5G mmWave Guide

A Resource for Operators

February 2022

GSMA.com/5GmmWave

Not for public release

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Introduction

Developed for operators and industry stakeholders, the GSMA 5G mmWave Guide explains how 5G mmWave technology works, describes some 5G mmWave applications and addresses questions about the safety of 5G mmWave technology.

The Guide also includes suggestions on how to explain these topics to third parties that may be unfamiliar with cellular technologies.

Accompanying the Guide is a new publicly available GSMA fact sheet designed to provide high-level information on 5G mmWave, the benefits and safety.

The Guide is part of both the GSMA 5G mmWave Accelerator to help operators introduce 5G mmWave and the GSMA resource pool that helps address stakeholder questions.

We welcome your feedback and future contributions to the GSMA 5G mmWave Guide.

Henry Calvert
Head of Networks, GSMA

The Business Case Summary for 5G mmWave

By the end of 2021, 5G had been commercially launched by nearly 180 operators in more than 60 countries. While 4G continues to support the bulk of mobile broadband users, operators are focusing their capex and technology innovation strategies on 5G.

A significant break from previous network generations, the adoption of 5G gives operators an opportunity to introduce a wide range of new technologies, and to do things differently in their networks.

5G in millimetre wave (mmWave) spectrum may not be suitable for extensive coverage, but it is a valuable complementary solution to serve areas where traffic is concentrated. It is also an enabler of 5G use cases in places where high capacity and throughput are required, such as entertainment venues and other high-density locations. These capabilities are attracting clear interest from multiple verticals and industries. Especially attractive is the support for gigabit speeds in both downlink and uplink, enabled by the large bandwidth and the possibility to locally use different TDD schemes.

At the same time, 5G fixed wireless access (FWA) is now gaining traction in developed and developing countries around the world. While FWA solutions have been around for more than two decades, the massive performance improvements enabled by 5G in mmWave spectrum make 5G FWA a highly competitive alternative to fixed-lines in many markets. 5G FWA in mmWave can enable speeds that are over 10 times that of 4G over distances of several kilometres.

As 5G evolves, the industry will increasingly look to make more spectrum available for 5G, while managing local spectrum capacity. Access and use of mmWave spectrum will play a key role as sub 6 GHz spectrum capacity is exceeded. Deployments in mmWave spectrum, coupled with 5G device developments, will also open up new 5G use cases.

The full potential of 5G is unlocked with 5G standalone, carrier aggregation, network slicing, and the fully coordinated, flexible configuration of multi-layer networks where mmWave spectrum provides massive capacity and low latency.

Use cases that take advantage of the capabilities of 5G mmWave continue to emerge. A growing number of reports point to the positive business case for 5G mmWave deployments in FWA and high traffic, high-density scenarios, in both the consumer and Industry 4.0 markets.

Important indicators of market readiness for 5G mmWave include spectrum availability and a sufficiently wide range of consumer devices and equipment that can take full advantage of 5G’s flexibility, across both mmWave and sub-6 GHz bands.

Please consult the GSMA website for further reading on the 5G mmWave business case: www.GSMA.com/5GmmWave

5G mmWave Technology Overview

What is meant by 5G mmWave?

5G mmWave (pronounced as *millimetre-wave*) refers to the higher range of radio frequencies supported by 5G (beyond 4G frequencies). This is termed 5G FR2 (Frequency Range 2) and extends above 24 GHz. The lower 5G FR1 bands are from 410 MHz to 7125 MHz.

What are the benefits of 5G mmWave?

5G mmWave supports high capacity and fast data throughput with low latency. This enables a higher density of users, faster downloads of high-quality videos, quicker reaction times for online gaming, better VR experiences and minimal throttling at peak traffic times.

5G mmWave Spectrum

The 5G mmWave frequencies are part of the radio frequency (RF) region within the overall electromagnetic spectrum. A wide range of applications, such as radio broadcast, TV broadcast, radio links, satellite communication etc., make use of frequency bands within the RF region as depicted in Figure 1.

Figure 1: The electromagnetic spectrum showing 5G mmWave

5G uses three broad frequency ranges:

- Low-bands (below 1 GHz) – for widespread coverage across urban, suburban and rural areas and to support IoT services through better in-building coverage.
- Mid-bands (between 1 GHz and 7 GHz) – a good mixture of coverage and capacity benefits. This includes spectrum within the 3.3-3.8 GHz range which forms the basis of many initial 5G services.
- High-bands (above 24 GHz including 5G mmWave) – for ultra-high speed, very low latency, high-capacity hotspots.

