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Electromagnetic field compliance assessments for 5G wireless networks

Supplement 16 to ITU-T K-series Recommendations

Electromagnetic field compliance assessments for 5G wireless networks

Summary

Supplement 16 to the ITU-T K-series Recommendations provides guidance on the radio frequency-electromagnetic field (RF-EMF) compliance assessment considerations for the International Mobile Telecommunication system (IMT-2020) wireless networks also known as 5th generation of wireless networks (5G). Also, the 5G technical standards have been finalized and commercial 5G networks are now launched in many countries.

History

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Supplement 16 to ITU-T K-series Recommendations

Electromagnetic field compliance assessments for 5G wireless networks

1 Scope

This Supplement 16 to the ITU-T K-series Recommendations provides guidance on the radio frequency (RF) – electromagnetic field (EMF) compliance assessment considerations for 5th generation (5G) of wireless networks, including 5G base stations (BS) located at existing wireless network facilities.

2 References

[ITU-T K.52]	Recommendation ITU-T K.52 (2021), *Guidance on complying with limits for human exposure to electromagnetic fields*.
[ITU-T K.70]	Recommendation ITU-T K.70 (2020), *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations*.
[ITU-T K.91]	Recommendation ITU-T K.91 (2022), *Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields*.
[ITU-T K.100]	Recommendation ITU-T K.100 (2021), *Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service*.
[ITU-T K.Sup.9]	ITU-T K-series Recommendations – Supplement 9 (2019), *5G technology and human exposure to radiofrequency electromagnetic fields*.
[IEC/IEEE 62209-1528]	IEC/IEEE 62209-1528:2020, *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-worn wireless communication devices – Human models, instrumentation and procedures (Frequency range of 4 MHz to 10 GHz)*.
[IEC 62209-3]	IEC 62209-3:2019, *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Part 3: Vector measurement-based systems (Frequency range of 600 MHz to 6 GHz).*
[IEC 62232]	IEC 62232:2022, *Determination of RF field strength, power density and SAR in the vicinity of base stations for the purpose of evaluating human exposure*.
[IEC/IEEE 63195-1]	IEC/IEEE 63195-1:2022, *Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz) – Part 1: Measurement procedure*.

[IEC/IEEE 63195-2] IEC/IEEE 63195-2:2022, *Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz) – Part 2: Computational procedure*.

[IEC PAS 63446] IEC PAS 63446:2022, *Conversion method of specific absorption rate to absorbed power density for the assessment of human exposure to radio frequency electromagnetic fields from wireless devices in close proximity to the head and body – Frequency range of 6 GHz to 10 GHz*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 actual maximum power [b-IEC TR 62669]: Value of transmitted power reached during operations at a given percentile of the cumulative distribution function (CDF) of a statistical evaluation taking into account the averaging time tavg and the variation of the base station (BS) load for the whole duration of the statistical evaluation.

NOTE – For a given base station (BS) site, the actual maximum transmitted power or equivalent isotropically radiated power (EIRP) of radio frequency (RF) exposure or RF compliance boundary is defined as the default value for a 95th percentile when using computational methods or for a 100th percentile when using measurement methods. When another percentile is used for this BS site, the recommended notation is to add the "-*pxx*" suffix to the assessed quantity, where xx is the percentile used for the statistical evaluation. For example, P_{TXA}-p99 is the actual maximum transmitted power based on statistical approaches using a 99th percentile.

3.1.2 antenna: [ITU-T K.70].

3.1.3 averaging time [b-IEC TR 62669]: Appropriate time over which exposure is averaged for purposes of determining compliance.

3.1.4 base station: [ITU-T K.100].

3.1.5 basic restrictions: [ITU-T K.70].

3.1.6 compliance boundary: [ITU-T K.100].

3.1.7 electromagnetic field (EMF): [ITU-T K.91].

3.1.8 equivalent isotropically radiated power (EIRP): [ITU-T K.100].

3.1.9 exposure: [ITU-T K.52].

3.1.10 exposure level: [ITU-T K.52].

3.1.11 exposure limits: [ITU-T K.70].

3.1.12 general public: [ITU-T K.52].

