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5G technology and human exposure to radio frequency electromagnetic fields

ITU-T K-series Recommendations – Supplement 9

Supplement 9 to ITU-T K-series Recommendations

5G technology and human exposure to radio frequency electromagnetic fields

Summary

The deployment of fifth generation (5G) will see the evolution and expansion of existing fourth generation (4G) networks and the introduction of new radio access networks in millimetre wavebands. As a result of the use of much higher frequency ranges, the number of base stations will substantially increase. These networks will include a range of installations including smaller cell deployments and advanced antenna technologies. Massive multiple input multiple output (MIMO) antennas will allow the use of very narrow beams that will follow the user with an impact on the surrounding exposure level different from that of current systems. The number of wireless devices will dramatically increase. New technology allows for the use of more efficient systems that require lower communication signal levels.

Supplement 9 to ITU-T K-series Recommendations contains an analysis of the impact of the implementation of 5G mobile systems with respect to the exposure level of electromagnetic fields (EMFs) around radiocommunication infrastructure.

History

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Keywords

5G mobile systems, EMF, exposure limits, small cells, smart antennas, MIMO

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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5G technology and human exposure to radio frequency electromagnetic fields

1 Scope

This Supplement contains an analysis of the impact of the implementation of fifth generation (5G) mobile systems on exposure level to electromagnetic fields (EMFs) around radiocommunication infrastructure.

2 References

[ITU-T K.100]	Recommendation ITU-T K.100 (2019), *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.16]	ITU-T K-series Recommendations – Supplement 16 (2019), *Electromagnetic field compliance assessments for 5G wireless networks*.
[ITU-R P.1411-9]	Recommendation ITU-R P.1411-9 (2017), *Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz*.
[ITU-R P.2108-0]	Recommendation ITU-R P.2108-0 (2017), *Prediction of clutter loss*.
[ITU-R P.2109-0]	Recommendation ITU-R P.2109-0 (2017), *Prediction of building entry loss*.
[IEC 62232]	IEC 62232:2017, *Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure*.

3 Definitions

3.1 Terms defined elsewhere

This Supplement uses the following terms defined elsewhere:

3.1.1 antenna [b-ITU-T K.70].

3.1.2 base station [ITU-T K.100].

3.1.3 basic restrictions [b-ITU-T K.70].

3.1.4 compliance boundary [ITU-T K.100].

3.1.5 electromagnetic field (EMF) [b-ITU-T K.91].

3.1.6 exposure [b-ITU-T K.52].

3.1.7 exposure level [b-ITU-T K.52].

3.1.8 exposure limits [b-ITU-T K.70].

3.1.9 general public [b-ITU-T K.52].

3.1.10 power density (S) [b-ITU-T K.52].

3.1.11 radio frequency (RF) [b-ITU-T K.70].

3.1.12 specific absorption rate (SAR) [b-ITU-T K.52].

3.1.13 transmitter [b-ITU-T K.70].

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

2G	second Generation
3G	third Generation
4G	fourth Generation
5G	fifth Generation
BS	base station
EIRP	Equivalent Isotropically Radiated Power
EMF	Electromagnetic Field
EUT	Equipment Under Test
IMT-2020	International Mobile Telecommunications 2020
IoT	Internet of Things
LTE	Long-Term Evolution
MIMO	Multiple Input Multiple Output
mmWave	millimetre Waveband
RF	Radio Frequency
SAR	Specific Absorption Rate
Wi-Fi	Wireless Fidelity

5 Conventions

None.

6 Background

5G is the fifth generation of mobile networks, a significant evolution of the fourth generation (4G) long-term evolution (LTE) networks. 5G has been designed to meet the extensive growth in data and connectivity of today's modern society, the Internet of things (IoT) with billions of connected devices, and tomorrow's innovations (see Figure 1).