The International Telecommunications Union (ITU) is the UN agency responsible for agreeing use of radio spectrum. Its international treaty – the Radio Regulations – defines guidelines and uses for different spectrum bands. This treaty is updated approximately every four years by the ITUs World Radiocommunication Conferences (WRCs).

Note, 5G will use existing 2G, 3G and 4G bands as well as new bands, including 5G mmWave.

Low band frequencies employed by cellular include 600 MHz, 700 MHz, 800 MHz and 900 MHz while existing mid-bands include 1800 MHz, 2100 MHz and 2600 MHz. All of these will, over the next decade or so, be re-farmed for use by 5G. New mid-bands, such as 3.5 GHz and 6 GHz, are or will also be used by 5G.

5G mmWave frequencies were not used by previous generations of mobile networks. The main 5G mmWave bands are:

- 26 GHz (24.25-27.5 GHz)
- 28 GHz (26.5-29.5 GHz)
- 40 GHz (37.5-40.5 and 40.5-43.5 GHz)
- 66 GHz (66-71 GHz)

Suggestions for how to explain 5G mmWave spectrum:

- One way to explain the 5G mmWave spectrum is to show a graphic or an illustration. People can relate to everyday applications and devices, so it's good to show where they fit in the spectrum.
- Explain that 5G mmWave is part of the radio frequency region. In the 5G mmWave frequencies, there is more spectrum available for mobile use – up to 10x more. Using a suitable graphic on a banner or slide can be effective as part of a display, a lecture and online meetings.
- Other examples can be found in the Resources section of this Guide.

How does 5G mmWave work?

5G mmWave transmission works in a similar way to any other radio frequency (RF) transmission, except that the range is shorter, typically requiring a line of sight to the antenna. The power into the antenna is also low, typically about 1W.

There is much more spectrum available in the 5G mmWave region of the RF spectrum than at lower frequencies and this means larger bandwidths can be allocated to each user, resulting in higher data rates and lower latency.

The equipment used for 5G mmWave transmission and reception is smaller than the equipment used for lower frequencies (for example, those used for 2G, 3G or 4G). (See below for some examples of 5G mmWave antennas used by operators).

The length of the antenna elements is directly proportional to the wavelength of the signal to be transmitted/received (and therefore, inversely proportional to the frequency of the signal). At 5G mmWave frequencies, in which signals have short wavelengths, multiple antenna elements can be used in a small space. These multiple antenna elements can support increased data rates compared to a single antenna as well as better directionality through a technique called beamforming (see below).

What is beamforming?

Just as a light from a light source can illuminate a wide area (for example a floodlight) or a narrow area (for example a stage light), a transmitted radio signal can also be used to cover a wide area or a narrow area.

With a light source, a reflector is used to focus the light. With 5G mmWave transmission, multiple small active antenna elements are used to direct the radio energy as a beam pointing towards a specific area (as shown in Figure 2). This narrow beam can be steered to follow the user [4]. This makes the communication efficient in several ways: it focuses the energy of the radio signal towards a desired area, increases spatial reusability, minimises energy wastage, allows for higher data rates and provides a better user experience.

Figure 2: Conventional antenna coverage compared to the antenna with beamforming

Suggestions for how to explain beamforming:

- A way to explain beamforming is to use the graphical illustration above showing beams going to individual devices. There is a GSMA video illustrating this here.
- Beamforming can also be likened to an usher at a cinema showing guests to seats using a small torch that points a narrow light beam to the seat, rather than turning on the main cinema lights every time.
- Other examples are shown in the Resources section of this Guide.

What does a 5G mmWave antenna or small cell/base station look like?

As 5G mmWave antennas operate at higher frequencies they are typically much smaller than 3G, 4G and 5G mid-band antennas (as shown in Figure 3).