3.1.13 massive MIMO [b-IEC TR 62669]: Method used for multiplying the capacity of a radio link in a multicarrier cellular network in which a BS j is equipped with Mj >> 1 antennas, to achieve channel hardening and communicates with Kj single-antenna UEs simultaneously on each time/frequency sample, with antenna-UE ratio Mj/Kj > 1.

3.1.14 power density (S): [ITU-T K.52].

3.1.15 radio frequency (RF): [ITU-T K.70].

3.1.16 rated maximum power: [b-IEC TR 62669]: Value of transmitted power as declared by the manufacturer.

3.1.17 specific absorption rate (SAR): [ITU-T K.52].

3.1.18 transmitter: [ITU-T K.70].

3.1.19 transmitted power [b-IEC TR 62669]: Total power transmitted by a base station under test during the transmitter ON period assessed either at the antenna input port(s) for passive antennas or as the total radiated power for base stations with built-in antennas.

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

5G	5th Generation of Wireless Networks
APD	Absorbed Power Density
BS	Base Station
EIRP	Equivalent Isotropically Radiated Power
EMF	Electromagnetic Field
FDD	Frequency Division Duplex
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IMT-2020	International Mobile Telecommunication system
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
mMIMO	massive MIMO
mmWave	millimetre-wave
RAN	Radio Access Network
RF	Radio Frequency
SAR	Specific Absorption Rate
TDD	Time Division Duplex
Wi-Fi	Wireless Fidelity
WRC	World Radiocommunication Conferences

5 Overview of 5G networks

5G is the 5th generation of wireless networks, a significant evolution of the 4G long term evolution (LTE) networks. 5G has been designed to meet the very large growth of data and connectivity in today's modern society, the Internet of things with billions of connected devices, and tomorrow's innovations.

The 5G wireless network that enables high-speed data transmission with ultra-low latency is the key infrastructure for future technology that will lead the fourth or next industrial revolution such as artificial intelligence, autonomous vehicle, big data and cloud.

5G will initially operate in conjunction with existing 4G networks before evolving to fully standalone networks in subsequent releases and coverage expansions.

General information on 5G wireless networks can be found in [ITU-T K-Sup.9].

6 5G spectrum

5G will use additional spectrum predominately in the 3-86 GHz range to significantly add more capacity compared to the current mobile technologies. The additional spectrum and greater capacity will enable more users, more data, and faster connections. It is also expected that there will be future reuse of existing low band spectrum for 5G as legacy networks decline in usage and also to support future use cases.

The increased spectrum also includes the millimetre-wave (mmWave) bands. The mmWave frequencies provide localised coverage as they mainly operate over short line of sight distances.

Figure 1 shows the existing and new spectrum that will be used for 5G mobile communications.

– **Low band (below 1 GHz)** – providing widespread coverage across urban, suburban, and rural areas and supporting IoT for low data rate applications.
– **Medium band (1 – 6 GHz)** – providing good coverage and high speeds and includes the expected initial 5G range of 3.3 – 3.8 GHz which has been identified as the most likely band for launching 5G globally.
– **High band (above 6 GHz)** – providing ultra-high broadband speeds for advanced mobile broadband applications, and which is most suitable for applications in dense traffic hotspots. The 26 – 28 GHz band has been identified by some administrations for future 5G applications.