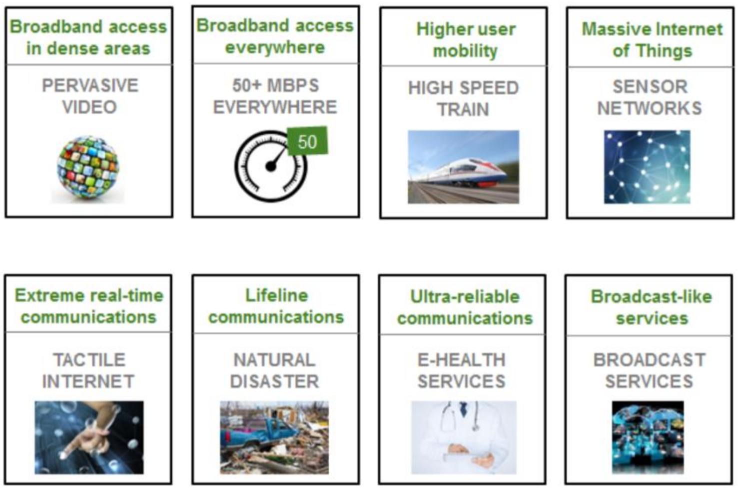

Figure 1 – Main usage for 5G networks
(Source: [b-NGMN 5G WP])

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

5G will predominately use additional spectrum in the 3-100 GHz range to add significantly more capacity compared to 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 the existing low-band spectrum for 5G as legacy networks decline in usage and to support future use cases.

The increased spectrum also includes the millimetre waveband (mmWave) above 30 GHz. The mmWave frequencies provide localized coverage as they mainly operate over short line of sight distances.

7 Agenda for 5G deployment

The work on 5G mobile systems (also called 5G International Mobile Telecommunications 2020 (IMT-2020)) started just after the 4G mobile system (LTE) was approved. Implementation of the system is planned for 2020 (summer Olympic Games in Tokyo), but experimental implementation started during the 2018 winter Olympic Games in PyeongChang (Korea).

Extensive work on this new system is ongoing at many standardization bodies including ITU-R, European Communication Commission (ECC), European Telecommunications Standards Institute (ETSI) and 3rd Generation Partnership Project (3GPP). In ITU-R, a special Task Group 5/1 (TG 5/1) has been established for the 5G mobile system (Agenda item 1.13) and should complete its work at the 2019 World Radiocommunication Conference (WRC-19).

According to the schedule, ITU-R has developed models for radio wave propagation, clutter and building entry loss and delivered them via TG 5/1 as [ITU-R P.1411-9], [ITU-R P.2108-0] and [ITU-R P.2109-0]. These Recommendations are required for compatibility and sharing studies that are now being conducted in ITU-R with the major contribution from ITU-R WP 5D. ITU-R WP 5D and ITU-R WP 5C are responsible for the determination of the parameters to be used in sharing and compatibility studies concerning the implementation of the 5G mobile system. The main challenges are compatibility and sharing studies in the frequency ranges above 6 GHz that is used by broadband systems to ensure high speed data transfer.

The standardization work is ongoing in many standardization bodies, including ITU, ECC, ETSI and 3GPP. According to the current agreement, the first priority frequency bands are 3.4-3.8 GHz and 24.25-27.5 GHz. Figure 2 presents the current schedule of work on the 5G IMT-2020 system.