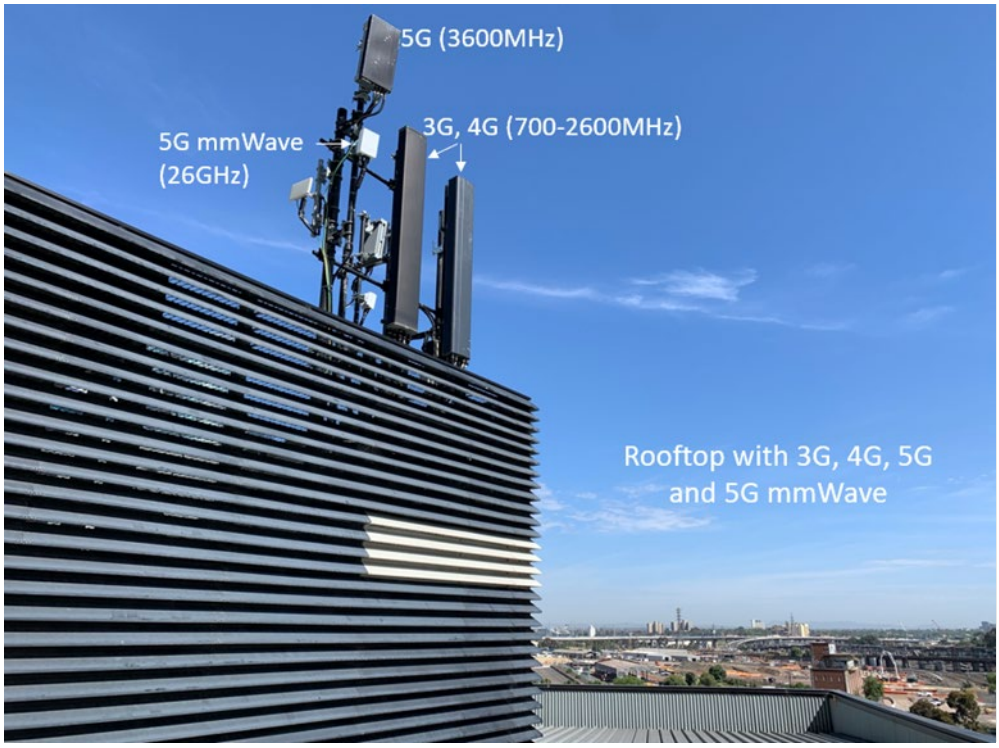


Figure 3: Example cellular base station in Australia with 3G, 4G, 5G mid-band and 5G mmWave. The 5G mmWave antenna is the small white box.

Due to their small size, 5G mmWave small cell antennas can easily be placed in both urban and residential areas. See Figure 4.

Example: residential

Example: city information booth
(with other antennas)

Figure 4: 5G mmWave small cells

What is the range or coverage from a 5G mmWave site and how close together do they need to be?

The area covered by a 5G mmWave site is smaller than a site using a lower frequency spectrum. Therefore, 5G mmWave will require more transmitters to cover the same area as a cellular network operating at a lower frequency but 5G mmWave sites can serve more users in the same area or provide higher bandwidth to each user or a combination of both.

The range or coverage from a 5G mmWave site is typically the line-of-sight distance to the receiving antenna. For 5G mmWave small cells placed on street furniture, such as bus shelters and light poles, this will be shorter than for a 5G mmWave antenna positioned on a taller structure.

The typical distance between 5G mmWave small cells depends on the surrounding environment, the type of 5G mmWave service being provided and the position of the antenna. For example, for 5G mmWave mobile phone and device connections in urban areas, the separation could be between 200m and 400m. As another example, 5G mmWave fixed wireless services may work over 1km or more.

Do 5G mmWave signals go inside my house or apartment?

5G mmWave signals don't pass through objects, such as buildings, trees, and windows, as well as those in lower mobile frequencies.

5G mmWave signals may just reach a short distance into a house or apartment, through a window, if there is line of sight to a 5G mmWave base station.

The ability of radio signals to travel through walls and ceilings depend on the construction material, the thickness of the structure (for example wall thickness), the angle of the radio signal and the signal frequency [5], [6]. Different building materials reflect or absorb different proportions of the radio signals.

The building structure itself can also influence the received signal; sharp corners and flat structures can cause the signal to bounce around. The same signal reaching the receiver via different paths will cause interference and result in lower quality reception.

External or window mounted antennas are typically used to provide a 5G mmWave connection to homes and apartments. This external antenna can then be connected to an indoor antenna, which then enables devices inside the building to get online.

Suggestions on how to explain how 5G mmWave technology works:

- Emphasise that 5G mmWave works in the same way as any other radio frequency transmission except the range is shorter, typically a line of sight to the antenna.
- Homes and apartments can use 5G mmWave through an antenna mounted outside or on a window, which is visible to the 5G mmWave network antenna.
- 5G uses advanced antennas to send mmWave signals in a narrow beam to devices – this improves efficiency significantly. (See also the advice on explaining beamforming).

5G mmWave Applications

High throughput, low latency 5G mmWave connectivity can enable applications, such as interactive gaming, industrial automation, virtual and augmented reality, and connected cars, that are not feasible with previous generations of mobile connectivity. This is illustrated in Figure 5.

