band without interference indoors. In practice, this may not be the case depending on the power restriction, especially in 'shallow' indoor locations. This would potentially involve additional mitigation costs, as well as potential impacts on how the upper 6 GHz band is used by Wi-Fi. The benefits in Scenario 3 should therefore be considered as an upper bound.

Figure A2
Wi-Fi traffic demand and capacity supply model



Source: GSMA Intelligence

40. Traffic forecasts for fixed broadband are based on The Evolution of Data Growth in Europe, Arthur D Little, 2023.
41. For example, the European Commission's Digital Decade 2030 Strategy aims to deliver gigabit coverage to all EU households by 2030.
42. For example, see Broadband India Forum (2021), The Economic Value of Wi-Fi Spectrum for India. The study highlights WiGig as one of the key use cases of V-Band spectrum. This can link devices at up to 7 Gbps over a distance of up to 12 metres.

Table A2
Wi-Fi model data inputs

Input	Data	Remarks and source
Wi-Fi spectral efficiencies (bps/Hz)	3.5 bps/Hz in 2023–2030 5.5 bps/Hz in 2031–2035	Comtel (2024). These assumptions are conservative, as they assume every household faces high levels of interference in an apartment block setting. Spectral efficiencies will be much higher in a house and will also be higher in apartments not at the centre of a building. These spectral efficiencies also do not reflect devices having more antennas in the long term.
Spectrum available	Country-specific assumptions on existing unlicensed spectrum assignments by country in the 2.4 and 5 GHz bands. We also assume 500 MHz is available in the lower 6 GHz band. For DFS channels in the 5 GHz band, we assume 50% utilisation (equivalent to assuming the capacity is halved).	Linux wireless regulatory database and national regulators
DL/UL ratio	Downlink traffic: 75% Uplink traffic: 25%	GSMA Intelligence
Peak hour	20%	GSMA Intelligence
Network loading factor	85%	GSMA Intelligence
Household traffic over Wi-Fi network	95% This refers to the proportion of fixed traffic delivered over Wi-Fi. It excludes any fixed data traffic transmitted to a device via a cable or wired connection from the access point.	GSMA Intelligence
FTTH/B and cable adoption in the city and other urban areas	Country-specific assumptions	GSMA Intelligence, ITU and Gallup World Poll
Data traffic per fixed connection (traffic approach)	Country-specific assumptions	Data to 2023 is sourced from the ITU. Traffic forecasts are sourced from Arthur D Little (2023)
Performance requirements (speed approach)	Speed requirement of 1 Gbps	GSMA Intelligence

Source: GSMA Intelligence

A1.3 Timing of 6 GHz use

In most countries, spectrum in the 6 GHz band is currently used for fixed services (including mobile backhaul and fixed satellite services in some countries). Studies to ensure co-existence with these services, and in particular with FSS UL (Earth to space direction), were completed prior to WRC-23. It is likely that 6 GHz will be available for large-scale 5G commercial deployments after WRC-27 has concluded. We therefore assume that 6 GHz will be available for licensed use from 2029 in our model. In terms of using 6 GHz for unlicensed use, we assume it can be used immediately, given the availability of Wi-Fi 6E equipment.

A1.4 Modelling the impact on mobile and fixed broadband users

When modelling the impacts of 6 GHz spectrum assignment on mobile and Wi-Fi, we focus on capacity rather than coverage – the assumption being that assigning additional upper mid-band spectrum will primarily allow operators to improve wide-area capacity and Wi-Fi providers to deliver faster speeds. Expanding wireless coverage, particularly in rural areas, generally requires low-band spectrum (below 1 GHz), and it is unlikely that the propagation characteristics of the 6 GHz band will enable the expansion of mobile and Wi-Fi coverage in rural or underserved areas.

To determine the impact of supply and demand on end-user experience, we model this in two ways:

1. Where demand exceeds supply in a given year, we assume a proportionate reduction in 5G mobile or FTTH/B and cable adoption. For example, if there is a capacity gap of 20% with no upper 6 GHz spectrum allocated for unlicensed (or licensed) use, we assume FTTH/B and cable (or 5G) adoption falls by 20% in that scenario. The rationale is that users do not get the full benefits of the service they require and which was purchased.