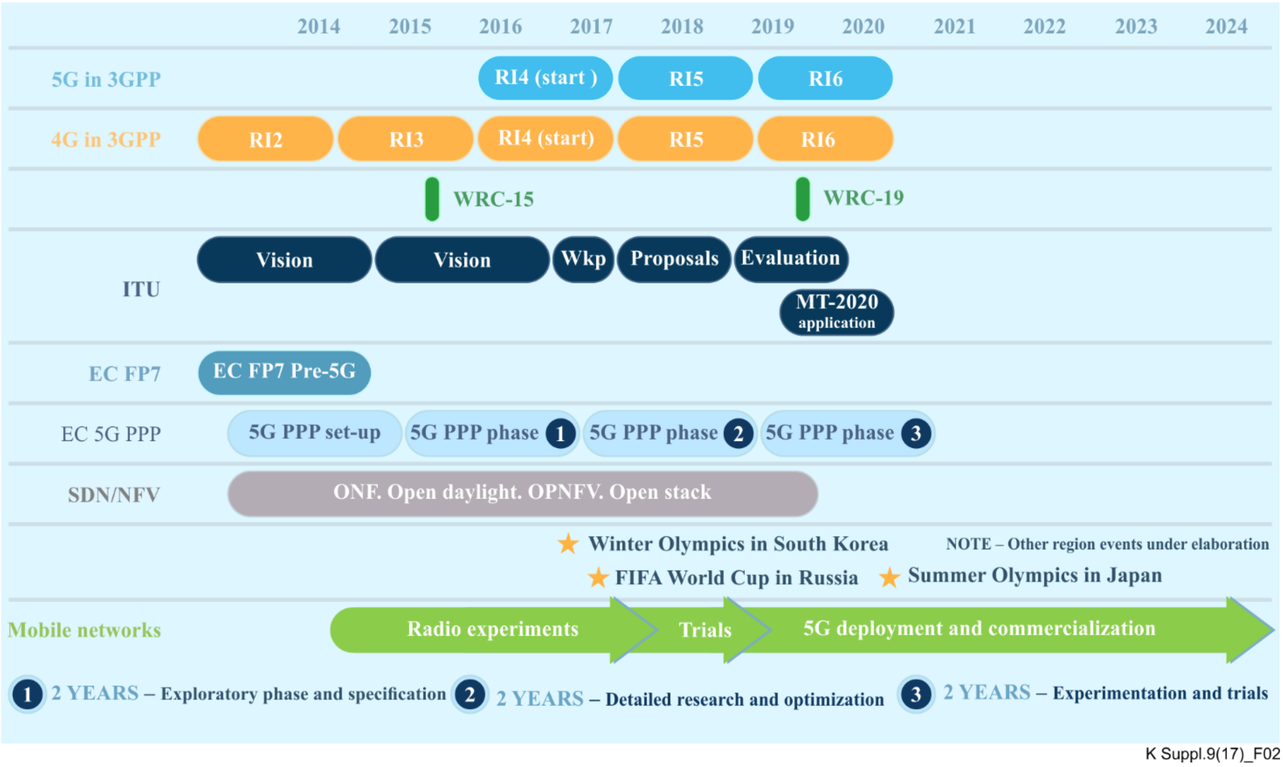

Figure 2 – 5G international deployment agenda
(Source: [b-5GPPP])

8 Overview of radio frequency electromagnetic field exposure limits

5G systems will use frequencies that are already addressed by international radio-protection standards. Two international bodies: the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Institute of Electrical and Electronics Engineers (IEEE) have developed exposure guidelines and defined exposure limits in terms of specific absorption rate (SAR) and electric and magnetic field strength and power density in the 5G frequency band. These exposure guidelines form the basis of policy and regulation in many countries. However, exposure limits differ in some countries and in some cases are more restrictive. ITU recommends that if radio frequency (RF) EMF limits do not exist, or if they do not cover the frequencies of interest, then ICNIRP limits should be used.

Restrictions are based directly on established health effects. Reference levels for human exposure to electric, magnetic and electromagnetic fields are derived from the basic restrictions using the worst-case assumption about exposure. In many cases, it is difficult to assess basic restriction levels in real situations. If the reference limits are met, then the basic restrictions will also be met; however, if the reference levels are exceeded, it does not necessarily mean that basic restrictions are exceeded. Reference levels are used, as it is comparatively easy to measure them; basic restrictions are used mainly for mobile handsets and in cases where exposure exceeds reference levels.

In Table 1, basic restrictions and reference levels from [b-ICNIRP Guidelines] and [b-IEEE Std C.95.1] are presented. Average limits values shall be measured over 6 min. Note that there is a difference between [b-ICNIRP Guidelines] and [b-IEEE Std C.95.1] at 6 GHz. In [b-IEEE Std C.95.1] frequency ranges between 3 and 6 GHz are considered as transition frequencies, meaning that exposure metrics may be SAR or power density.

Table 1 – Electromagnetic field international whole body exposure limits

Frequency band	[b-ICNIRP Guidelines] limit	[b-IEEE StdC.95.1] limit
10 MHz < $f \leq$ 3 GHz	0.08 W/kg	0.08 W/kg
3 GHz < $f \leq$ 10 GHz	0.08 W/kg	10 W/m^2
10 GHz < $f \leq$ 300 GHz	10 W/m^2	10 W/m^2
400 MHz < $f \leq$ 2 GHz	2 W/m^2-10 W/m^2 (28 V/m-61 V/m)	2 W/m^2-10 W/m^2 (27.5 V/m-61V/m)
f > 2 GHz	10 W/m^2 (61 V/m)	10 W/m^2 (61 V/m)

Stringent regulations exist to protect users from radio frequency exposure. To test compliance with these regulations, evaluation methods have been standardized on these exposure metrics. These compliance tests are based on extremely conservative non-realistic assumptions (i.e., maximum power emitted) and are not always representative of real-life exposure.