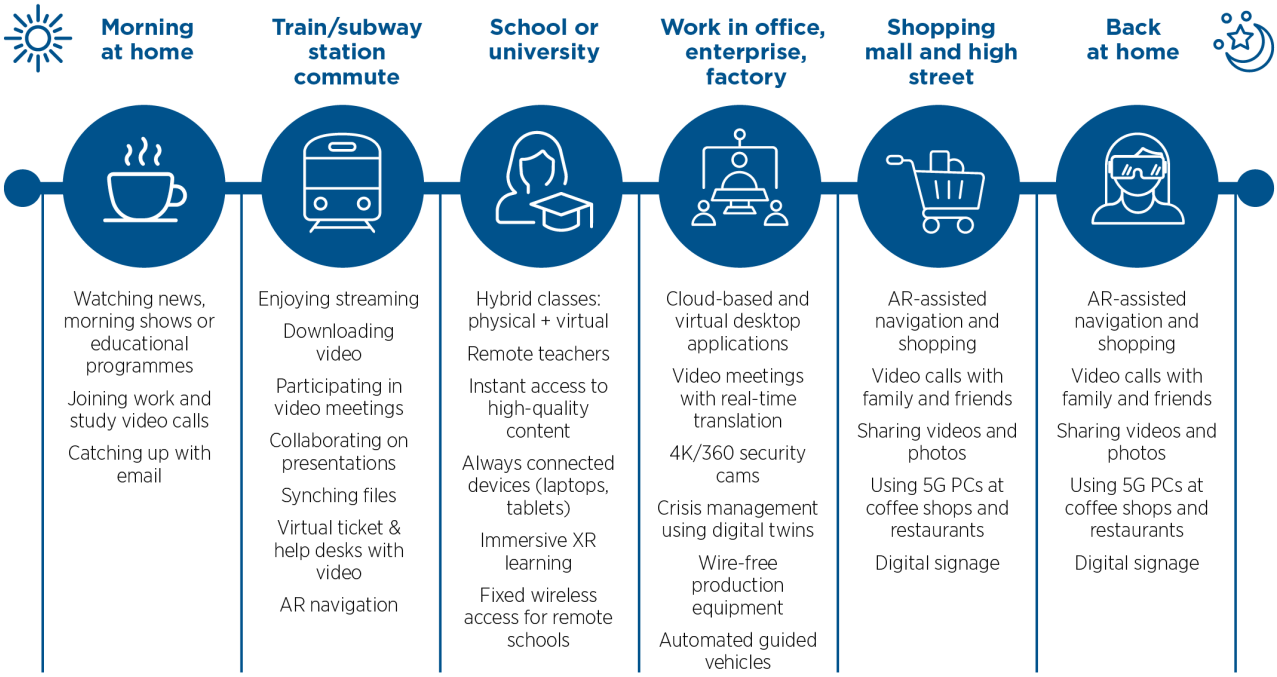


Figure 5: Some 5G mmWave applications

How is 5G mmWave being used?

5G mmWave is being used to significantly increase capacity in areas requiring faster connectivity to the internet. Such areas include city centres, public transport hubs, large venues and sports stadiums, densely populated residential areas, and homes. With the significant increase in people depending on wireless technology, and the growth of smart cities and societies, 5G mmWave technology enables many more users and devices to connect to the internet with faster response times.

In many countries, 5G mmWave spectrum is being used to bolster the low and mid-band 5G connectivity, enabling for smart city services, together with advanced medical and industrial applications requiring low latency.

What does 5G mmWave enable?

To meet the growing demand for connectivity, the 5G technical specifications (and standards) set by 3GPP have some key requirements relative to 4G [7],[8]:

- 1,000x higher data volumes
- 10-100 times more connected devices
- 10-100x higher typical user data rates
- 5x lower latency

To fulfil such performance metrics, 5G will need to make use of a variety of spectrum bands. Low- and mid-band spectrum provides wide-area coverage, but has limited bandwidth, 5G mmWave can provide much greater bandwidth in local areas for each user as depicted in Figure 6.