   An alternative approach would be to assume that operators increase capacity by densifying the network with less spectrum at higher cost. This would be passed on to consumers, which would reduce demand and therefore mobile broadband or FTTH/B and cable adoption. However, it is possible that the required densification may not be feasible from an interference perspective (i.e. requiring too many sites in a given area). We therefore model the economic impacts based on a reduction in quality of service. When applying the network densification methodology in the GSMA Intelligence 2022 study, we found the impacts on 5G adoption were comparable to using a quality-of-service based approach.

2. We also model the impact of additional spectrum on user experience, proxied by increased download speeds. Even if supply exceeds demand, the additional spectrum for licensed or unlicensed could result in faster speeds that allow users to realise additional benefits from fixed or mobile broadband connectivity. We assume that the increase in spectrum drives a proportionate increase in speeds (for example, a 10% increase in spectrum increases speeds by 10%[43]), which we then scale based on excess capacity where it exists. The latter means that if supply only just exceeds demand by a small amount, we assume a larger increase on speeds than if supply greatly exceeds demand. This is because if there is a lot of excess capacity, the impact on consumer experience will be less than if the network is capacity constrained.

This analysis is carried out in each of the nine cities included in the model. We then extrapolate the supply and demand analysis to other urban populations in the country. Regulators would ideally carry out separate analysis in each city and urban area, but we extrapolate in this study to illustrate the results at a country level.

43. This results from assuming a linear relationship determined by spectral efficiencies.

A1.5 Modelling the socioeconomic impacts of mobile and Wi-Fi

Having estimated the impact of each of the scenarios on adoption and speeds for mobile and FTTH/B & cable, the next step is to estimate the wider socioeconomic impacts of each policy. Both mobile and fixed broadband are digital technologies widely regarded as general purpose. They drive economic growth because they enable tools and processes for quicker, cheaper and more convenient production, which improves the productivity of firms and workers. They also lower information search and knowledge costs of consumers and producers, enabling new transactions and improving existing ones, thereby stimulating more trade and competition.

A number of studies have found a causal link between the adoption of mobile and fixed internet and GDP, suggesting a 10% increase in mobile or fixed internet adoption can increase a country's GDP by between 0.5% and 2.5%.[44] The impact of introducing 5G or faster fixed broadband is unlikely to deliver the same benefit as connecting an individual or business for the first time. Rather, the impact will reflect an improvement or 'upgrade' to the technologies people are already using – for example, by offering faster data rates, lower latencies and higher reliability.

A study by GSMA Intelligence[45] found that upgrading connections from 2G to 3G, and 3G to 4G, increased the economic impact of mobile by around 15%.[46] We therefore assume a similar uplift when estimating the impact of upgrading from 4G to 5G. As this reflects the overall impact of a technology upgrade on GDP growth, it will capture both direct and indirect impacts. Direct economic impacts include the value-add of firms in the mobile ecosystem, including operators, handset manufacturers, equipment and infrastructure vendors, and content providers. The indirect economic impacts include wider productivity benefits that mobile drives in other sectors.

The benefit at the country level is calculated as a function of 5G penetration rate, as follows:

t = time

i = country

α = 5G adoption rate[47]