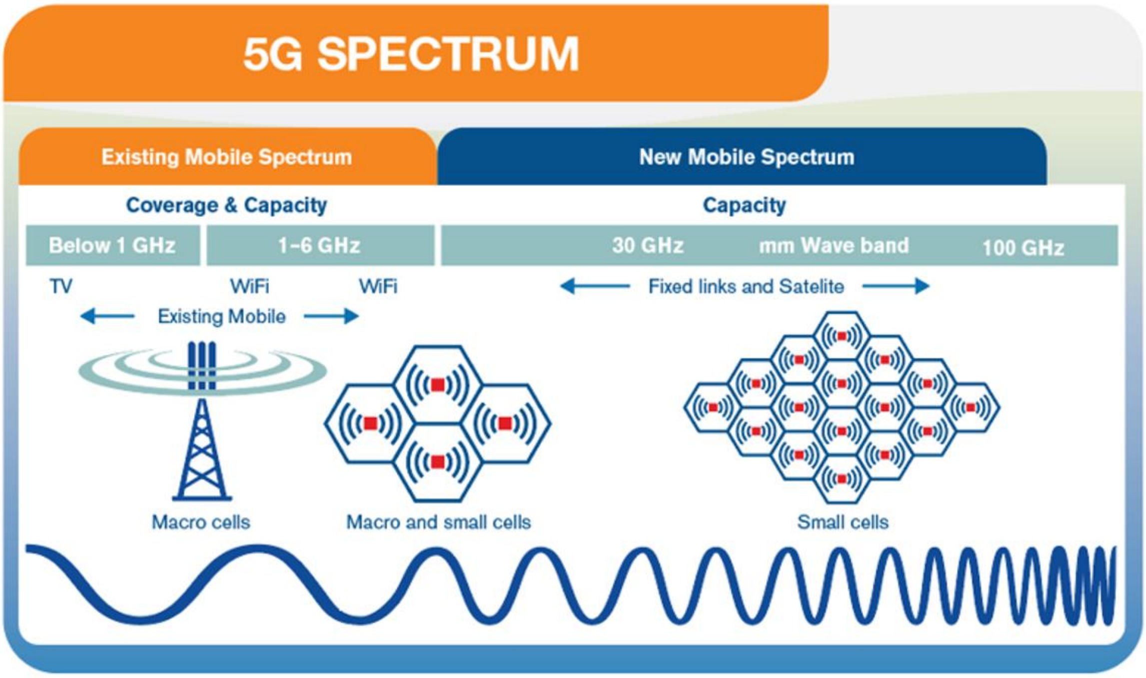

Figure 1 – Existing and new spectrum to be used for 5G mobile communication services [b-EmfExpl]

Spectrum for mobile telecommunication services including 5G is determined by the World Radiocommunication Conferences (WRC) which are held every three to four years. It is the job of the WRC to review, and, if necessary, revise the radio regulations, the international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits. Revisions are made based on an agenda determined by the ITU council, which takes into account proposals made by previous WRC. The WRC designates frequencies for use by the IMT-2020.

The 5G standards are expected to support both frequency division duplex (FDD) and time division duplex (TDD). Research is also underway on full duplex systems for 5G to transmit and receive simultaneously on the same channel. Full duplex effectively doubles the spectrum efficiency.

7 How 5G wireless networks work

Most operators will initially integrate 5G networks with existing 4G networks to provide a continuous connection. In Figure 2, an illustration of the 5G network architecture is provided. More information can be found in [ITU-T K.Sup.9].

A wireless network has two main components, the 'radio access network' (RAN) and the 'core network'.