9 Radio frequency electromagnetic field exposure due to future 5G deployment

9.1 Biological research studies on 5G signals

To date, the World Health Organization (WHO), the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) of the European Union and ICNIRP have 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. These opinions are based on considerable scientific research that has been conducted on mobile phone frequencies. There are fewer biological studies on frequencies above 24 GHz. Some countries plan to support research on biology, epidemiology and dosimetry in this area. In terms of research specifically on the 5G frequency range, [b-EMF portal] (endorsed by [b-WHO]) lists approximately 350 studies on mmWave EMF health-related research. Further research may still be required on some specific implementations of 5G technologies.

This information is highly relevant, since it will allow health authorities to update their opinions.

9.2 Frequency bands proposed for 5G

The 5G systems will use much more dense networks with a large number of micro base stations, localized much closer to the users. Inside buildings, there could be many indoor micro base stations. In less populated areas, both macro base stations and small cells will continue to be deployed, so the network will be highly heterogeneous. 5G needs spectrum within three key frequency ranges to deliver wide coverage and support all the planned services: sub-1 GHz, 1-6 GHz and above 6 GHz.

– Sub-1 GHz will support widespread coverage across urban, suburban and rural areas and help support IoT services through better in-building coverage.

– 1-6 GHz offers a good mixture of coverage and capacity benefits. This includes spectrum within the 3.3-3.8 GHz range that is expected to form the basis of many initial 5G services.

– Above 6 GHz is needed to meet the ultra-high broadband speeds planned for 5G. A focus will be on bands above 24 GHz. The 26 GHz band is under consideration in the EU and 28 GHz has been identified for 5G in the USA.

Low frequency bands f < 6 GHz: Some of the potential bands for 5G are at similar frequencies to mobile technologies already in use. Today's third generation (3G) and 4G mobile technologies typically operate in several bands between 700 MHz and 2.7 GHz. Wireless fidelity (Wi-Fi) operates at 2.45 and 5 GHz. These bands will be used for *coverage* and *capacity*.

While a 5G network could be deployed at 700 MHz and deliver national coverage, channel bandwidth may limit data rates to 50 Mbit/s down to 10 Mbit/s. Due to its technical qualities (wide territorial reach, good penetration of buildings and other obstacles), this frequency band should be ideal for new digital services that rely on very good coverage (e.g., for connected cars) and is already used for 4G and 4G+.

The spectrum around 3.6 GHz offers enhanced capacity over dense urban areas, perhaps delivering 1 Gbit/s depending on the RF channel width available. Many countries have already carried out work in this frequency band and have done trials of new antennas in anticipation of the deployment of 5G.

High frequency bands *f* > 24 GHz (mmWaves): Higher frequencies, such as 24-86 GHz, are mostly used for satellite and point-to-point radio links today. The mmWave frequency ranges are of special interest for 5G mobile system applications. They will allow, at least as complementary bands, a substantial increase in system capacity. Their use is now under study for short range areas and indoor applications.

See Figure 3.