β = 5G productivity impact

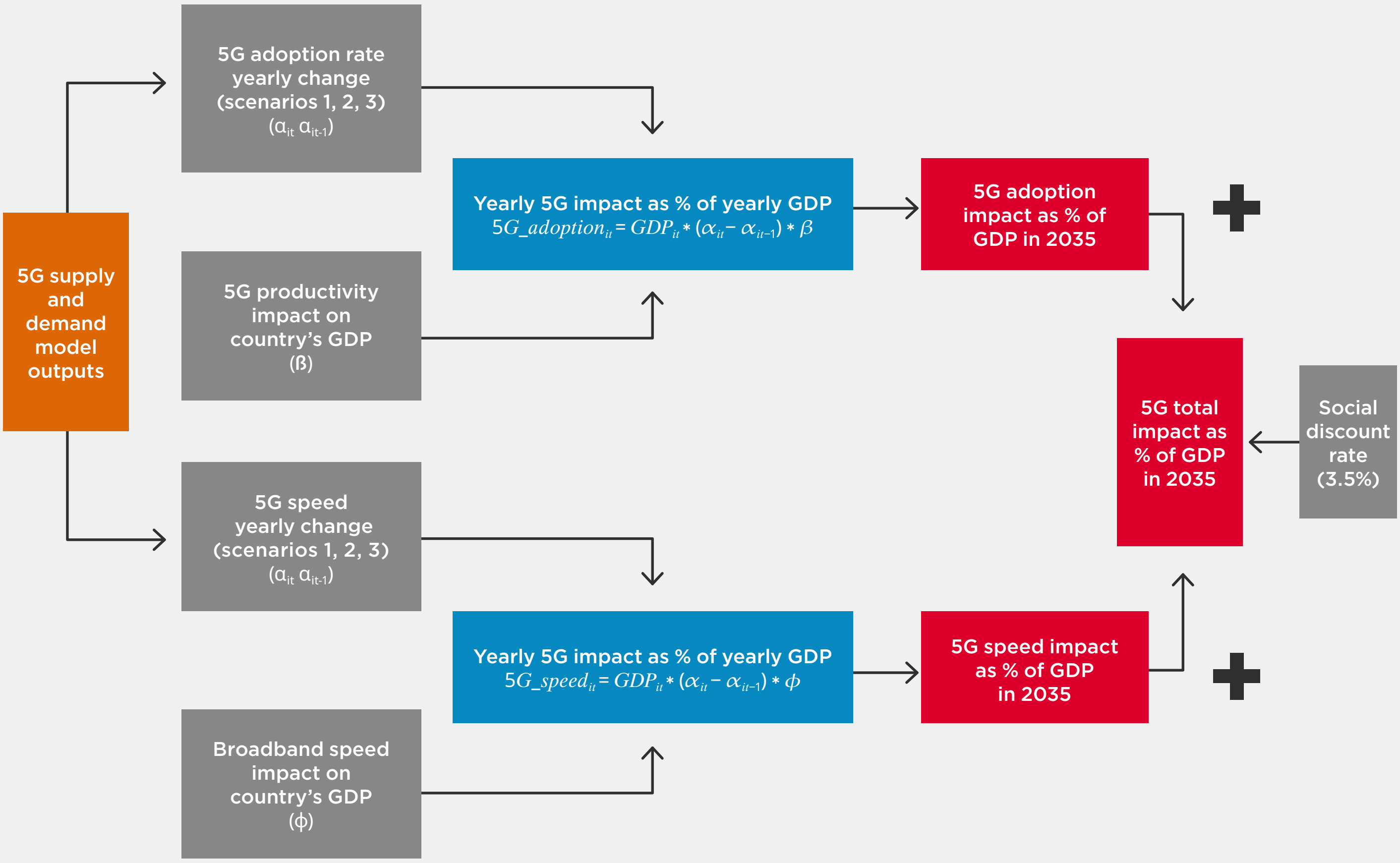
$$Total\_Benefit_{it} = GDP_{it} * (\alpha_{it} - \alpha_{it-1}) * \beta$$

The α parameter is based on the 5G forecasts for each country and the impact of each scenario. For the β parameter, the model assumes a value of 0.0195 for low-income countries, 0.0150 for middle-income countries and 0.0075 for high-income countries. This reflects the fact that mobile broadband has been found to have greater impacts in lower-income countries.

When modelling the economic impact of speeds, there are a number of studies that demonstrate faster broadband speeds (fixed and mobile) can drive improved macroeconomic outcomes.[48] For this study, we assume that a doubling of broadband speeds drives a 0.3% increase in GDP, and apply the same assumption for both mobile and fixed.