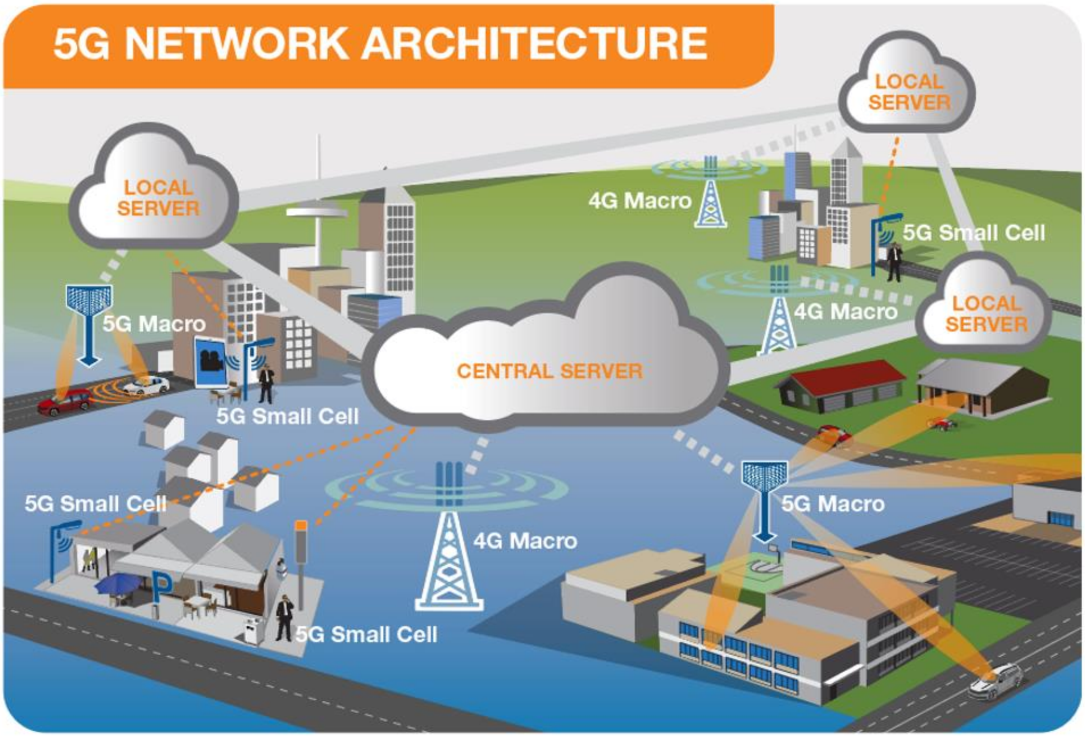

Figure 2 – Schematic illustration of the architecture for 5G mobile communication networks [b-EmfExpl]

7.1 The radio access network

The radio access network (RAN) consists of various types of facilities including small cells, towers, masts, street furniture and dedicated in-building and home systems which connect mobile users and wireless devices to the main core network.

Small cells will be a significant feature of 5G networks, particularly at the new mmWave frequencies where the connection range is very short. To provide a continuous connection, small cells will be distributed in clusters depending on where users require connection, and this will complement the macro network.

5G macro cells will use antennas that have multiple elements to send and receive more data simultaneously and cater to multiple connections. The benefit to users is that more people can simultaneously connect to the network and maintain high throughput. Antenna arrays for 5G are often referred to as 'massive multiple input multiple output' (mMIMO) due to a large number of multiple elements.

7.2 5G massive MIMO antenna configurations

5G massive MIMO (mMIMO) antennas are similar to existing 3G and 4G base station antennas, however, with a much higher frequency. The individual element size is smaller allowing more elements (for example 64 or 512). Figure 3 shows the difference between conventional sector antennas and the mMIMO antennas used in 5G networks.

Beam steering and beamforming is a technology that allows the mMIMO base station antennas to direct the radio signal to the users and devices rather than in all directions. The beam steering technology uses advanced signal processing algorithms to determine the best path for the radio signal to reach the user. This increases efficiency as it reduces interference (unwanted radio signals). Figure 4 illustrates how beam steering and beamforming works in a 5G network.