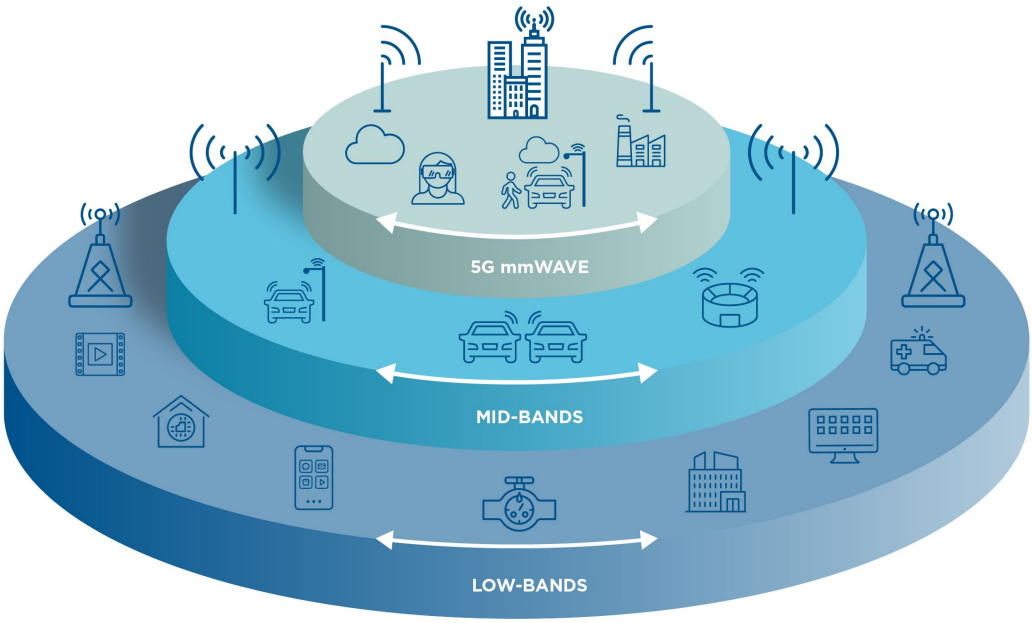


Figure 6: Illustrative coverage and uses of 5G spectrum bands

In the 5G mmWave frequencies, each mobile operator can be allocated a wider block of spectrum, which translates into a significant capacity increase, as depicted in Figure 7.

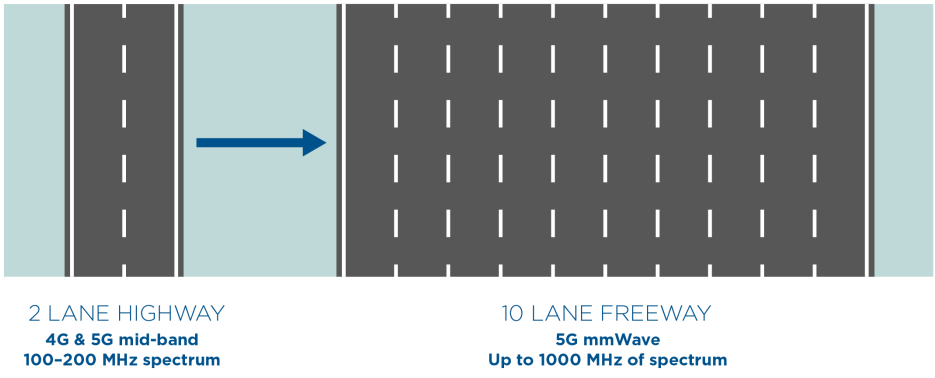


Figure 7: Wider 5G mmWave spectrum allocations provide a significant capacity increase

5G mmWave Safety

Do safety standards exist for 5G mmWave?

Yes, the mmWave frequencies used for 5G are covered by national standards and/or international guidelines on radio frequency electromagnetic field (RF-EMF) exposure that provide protection for all people against all established health hazards.

View the GSMA video explainer on 5G safety here.

The consensus among national health agencies and international bodies, such as the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the European Commission, is that RF- EMF exposures below international guidelines have no known health consequences.

World Health Organization (WHO)

'As the frequency increases, there is less penetration into the body tissues and absorption of the energy becomes more confined to the surface of the body (skin and eye). Provided that the overall exposure remains below international guidelines, no consequences for public health are anticipated.' reference

International Commission on Non-Ionizing Radiation Protection (ICNIRP)

'The ICNIRP RF-EMF guidelines have taken the above considerations into account and protect against all potential adverse health effects relating to exposure to RF EMFs from 5G technologies. This includes potential differences in the effect of RF EMFs as a function of age, health status, and depth of penetration, the effect of both acute and chronic exposures, and it includes all substantiated effects regardless of mechanism.' reference

The European Commission

'The European Commission takes the protection of public health very seriously and ensures that any emissions are subject to high precautionary measures. 5G networks will use small cells with lower power levels and therefore lower EMF exposure levels than the existing large cells in 4G networks. A recent Commission study showed that in urban areas where 5G will be deployed and 4G antennas are still in use, the overall exposure levels will modestly increase, but this will still be a long way below safe limits, which are 50 times lower than levels at which health effects are possible. As the 4G antennas go out of use, exposure levels will go down.' reference

What EMF research has been done on mmWaves?

There is a significant and ever-growing body of research publications related to EMFs and health. Research on the possible human health effects of exposure to RF-EMF, including the 5G mmWave frequencies goes back many decades and is continuing.