44. For example, see How broadband, digitization and ICT regulation impact the global economy, ITU, 2020; and Briglauer, Wolfgang; Krämer, Jan; Palan, Nicole (2023) : Socioeconomic benefits of high-speed broadband availability and service adoption: A survey, Research Paper, No. 24, EcoAustria – Institute for Economic Research, Vienna
45. Mobile technology: two decades driving economic growth, Working Paper, GSMA Intelligence, 2020
46. For example, if a 10% increase in 2G adoption increases GDP by 1%, then a 10% increase in 2G-to-3G adoption increases GDP by an additional 1% * 15% = 0.15%.
47. This reflects the expected level of 5G adoption (number of 5G users relative to population) in each country over time.
48. See for example: Rohman, Ibrahim Kholilul, and Erik Bohlin. "Does broadband speed really matter as a driver of economic growth? Investigating OECD countries." International Journal of Management and Network Economics 5 2, no. 4 (2012): 336-356; Edquist, Harald. "The economic impact of mobile broadband speed." Telecommunications Policy 46, no. 5 (2022): 102351, and; Acosta, Camilo, and Luis Baldomero-Quintana. "Quality of communications infrastructure, local structural transformation, and inequality." Journal of Economic Geography 24, no. 1 (2024): 117-144.
A full list of papers is provided in Briglauer, Wolfgang; Krämer, Jan; Palan, Nicole (2023) : Socioeconomic benefits of high-speed broadband availability and service adoption: A survey, Research Paper, No. 24, EcoAustria – Institute for Economic Research, Vienna.