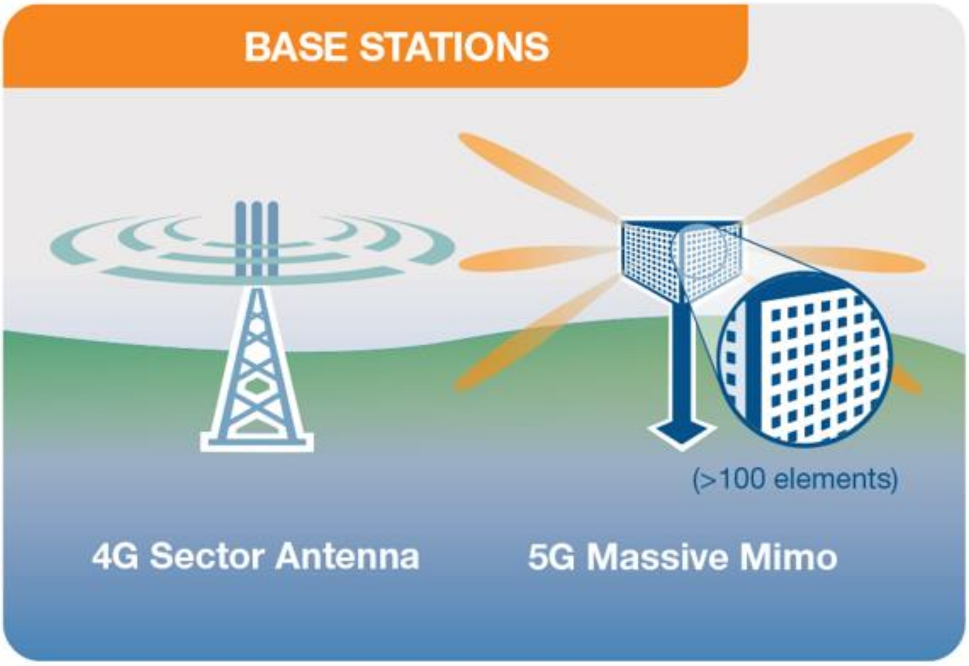

Figure 3 – 4G base station with sector antennas and 5G base station with multi-element Massive MIMO antenna array [b-EmfExpl]

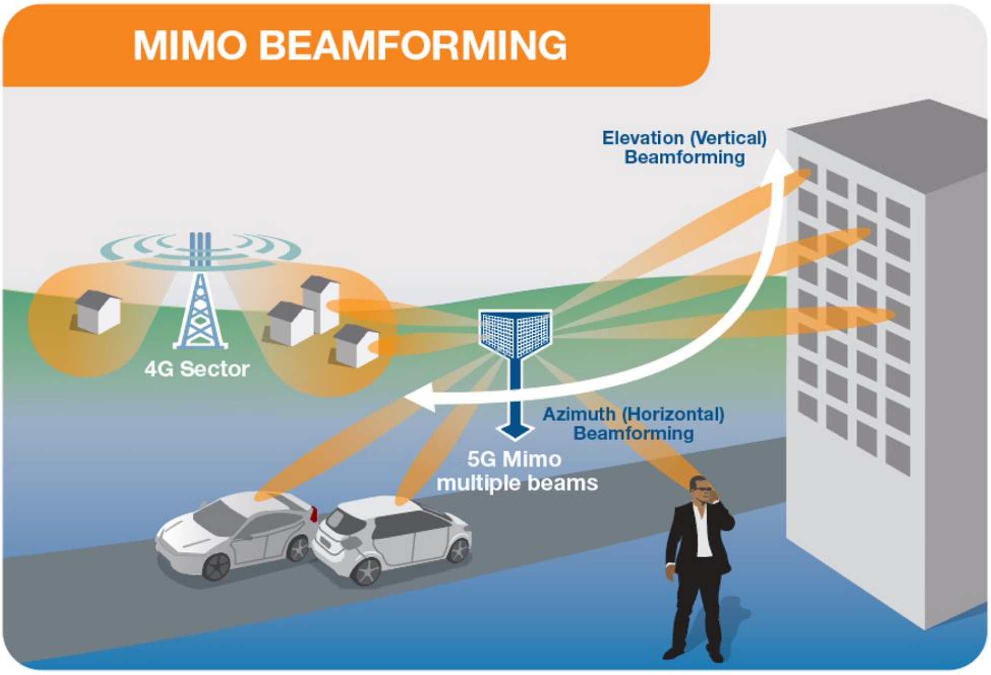

Figure 4 – Massive MIMO beamforming and beam steering in a 5G network [b-EmfExpl]

7.3 The core network

The core network is the mobile exchange and data network that manages mobile voice, data and internet connections. For 5G, the core network is being redesigned to better integrate with the internet and cloud based services and includes distributed servers across the network improving the response time (reducing latency).

Many of the advanced features of 5G, including network virtualization and network slicing for different applications and services, will be managed in the core network.

7.4 5G working with 4G

In non-standalone deployments (i.e., 5G working jointly with 4G), when a 5G connection is established, the user equipment (or device) connects to the 4G network to provide the control signalling and to the 5G network to help provide the fast data connection by adding to the existing 4G carriage.

Where there is limited 5G coverage, the data is carried on the 4G network providing a continuous connection. Essentially with this design, the 5G network is complementing the existing 4G network. Figure 5 illustrates how 5G integration with 4G networks will work.