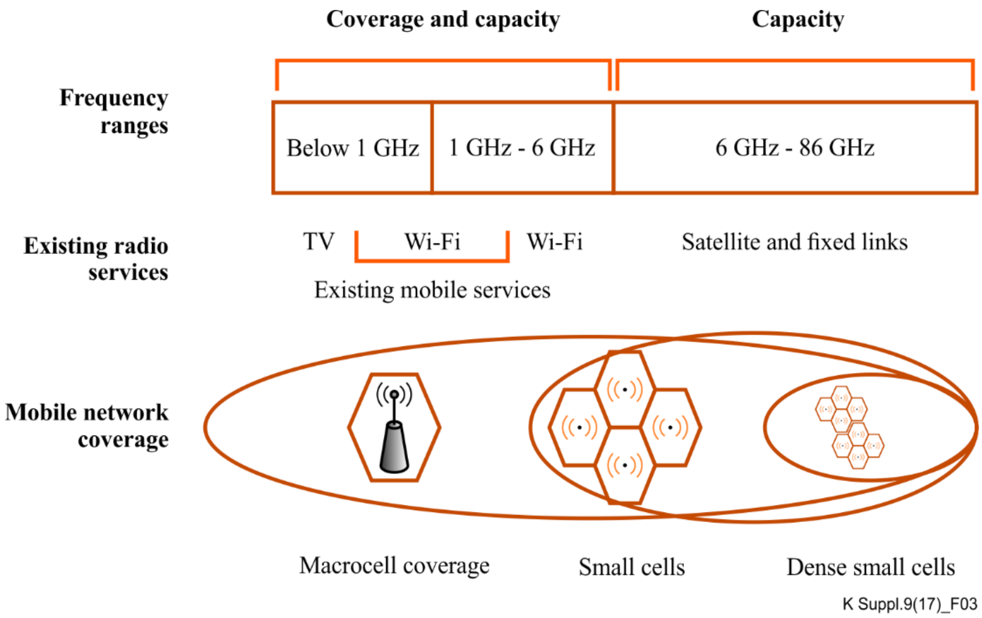

Figure 3 – Frequency band allocation
(Source: Orange)

At mmWave frequencies, RF energy is absorbed superficially by the body, mostly by the skin. Some studies are already underway using these mmWave exposures. The mmWave frequencies will be used in conjunction with increased small cell deployments.

All experiments and future deployment use frequencies already addressed by existing standards. Wireless 5G networks will use frequencies comparable to legacy networks, like second generation (2G), 3G or 4G.

9.3 Assessment of radio frequency electromagnetic field exposure from 5G

Electromagnetic exposure assessments for 5G technologies may be carried out using computational and measurement methods. IEC has been developing exposure assessment methodologies for frequency bands above 6 GHz.

Compliance standards have been developed and updated by international standards development organizations (i.e., IEC, ITU, IEEE and CENELEC).

– [IEC 62232] extends the frequency band up to 100 GHz.

– [b-IEC TR 62669] contains case studies supporting [IEC 62232] for 5G compliance assessment.

9.4 Expected radio frequency electromagnetic field exposure levels from 5G deployment

New technologies bring many benefits, but may also raise questions from the public in terms of exposure to RF EMF. It is important to address these questions and provide information on likely exposure.

5G networks are specifically designed to minimize transmitter power, even more than existing 4G networks. 5G networks use a new advanced radio and core architecture that is very efficient and minimizes transmissions, which results in lower EMF levels.

With the introduction of new technologies, there may be a small localized increase in the overall level of radio signals due to the fact that new transmitters are active. In some countries, deployment of 5G may occur as part of the closure of earlier wireless networks. Based on the transition from previous wireless technologies, we can expect that overall exposure levels will remain similar and will be a small fraction of the international exposure limits.

9.5 Radio frequency electromagnetic field exposure from massive multiple input multiple output and smart antennas

Some deployments of 5G will use "massive" multiple input, multiple output (MIMO) antennas that have multiple elements or connections to send and receive more data simultaneously. See Figure 4. The benefit to users is that more people can simultaneously connect to the network and maintain high throughput in more efficient ways. The smart antennas will have the possibility to transmit required data only in the direction of the user and only during the time of usage. 5G technology with smart antennas will be more efficient, which will result in minimized RF EMF exposure.

Beamforming has the benefit of reducing network interference and electromagnetic emission in unintended directions by focusing antenna beams in desired directions.