Figure A3
Modelling the socioeconomic impacts of 5G



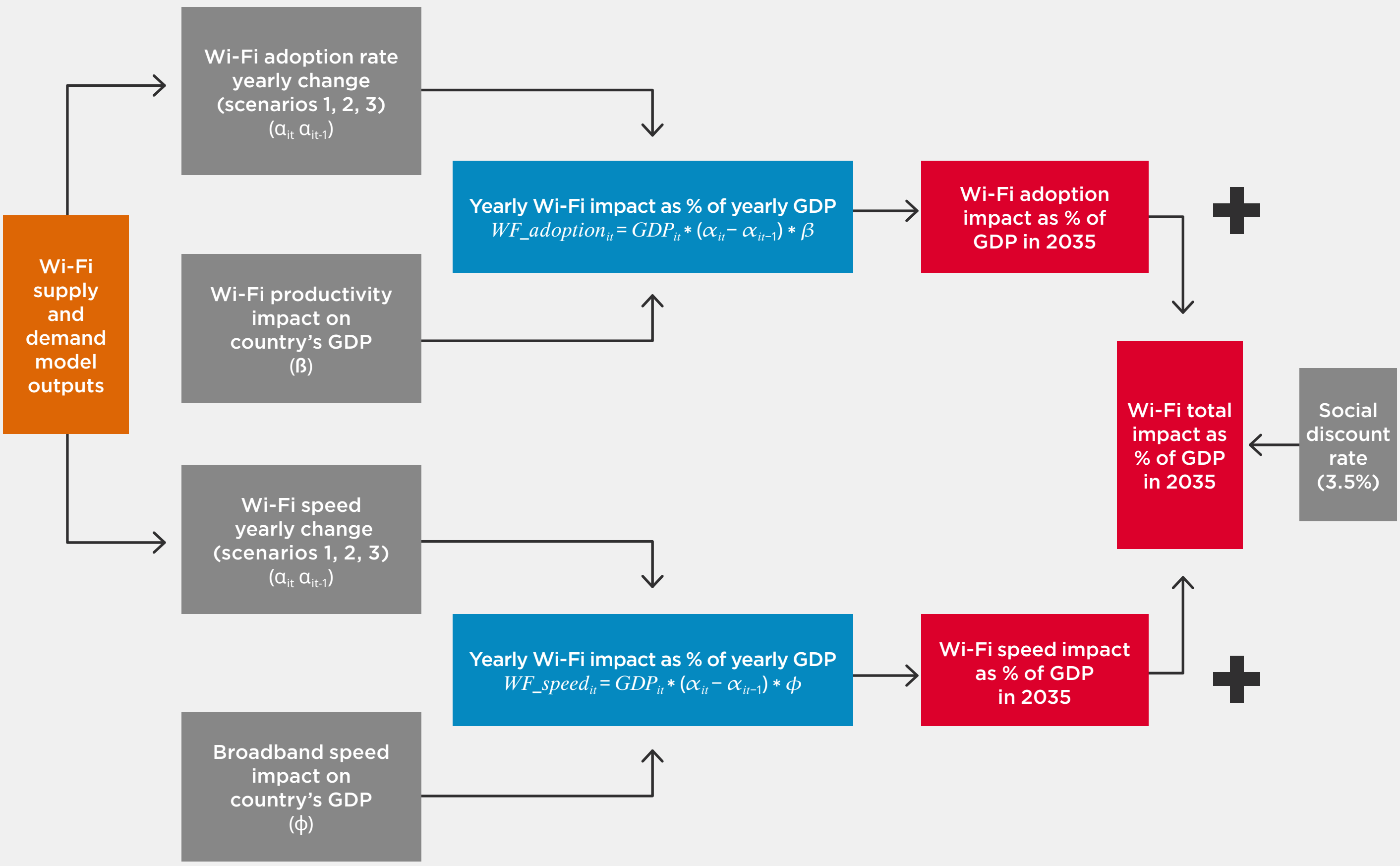
Source: GSMA Intelligence

This allows us to calculate the overall contribution of 5G technology to a country's economy in each year. We then aggregate the overall economic benefit in the 2023–2035 period by taking the net present value of economic benefits, using a social discount rate of 3.5%. In our presentation of results, we express this as a proportion of expected GDP in 2035.

The incremental economic impact of more or less FTTH/B and cable adoption is assumed to be the same as the impact of 5G. For example, if a 10% increase in 5G penetration drives a 0.15% increase in GDP, we assume that a 10% increase in FTTH/B and cable penetration also drives a 0.15% increase in GDP. This ensures we apply a consistent approach to both technologies. It also means the results between scenarios are not sensitive to the specific impact assumption (as it is applied in the same way to mobile and Wi-Fi). The same applies to the impact of faster speeds, where we assume that a doubling of broadband speeds drives a 0.3% increase in GDP.

Figure A4

Modelling the socioeconomic impacts of Wi-Fi



Source: GSMA Intelligence

Both models of mobile and Wi-Fi are based on urban demand and urban residential requirements respectively. We then apply the economic impact analysis based on overall 5G and FTTH/B & cable adoption (and overall mobile and fixed broadband speeds).[49] This captures the economic impacts consistent with existing evidence, as the empirical literature demonstrating the impact of mobile and fixed broadband on GDP is based almost entirely on broadband adoption at the national level by individuals or households.

49. Put another way, if we expect one of the scenarios to increase urban 5G or FTTH/B and cable adoption by 5%, we then estimate the uplift at a national level based on the proportion of populations living in urban areas and the proportion of 5G or FTTH/B and cable users that are in urban areas. This means the national adoption increase will be less than 5%, which we then apply the economic impact analysis to.