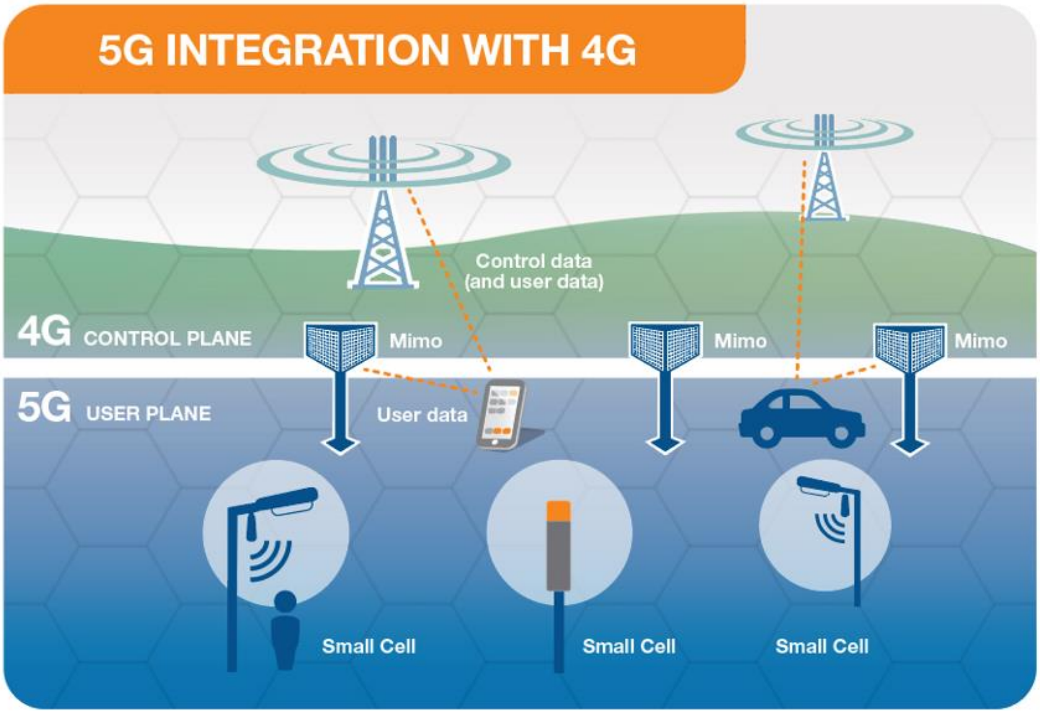

Figure 5 – Illustration of how the 5G networks will initially be integrated with existing 4G networks [b-EmfExpl]

8 5G and RF-EMF exposure

8.1 5G, RF-EMF and health

The radio frequency bands allocated for use by 5G including the mmWave frequencies have been used by other radio frequency applications such as microwave communication, satellite and radar for decades. 5G wireless networks are designed to be very efficient. This means both the network and device transmission power will be low, which means that the levels of RF-EMF in a 5G environment are within the International Commission on Non-Ionizing Radiation Protection (ICNIRP) exposure limits.

The World Health Organization (WHO), the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) of the European Union and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) concluded that exposure related to wireless networks and their use does not lead to adverse effects for public health if it is below the limits recommended by the ICNIRP. Research on possible human health effects of RF-EMF exposure to mmWave frequencies goes back many decades and is continuing. In terms of research specifically on the 5G frequency range, the EMF portal database [b-EMF] lists approximately 350 studies on mmWave RF-EMF health related research. Extensive research on mmWave and health has been conducted on radar, microwave and military applications.

Tissue heating remains the only recognised and substantiated hazard of exposure to mmWave frequencies based on scientific research to date.

However, despite much research and communication efforts to resolve it, there is still some public concern about the possible harmfulness of RF-EMFs from mobile communication equipment. In addition, there will be numerous new 5G base stations around the areas where people live and work, which may lead to additional public concern. It is very important to properly address these concerns, and to ensure the efficiency of wireless networks and maintain low RF-EMF levels through the evolution of the current networks and expansion of 5G wireless networks, which constitute the key infrastructure that will enable entry into the smart information society.