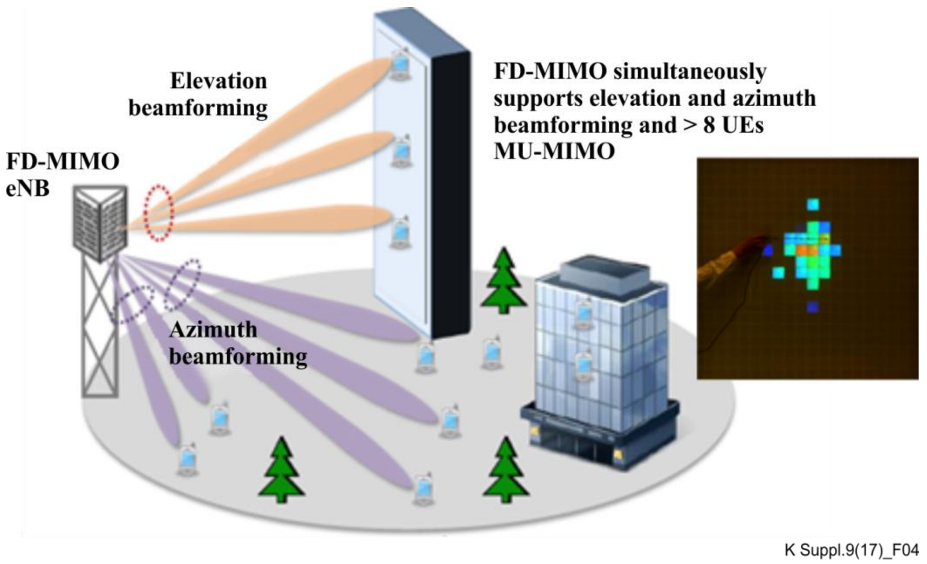

Figure 4 – Massive multiple input multiple output antenna (3.4-3.8GHz)
(Source: Orange)

Moreover, RF exposure assessment approaches based on actual maximum transmitted equivalent isotropically radiated power (EIRP) (directly or derived from the maximum transmitted power) described in [ITU-T K.100], [b-IEC TR 62669] and [ITU-T K-Sup.16] are appropriate for base stations with massive MIMO systems taking into account time averaging as defined in the international exposure limits.

9.6 Compliance boundaries

Compliance boundaries are zones around antennas outside which EMF levels are at or below limits and where the general public cannot access. Those zones are generally positioned around antennas on rooftops in urban or suburban locations. Their shape and dimensions are harmonized and computed using appropriate tools, taking into account the activated frequencies and the radiated maximum power (see Figure 5).

Note that not all the antennas have a physical "compliance boundary". For example, those on masts, especially in rural areas, do not need any physical boundary as the area is not accessible to the general public. Furthermore, some other transmitters do not have any compliance boundary, as the installed power is so low that they are compliant even when touching the transmitter, such as home or indoor small cells.

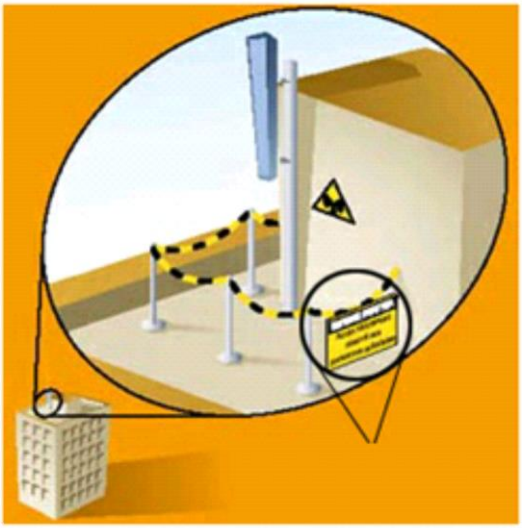

Figure 5 – Example of compliance materialization

9.7 Small cells

Future networks will rely on a heterogeneous network of macro-cells and small cells (low-power radio transmitters) that will ensure capacity. Nowadays, small cells are important for 4G networks in some countries. They will increase in importance for 5G, especially in the higher frequency bands. Access to power and data backhaul are necessary for the operation of small cells and easy access to existing physical infrastructure (e.g., buildings, street lights and bus shelters), as well as simplified permit procedures for successful deployment.

Small cell antennas are low-power access points (e.g., base stations with transmitter input power less than 6 W per antenna port according to the 3GPP definition). Over the next few years, these small cell antenna installations should multiply in mobile networks to rapidly advance towards 10 small cells per macro site in dense urban areas. See Figure 6.