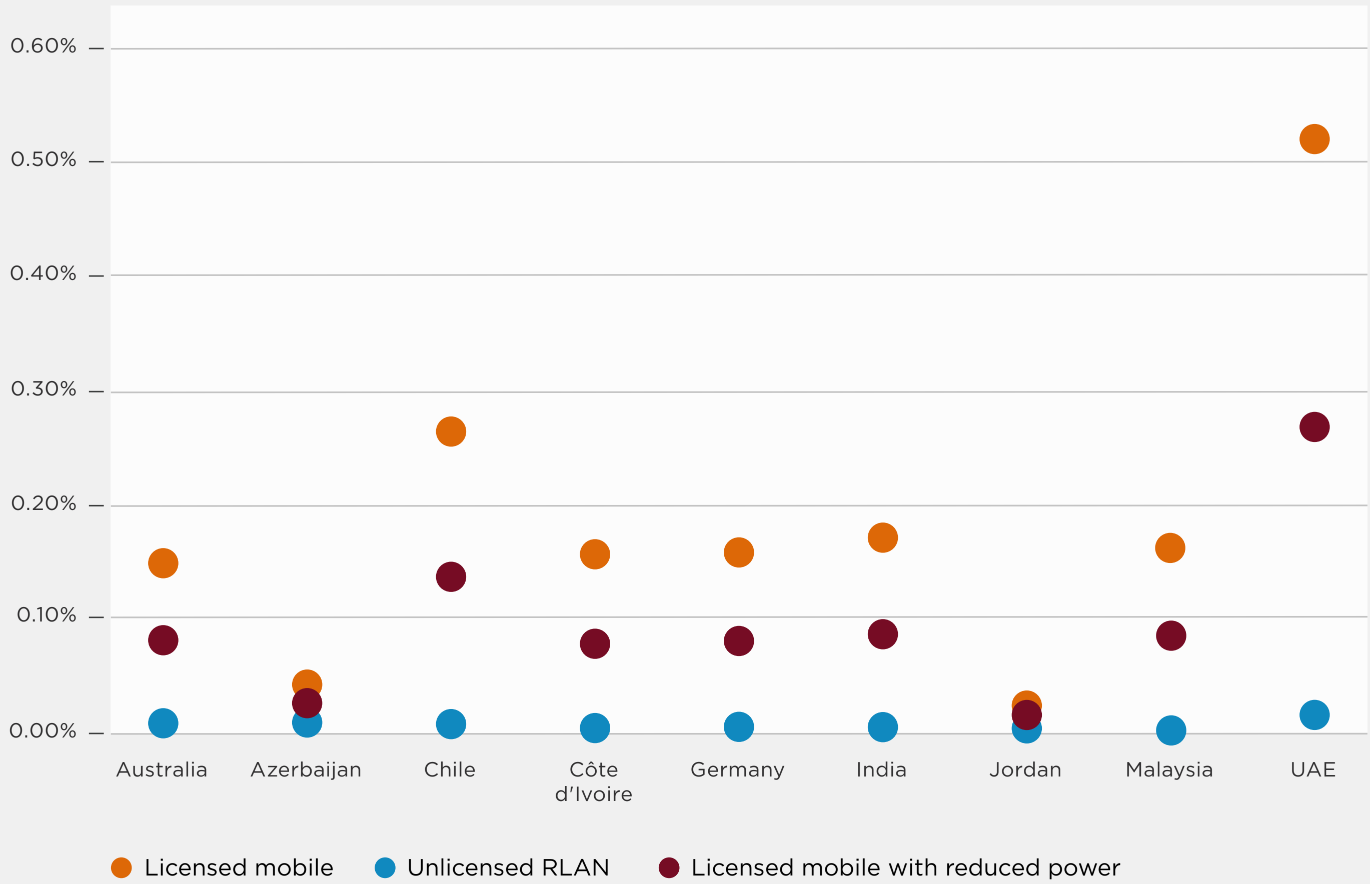
A1.6 Results using the data traffic approach

The results of the economic modelling presented in Chapter 4 are based on the speed approach. Figure A5 shows the results based on the data traffic approach, which are consistent in terms of demonstrating that, in all nine countries, Scenario 1: Licensed mobile drives the greatest benefit, followed by Scenario 3: Licensed mobile with reduced power and then Scenario 2: Unlicensed RLAN

Figure A5

The economic benefits of the three scenarios in nine countries (data traffic approach)