At mmWave frequencies, RF energy is absorbed superficially by the body, mostly by the skin (to a depth of about 1 mm or less). The biological effects of these frequencies have been studied previously and new studies are underway.

The radio signal exposure characteristics of 5G are like those of existing mobile technologies. In particular, it uses similar transmission powers and operates in similar frequency ranges. A European Commission expert committee[1] concluded that current knowledge about how EMF interacts with the human body can be used to set exposure limits for the whole frequency range up to 300 GHz. Therefore, existing health risk assessments are valid independently of the wireless technology for the whole RF frequency range.

Australian Radiation Protection and Nuclear Safety Agency

'This meta-analysis of the experimental studies also presented little evidence of an association between millimetre waves and adverse health effects. Studies that did report biological effects were generally not independently replicated and most of the studies reviewed employed low-quality methods of exposure assessment and control.' reference

Do higher frequencies mean increased exposure?

No, higher frequency does not mean higher exposure. Higher frequencies generally mean shorter ranges and higher data rates (due to the increase of the available bandwidth). Current 5G mmWave trials and commercial deployments use frequencies already covered by existing exposure standards.

Do higher data rates mean increased exposure?

No, higher data rates mean the information is transmitted far more quickly and efficiently and will cater for the increased data demand from end-users, whilst maintaining low RF-EMF levels. Assessments of 5G networks, operating across all bands, show exposure levels that are similar to existing mobile services.

[1] Final opinion on potential health effects of exposure to electromagnetic fields (EMF), Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), adopted on 27 January 2015.SCENIHR explains that at the frequencies used for mobile services, RF energy absorption and subsequent tissue heating is the major mechanism.

Can the EMF levels of 5G mmWave antennas with beamforming be measured?

Yes, international standards exist for the EMF compliance assessment of 5G network antennas and devices. These standards include approaches for beamforming antennas and the use of new frequency ranges.

What are the exposure levels from 5G mmWave antennas?

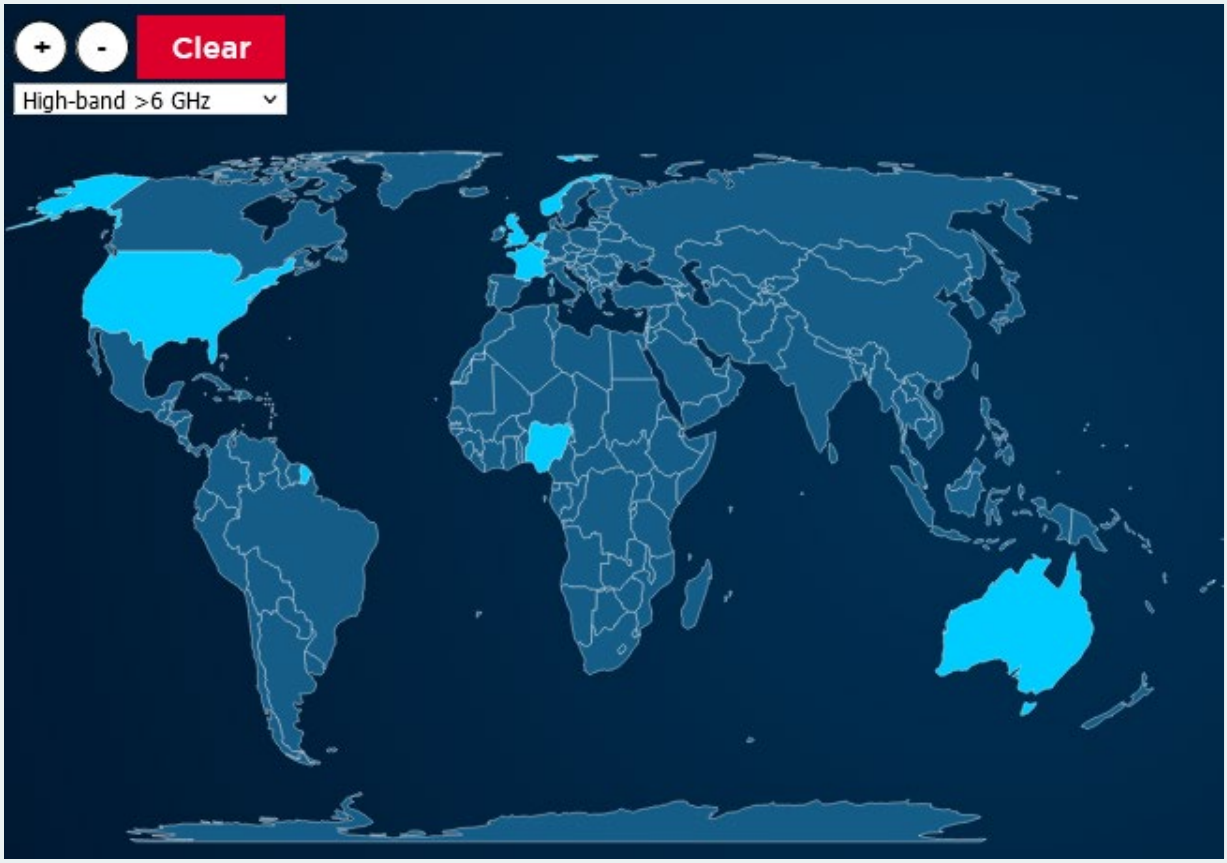
Across the world, national health agencies, government regulators, academia, test laboratories, mobile operators and manufacturers have conducted extensive testing on commercial and test networks in publicly accessible areas in the community to determine 5G RF-EMF exposure levels. These surveys show that:

- International safety and testing standards are in place for all 5G frequencies including 5G mmWave.
- Measured levels from 5G networks operating in all continents are low, and well below the international safety limits.
- 5G RF-EMF levels are similar to other wireless technologies with little difference between frequency bands.

Surveys of 5G mmWave sites in commercial and trial 5G networks show low levels ranging from 0.0002% to 1.5% of the international public limits. The typical maximum measured 5G RF-EMF level across the surveys in publicly accessible areas is less than 1% of the international public limits.

Resource: GSMA 5G EMF surveys interactive map

Data on measured 5G mmWave EMF levels from commercial and trial sites is presented on the GSMA 5G EMF Surveys map available here: https://www.gsma.com/publicpolicy/emf-and-health/safety-of-5g-networks/5g-emf-surveys



The interactive map includes a filter to select countries with 5G mmWave surveys (high-band > 6 GHz). An infographic can be downloaded that summarises the data. As the map is regularly updated, please access the website for current information.

What are the exposure levels from 5G mmWave devices?

Measurements [9] of actual output power levels of 5G mobile devices in commercial networks show levels that are below maximum output powers. 5G device levels, whether operating at mmWave or mid-band frequencies, are similar and are comparable to device output power levels in 3G and 4G networks.

Tips on explaining 5G mmWave safety:

- The term '5G mmWave' may be misunderstood – it's always good to clarify that 5G mmWave is just another part of the radio frequency spectrum.
- A unique aspect of 5G mmWave is that it doesn't penetrate objects, trees, buildings, and people. That essentially means that 5G mmWave signals don't get absorbed into the human body beyond the skin layers.
- The international human exposure guidelines for RF-EMF include the 5G mmWave frequencies and incorporate a large safety margin.
- The majority of national regulators adopt the international exposure guidelines into their domestic safety standards.
- Network operators, vendors and equipment manufacturers have procedures in place to design networks and devices to comply with national or international RF-EMF exposure guidelines.
- Measured levels from 5G networks, including 5G mmWave, operating in all continents are low, and well below the international safety limits.
- The GSMA global 5G EMF surveys map shows the low measured 5G mmWave RF-EMF levels in different countries.
- The GSMA 5G EMF surveys infographic provides a summary that can be used to communicate the results.

Positioning 5G mmWave

This section provides suggestions on how to position 5G mmWave in the marketplace and among other stakeholders.

1. About 5G mmWave Technology

Elevator pitch

5G mmWave helps deliver the full promise of 5G to consumers, businesses and society by delivering significant improvements to bandwidth, speed and latency, particularly in densely populated and high-capacity areas.

Features and benefits

5G mmWave delivers on the full promise of 5G

Flexible, capable and growing, 5G is delivering real benefits to people, businesses and society. An important element of the 5G technology mix, 5G mmWave fulfils the full promise of 5G by delivering massive capacity and supporting very large data rates and very low latency.

- 1,000x higher data volumes
- 10-100x more connected devices
- 10-100x higher typical user data rates
- 5x lower latency*

* Key requirements relative to 4G as laid out in 5G technical specifications and standards set by 3GPP. Sources: Ericsson, 2021; Nokia, 2016

5G mmWave complements the 5G technology mix

Whereas low- and mid-band 5G brings improved bandwidth, data speeds and latency over wide geographic areas, 5G mmWave is a high-band network technology designed to deliver ultra-high capacity connectivity in local and densely populated areas.

5G mmWave brings ultra-reliable and super-fast high-bandwidth connectivity to busy areas

5G mmWave facilitates reliable and high-quality connectivity in busy areas, including cities and densely populated residential areas, public transport hubs, such as airports and train stations, campuses, entertainment venues and sports stadiums.