8.2 RF-EMF exposure limits

Comprehensive international guidelines exist governing exposure to radio waves used at 5G frequencies. The limits have been established by independent scientific organizations, such as the ICNIRP and include substantial margins of safety to protect all population.

These guidelines have been widely adopted in standards and regulations around the world, and also endorsed by WHO. Where national limits do not exist, or if they do not cover the frequencies of interest, then ICNIRP limits should be used [ITU-T K.91].

9 RF-EMF exposure compliance assessments

The International Electrotechnical Commission (IEC) Technical Committee 106 is responsible for preparing international standards on measurement and calculation methods to assess human exposure to electric, magnetic and electromagnetic fields. The IEC and ICNIRP have agreed on the sharing of responsibilities for EMF standards. EMF exposure limit guidelines are developed by the ICNIRP, and EMF exposure assessment standards are developed by the IEC and ITU. IEC and IEEE International Committee on Electromagnetic Safety (ICES) TC34 have jointly developed dual-logo standards.

A list of the relevant IEC standards is available on the IEC TC106 website.

9.1 5G RF-EMF assessment standards

9.1.1 Base stations and wireless networks

[IEC 62232] specifies assessment methods for base stations and wireless networks. It covers a frequency range of up to 300 GHz and includes methodology applicable to 5G.

IEC Technical Report [b-IEC TR 62669] provides case studies for the implementation of [IEC 62232], including 5G base stations, and describes the general guidelines for the compliance of base stations using mMIMO. [b-IEC TR 62669] also includes case studies for the assessment of standalone and shared 3G, 4G and 5G base stations, and small cells.

9.1.2 Mobile devices

IEC has developed a Technical Report [b-IEC TR 63170] that describes the state-of-the-art measurement techniques and test approaches for evaluating local and spatial-average incident power density of wireless devices operating in close proximity of the users at 6 GHz to 100 GHz. As a follow-up, new standards were developed on computation methods [IEC/IEEE 63195-2] and measurement methods [IEC/IEEE 63195-1] covering from 6 GHz to 300 GHz. The methods in these standards are also included in [IEC 62232]. For specific absorption rate (SAR) assessments of 5G devices using frequency bands up to 10 GHz, [IEC/IEEE 62209-1528] and [IEC 62209-3] up to 6 GHz are applicable. Absorbed power density (APD) assessment method covering from 6 GHz to 10 GHz is also available [IEC PAS 63446].

9.2 5G wireless network RF-EMF compliance assessment methods

RF-EMF compliance assessments for 5G networks will require careful analysis of the design and configuration of the site to be evaluated, and whether an mMIMO or small cell configuration has been deployed. The purpose of the assessment is typically to determine the size of the RF-EMF compliance boundary (exclusion zone), for the general public and workers around the antennas, and to verify that the zone is not accessible. Alternatively, calculations or measurements may be conducted close to a base station site, in areas that are accessible to the general public, in order to verify that the RF-EMF exposure levels are below the applicable limits. Guidance on how to perform RF-EMF compliance assessments are provided in [ITU-T K.100] as well as [IEC 62232] and [b-IEC TR 62669].

9.3 Uncertainty considerations for 5G compliance assessments

Providing uncertainty estimates is particularly important when determining compliance with exposure limits.

The assessment of uncertainty relevant for 5G compliance assessments is detailed in [IEC 62232], [ITU-T K.91] and an example of uncertainty estimation including some of the factors listed in [IEC 62232] is described in [b-Kim].

9.4 Determining the actual maximum power for RF-EMF compliance assessments of 5G networks

The advances in wireless network technology for 5G have resulted in wireless networks becoming significantly more efficient and requiring less transmitted power to deliver the same data rates. 5G networks will transmit similar power levels compared to previous mobile technologies. Like current 2G, 3G and 4G networks, 5G base stations will not be designed to operate at maximum power except for very short times in order to handle traffic variations. This means that the transmitted power averaged over time periods of relevance for RF-EMF exposure assessments, e.g., six minutes, is significantly lower than the rated maximum transmitted power for the equipment.