Proportion of expected GDP in 2035



Source: GSMA Intelligence

Appendix 2: List of countries by region

Country	Region	Country	Region
Iraq	Middle East & North Africa	**Morocco**	Middle East & North Africa
Ireland	Europe	**Mozambique**	Sub-Saharan Africa
Israel	Middle East & North Africa	**Myanmar**	Southeast Asia
Italy	Europe	**Namibia**	Sub-Saharan Africa
Jamaica	Latin America & Caribbean	**Nauru**	Other Asia Pacific
Japan	Developed Asia Pacific	**Nepal**	South Asia
Jordan	Middle East & North Africa	**Netherlands**	Europe
Kazakhstan	Eurasia	**New Zealand**	Developed Asia Pacific
Kenya	Sub-Saharan Africa	**Nicaragua**	Latin America & Caribbean
Kiribati	Other Asia Pacific	**Niger**	Sub-Saharan Africa
Korea; North	Other Asia Pacific	**Nigeria**	Sub-Saharan Africa
Korea; South	Developed Asia Pacific	**North Macedonia**	Europe
Kosovo	Europe	**Norway**	Europe
Kuwait	GCC	**Oman**	GCC
Kyrgyzstan	Eurasia	**Pakistan**	South Asia
Laos	Southeast Asia	**Palau**	Other Asia Pacific
Latvia	Europe	**Palestine**	Middle East & North Africa
Lebanon	Middle East & North Africa	**Panama**	Latin America & Caribbean
Lesotho	Sub-Saharan Africa	**Papua New Guinea**	Other Asia Pacific
Liberia	Sub-Saharan Africa	**Paraguay**	Latin America & Caribbean
Libya	Middle East & North Africa	**Peru**	Latin America & Caribbean
Liechtenstein	Europe	**Philippines**	Southeast Asia
Lithuania	Europe	**Poland**	Europe
Luxembourg	Europe	**Portugal**	Europe
Macao; SAR China	Greater China	**Qatar**	GCC
Madagascar	Sub-Saharan Africa	**Romania**	Europe
Malawi	Sub-Saharan Africa	**Russian Federation**	EURASIA
Malaysia	Southeast Asia	**Rwanda**	Sub-Saharan Africa
Maldives	South Asia	**Saint Kitts and Nevis**	Latin America & Caribbean
Mali	Sub-Saharan Africa	**Saint Lucia**	Latin America & Caribbean
Malta	Europe	**Saint Vincent and the Grenadines**	Latin America & Caribbean
Marshall Islands	Other Asia Pacific	**Samoa**	Other Asia Pacific
Mauritania	Sub-Saharan Africa	**Sao Tome and Principe**	Sub-Saharan Africa
Mauritius	Sub-Saharan Africa	**Saudi Arabia**	GCC
Mexico	Latin America & Caribbean	**Senegal**	Sub-Saharan Africa
Micronesia	Other Asia Pacific	**Serbia**	Europe
Moldova	Eurasia	**Seychelles**	Sub-Saharan Africa
Monaco	Europe	**Sierra Leone**	Sub-Saharan Africa
Mongolia	Other Asia Pacific	**Singapore**	Developed Asia Pacific
Montenegro	Europe	**Slovakia**	Europe

Country	Region
Slovenia	Europe
Solomon Islands	Other Asia Pacific
Somalia	Sub-Saharan Africa
South Africa	Sub-Saharan Africa
South Sudan	Sub-Saharan Africa
Spain	Europe
Sri Lanka	South Asia
Sudan	Middle East & North Africa
Suriname	Latin America & Caribbean
Sweden	Europe
Switzerland	Europe
Syria	Middle East & North Africa
Taiwan; Province of China	Greater China
Tajikistan	EURASIA
Tanzania	Sub-Saharan Africa
Thailand	Southeast Asia
Timor-Leste	Southeast Asia
Togo	Sub-Saharan Africa
Tonga	Other Asia Pacific
Trinidad and Tobago	Latin America & Caribbean
Tunisia	Middle East & North Africa
Türkiye	Middle East & North Africa
Turkmenistan	EURASIA
Tuvalu	Other Asia Pacific
Uganda	Sub-Saharan Africa
Ukraine	Europe
United Arab Emirates	GCC
United Kingdom	Europe
United States of America	North America
Uruguay	Latin America & Caribbean
Uzbekistan	EURASIA
Vanuatu	Other Asia Pacific
Venezuela	Latin America & Caribbean
Vietnam	Southeast Asia
Yemen	Middle East & North Africa
Zambia	Sub-Saharan Africa
Zimbabwe	Sub-Saharan Africa

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