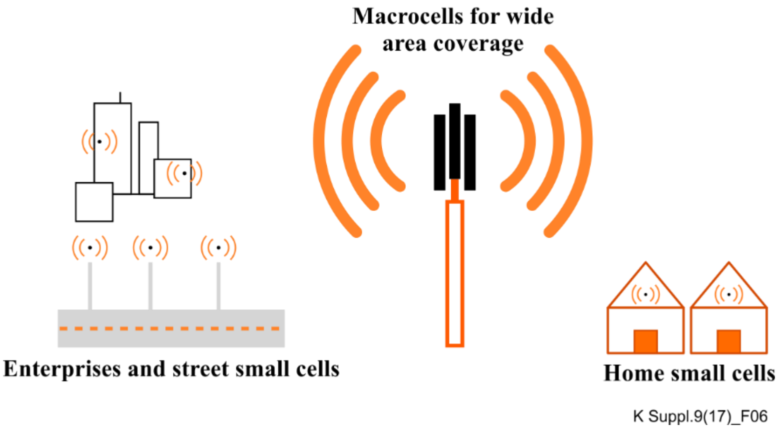

Figure 6 – Heterogeneous network integrating macro antennas supplemented by small antennas

Small cells are well suited for coverage extent, as well as capacity issues. Their proximity to users enables them to provide better quality and reduced power radiated to and from mobile phones. This is a good point in terms of exposure for mobile users. By reducing the distance between receivers and transmitters, small cells enable the reduction of the power emitted by mobiles phones and total EMF exposure.

Outdoor small cells also have little visual impact, they can hardly be seen and can fit inside almost any type of building. The fact that their emissions are low compared to macro-cells makes their compliance boundaries very small and they therefore do not require any safety provisions.

The roll out of small cells is a key point for success of 5G. There will be lot of small cells in 5G in the frequency band 3.6 GHz and many more in the higher frequency bands $f > 24$ GHz to bring data capacities.

[IEC 62232] and [ITU-T K.100] have specified base station (BS) installation classes that are applicable to small cells deployed in countries with exposure limits based on international guidelines (ICNIRP). Each installation class includes simple criteria, such as the EIRP of all equipment on the site or at installation height and are outlined in Figure 7.

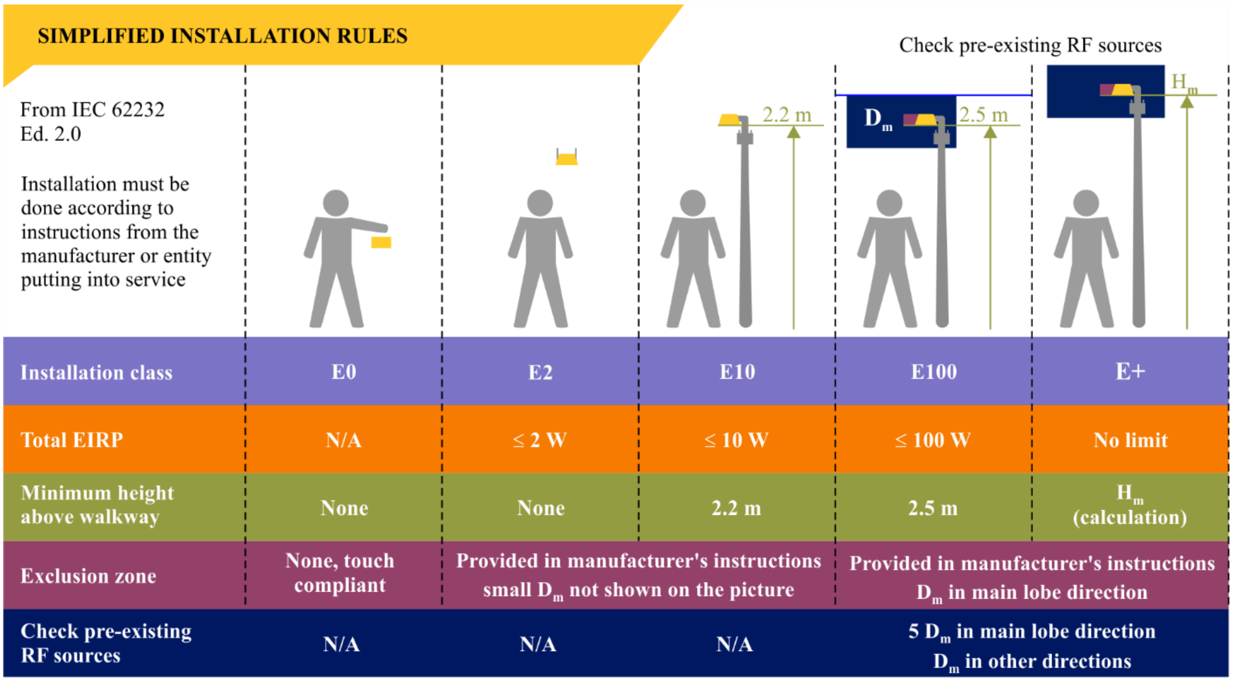

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Figure 7 – Simplified installation rules
(Source: [b-SCF012])