Consequently, using the rated maximum power will lead to overly conservative RF-EMF exposure values and compliance boundaries, especially in the case of several different technologies and antennas at the site. To address this issue, both [ITU-T K.100] and [IEC 62232] open up the possibility to use the 'actual maximum power', which can be determined from measurements of the base station's real output power, from measurements of a large number of representative base stations in the network, or by using statistical models or network simulations [b-Thors], [b-Baracca]. The actual maximum power can for example be taken as the 95th percentile value of the obtained power distribution [b-IEC TR 62669].

For EMF exposure assessments of 5G sites using mMIMO, it is important to accurately determine the actual maximum transmitted power. Massive MIMO base stations transmit a number of simultaneous beams to the connected devices. These beams vary rapidly in both time and space, and there will be no transmission in a certain direction at the rated maximum power for long time periods. [b-IEC TR 62669] provides detailed guidance on how to determine the actual maximum power for mMIMO antennas.

9.5 Transmitted power and RF-EMF exposure from 5G massive MIMO antennas

The configuration of a massive MIMO 5G site will vary depending on the operator network design and implementation of the applicable 3GPP standards. The calculation of actual maximum transmitted power and actual maximum EMF exposure from an mMIMO 5G antenna array requires several factors to be considered, including:

– total maximum transmitted power;
– fraction of power used for traffic beams and broadcast / synchronization beams;
– beam steering ranges and half-power beamwidths;
– antenna radiation pattern (envelope of all traffic beams);
– maximum gain for traffic beams and broadcast / synchronization beams;
– number of possible simultaneous traffic beams;
– installation environment;
– distribution of connected devices; and
– time division duplex (TDD) or frequency division duplex (FDD).

[b-IEC TR 62669] provides guidance on methods to determine the actual maximum power for mMIMO base station antennas and includes case studies describing how to assess RF-EMF compliance for a number of typical 5G sites. Given below are two case studies illustrating how EMF compliance assessments of 5G macro and small cell sites may be performed.

9.6 In-situ RF-EMF exposure measurements of 5G base stations

After a 5G base station has been taken into operation there may be a need to measure the RF-EMF exposure in its vicinity to either verify compliance with regulatory limits or to evaluate the exposure levels for communication purposes. The standards [IEC 62232] and [ITU-T K.100] provide detailed information on how to perform such measurements to get accurate and reliable results.

These standards specify requirements and guidelines related to the following:

- Site analysis and measurement area selection;
- Selection of exposure metric;
- Measurement equipment (broadband/frequency selective, frequency response, lower detection level, dynamic range, linearity, probe isotropy);
- Measurement procedure (including time and spatial averaging);
- Methods to extrapolate to actual or theoretical maximum exposure;
- Contributions from ambient sources;
- Uncertainty evaluation; and
- Reporting.

9.7 Results of 5G RF-EMF assessments

Around the world, national health agencies, government regulators, academia, test laboratories, mobile operators, and manufacturers have conducted extensive testing on commercial and test networks to determine 5G RF-EMF exposure levels.

An interactive map[1] includes data from multiple stakeholders. Measured levels are for publicly accessible areas, typically at ground level. 5G RF-EMF levels are converted to a percentage of the relevant international [b-ICNIRP] public RF-EMF limit.

The summary shows that:

- international safety and testing standards are in place for all 5G frequencies including millimetre waves.
- 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.

The typical maximum measured 5G RF-EMF level across the surveys is about or less than 1% (power density) of the international public limits.

5G networks are designed to use radio spectrum efficiently and this is evident in the testing. Reduced signalling requirements for 5G and the use of smart antenna systems mean more efficient use of RF-EMF energy.

1 https://www.gsma.com/publicpolicy/emf-and-health/safety-of-5g-networks/5g-emf-surveys

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[b-EmfExpl] EMF Explained 2.0
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<https://ieeexplore.ieee.org/document/8039290>

[2] When reference [b-ICNIRP] is used, it applies to [b-ICNIRP_1998] and [b-ICNIRP_2020].

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