5G mmWave will continue to transform business and society

5G mmWave enables applications that were not feasible with previous generations of mobile technologies, such as:

- Immersive online gaming
- Mobile AR/VR
- High-capacity industrial automation
- Digital twins
- Automated vehicles
- 5G smart factories
- Enhanced surveillance with 4k/360-degree security cameras
- AR-assisted navigation in public transport hubs, city centres and large entertainment venues

Safety (reactive positioning)

Like other mobile technologies, 5G mmWave uses radio frequency bands

5G mmWave frequencies are part of the RF spectrum bands that have been used for wireless communications for decades. However, it is only now that the mobile industry is able to leverage these frequencies for mobile connectivity.

5G mmWave complies with international safety standards

5G mmWave complies with national and international safety standards that provide protection for all people against all established health hazards, just like previous generations of mobile networks.

Measurements show that the total level of radio waves in publicly accessible areas from all mobile technologies, including 5G mmWave, remains well below the international safety guidelines.

The consensus of international bodies, such as the World Health Organization (WHO), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the European Commission, is that RF-EMF exposures below international guidelines have no known health consequences.

2. The GSMA 5G mmWave Accelerator Initiative

In November 2021, the GSMA announced the formation of a global accelerator initiative to drive awareness of 5G mmWave technology. Members of the initiative share mmWave intelligence, best practices and use cases to educate and inspire stakeholders around the world. The accelerator initiative aims to highlight the role that mmWave plays in unlocking the full potential of 5G.

3. The GSMA 5G mmWave Guide

The GSMA is a trusted thought leader in 5G

The GSMA is a source of authoritative 5G information and a gateway to key industry experts.

Available now, the GSMA 5G mmWave Guide helps the industry educate partners, customers & communities

As a collaborative industry effort, the GSMA 5G mmWave Guide (this document) is a crucial report with centralised information from a wide range of industry resources. The Guide provides mobile operators and industry stakeholders with an important means to educate their audiences on 5G mmWave features, benefits, applications, business case and compliance with safety standards. The report includes dedicated tips and a series of diagrams and visualisations to aid mobile operators and industry stakeholders in their efforts to explain 5G mmWave technology. The Guide is hosted on GSMA's InfoCentre[2] and is an industry-confidential document.

The GSMA 5G mmWave factsheet is available to everyone on GSMA.com

The Guide is accompanied by a publicly available factsheet providing high-level information on 5G mmWave features, benefits and safety compliance. The GSMA 5G mmWave webpage, which hosts the factsheet, can be found at www.gsma.com/5GmmWave

5G mmWave References

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[2] 3GPP TS 38.101-1, User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone, (Release 16), section 5.1. [https://www.3gpp.org/ftp/Specs/latest/Rel-16/38_series]

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[9] Network-based measurements of actual output power levels of UE in commercial 5G networks. Joshi et al., 2021. Poster presented at BioEM2021, Ghent Belgium, 26-30 September 2021.

Further 5G mmWave Resources

Business Case

GSMA - The Economics of 5G mmWave

GSMA – mmWave 5G Benefits

GSMA – Impacts of 5G mmWave in China

GSMA - The 5G FWA opportunity: a TCO model for a 5G mmWave FWA network

Ericsson – Fixed Wireless Access Handbook

Ericsson - Leveraging the potential of 5G millimeter wave

Qualcomm – The business of 5G mmWave

5G mmWave Technology

GSMA – Future Networks – 5G

GSMA - Understanding 5G – A guide for local communities

Qualcomm - Understanding mmWave: Faster connectivity highways for 5G

Ericsson - Leveraging the potential of 5G millimeter wave

5G Explained – mmWave spectrum

IEEE Video - 5G Technologies: Millimeter Waves Explained

IEEE Video - Everything You Need to Know About 5G

IEC Video – Understanding technology: 5G made simple - mmWave 5G beamforming demonstration

EMF Science, Research and Safety

ARPANSA - World-first reviews into 5G radio waves, published 17 March 2021.

ICNIRP 5G page and RF-EMF exposure guidelines (100 kHz to 300 GHz) page

GSMA Safety of 5G Networks page, GSMA Safety of 5G Mobile Networks fact sheet (in multiple languages), GSMA 5G, the Internet of Things and Wearable Devices booklet, GSMA 5G, EMF Exposure and Safety animated video and GSMA 5G EMF Surveys map

Telstra - 50 Surveys of 5G mmWave

GSMA Infocentre2 Knowledgebase – 5G EMF

GSMA HEAD OFFICE
Floor 2
The Walbrook Building
25 Walbrook
London
EC4N 8AF
United Kingdom
www.gsma.com