The lowest power devices can be installed with the minimum of design constraints. Touch compliant equipment (installation class E0), such as residential small cells, can be sited anywhere, much like wireless access points. For higher power sites, manufacturers' guidelines, minimum height requirements (H_m) and exclusion zones (D_m) must be considered. These site design parameters are generally provided in the product technical documentation.

Clear communication materials are recommended to ensure recognition of small cell benefits (coverage extent and reduced radio exposure from devices).

9.8 Internet of things in 5G technologies

The IoT concerns coordination of multiple machines, devices and appliances connected to the Internet through multiple fixed and wireless networks. See Figure 8. These include everyday objects, e.g., sensors, wearable devices, vehicles, buildings, actuators and monitors, embedded with IoT connectivity that allows them to send and receive data. Some IoT systems that require wide geographic or good in-building coverage will mostly be implemented on lower frequency bands.

Figure 8 – General picture showing Internet of things emitters

Basically, RF EMF exposure levels should not change appreciably because IoT devices will themselves will be very low power and transmit intermittently.

Energy issues such as low power consumption are central to the devices of the IoT, and as a result the EMF exposure caused by IoT devices will usually be much lower than from other devices and systems. Additionally, IoT devices will communicate in the event-based, periodic and automatic communication modes. So, usually the amount of data to be exchanged will be very small and periodic. Wearable devices (subset of IoT devices) will be located very close to the human body, but as they are low power and transmissions are of short duration, RF EMF exposure will be very low. Some wearable devices will be exempted from testing, because their operation means that they are certain to comply with RF EMF exposure limits. Other wearable devices will be tested using international technical standards.

10 Conclusions

The level of concern that members of the public may have about this new technology cannot be anticipated. Previous deployments of 3G and 4G have raised concerns in some countries; however, in recent years, consumers have become more accustomed to the existence of radio antennas and the use of mobile devices is ubiquitous. Notwithstanding this, it is recommended that some communication materials be written in order to educate and inform about the new 5G technology and human exposure to RF EMFs.

Key messages about 5G RF EMF exposure are:

– existing international exposure guidelines are not technology specific and apply to all new applications;
– visual impact: 5G will use similar physical antennas, and power as 4G, but with a new technology that allows very high data rates;
– exposure levels: home transmitters and their characteristics are not expected to differ significantly from that of existing Wi-Fi;
– in the short-term, the 5G network is not intended to replace existing networks, but will operate in conjunction with existing 4G networks.

New frequencies, close to those in use for mobile today, and additional spectrum at both lower and higher frequencies, will be activated and some others will be re-used. Where new antennas are added, all the regular steps should be taken during the deployment phase to respond to any public concern.

One contributing factor to public concern is the visibility of antennas, particularly on rooftops. Where possible, it is important to use multi-band antennas in order to reduce visual impact by maintaining the same number of antennas on rooftops.

Without any spectrum or technology reframing strategy, the 5G network will increase localized exposure resulting from wireless technologies, at least during the transition period. It is important to include national authorities at an early stage in establishing how 5G can be deployed and activated and compliance with national limits assessed. This has already been difficult in countries where exposure limits are more restrictive than those recommended by WHO, based on the ICNIRP RF-EMF exposure guidelines.

Efforts will be taken to engage in dialogue to explain the benefits of 5G to society and consumers.

[b-ITU-T EMF] is a website dedicated to EMF. [b-ITU-T EMF guide] will be updated with information about 5G in order to answer questions about this new service.

There are existing good channels of communication and information available through operator associations such as GSMA and national authorities. These would be an effective means of communicating the benefits of 5G and to proactively answer any questions.

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