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5G technology and human exposure to RF EMF

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Supplement 9 to ITU-T K-series Recommendations

5G technology and human exposure to RF EMF

Summary

The deployment of 5G will see the evolution and expansion of existing 4G networks and the introduction of new radio access networks in the millimetre wave bands. 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 for 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 level of the signals for communication.

Supplement 9 to the 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 (EMF) around radiocommunication infrastructure.

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Supplement 9 to ITU-T K-series Recommendations

5G technology and human exposure to RF EMF

1 Scope

This Supplement contains an analysis of the impact of the implementation of the 5G mobile systems with respect to the exposure level of the electromagnetic fields (EMF) around radiocommunication infrastructure.

2 References

[ITU-T K.52] Recommendation ITU-T K.52 (2016), *Guidance on complying with limits for human exposure to electromagnetic fields*.

[ITU-T K.70] Recommendation ITU-T K.70 (2007), *Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations*.

[ITU-T K.91] Recommendation ITU-T K.91 (2017), *Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields*.

[ITU-T K.100] Recommendation ITU-T K.100 (2017), *Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service*.

[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 [ITU-T K.70]

3.1.2 base station [ITU-T K.100]

3.1.3 basic restrictions [ITU-T K.70]

3.1.4 compliance boundary [ITU-T K.100]

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

3.1.6 exposure [ITU-T K.52]

3.1.7 exposure level [ITU-T K.52]

3.1.8 exposure limits [ITU-T K.70]

3.1.9 general public [ITU-T K.52]

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

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

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

3.1.13 transmitter [ITU-T K.70]

3.2 Terms defined in this Supplement

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

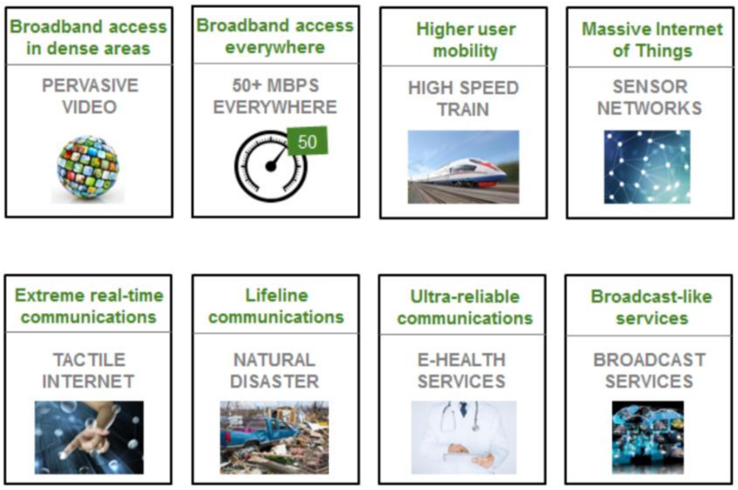
3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
ECC	European Communication Commission
EIRP	Equivalent Isotropically Radiated Power
EMF	Electromagnetic Field
ETSI	European Telecommunications Standards Institute
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IEEE	Institute of Electrical and Electronics Engineers
IMT-2020	International Mobile Telecommunications 2020
IoT	Internet of Things
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
RF	Radio Frequency
SAR	Specific Absorption Rate
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
WHO	World Health Organization
Wi-Fi	Wireless Fidelity

5 Conventions

None.

6 Background

5G is the 5th generation of mobile networks, a significant evolution of the 4th 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).



(Source: A Deliverable by the NGMN Alliance, NGMN 5G White Paper, 17 February 2015)

Figure 1 – Main usage for 5G networks

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 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 to support future use cases.

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

7 Agenda of 5G deployment

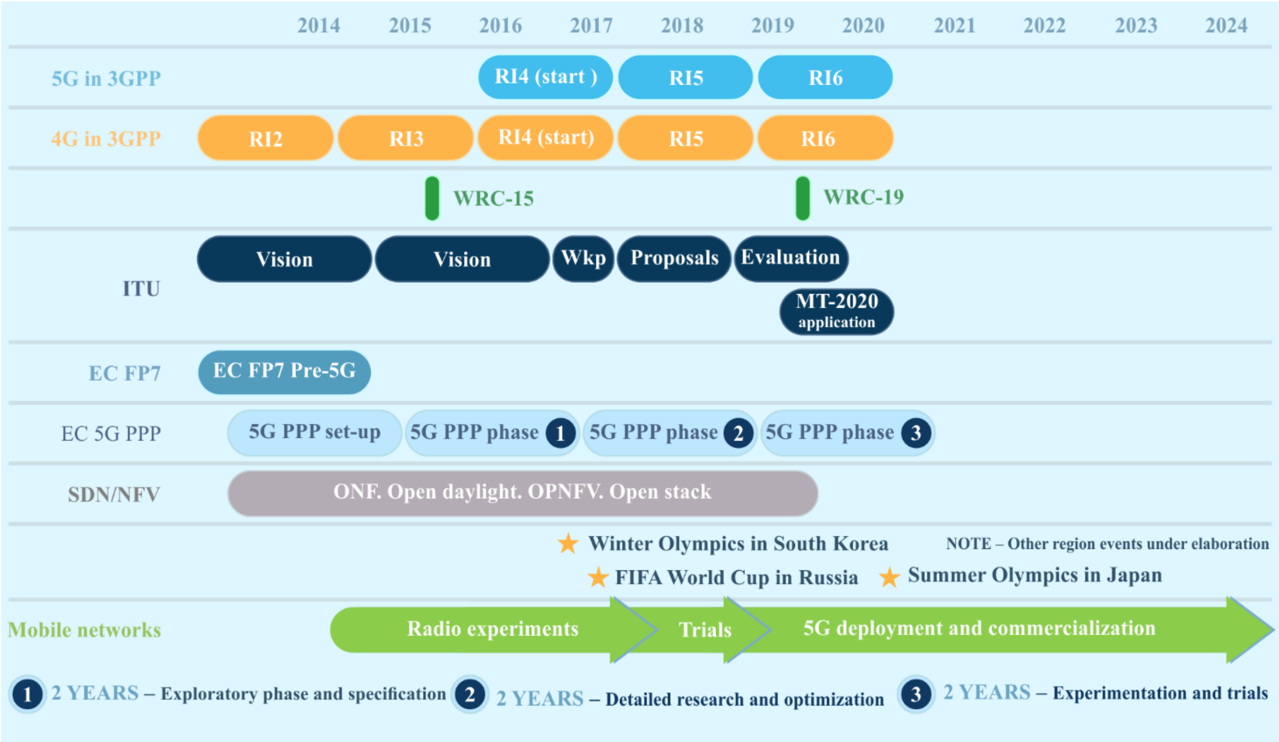
The work on 5G mobile systems (also called IMT 2020) started just after the 4G mobile system (LTE) was approved. Implementation of the system is planned for 2020 (summer Olympic Games in Tokyo) but experimental implementation may start during winter Olympic Games in PyeongChang (Korea) in 2018.

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) was established for the 5G mobile system (Agenda item 1.13) and should be completed at the World Radiocommunication Conference taking place in 2019 (WRC-19).

According to the schedule, ITU-R developed radio wave propagation models, clutter and building entry loss models and deliver them to TG 5/1 ([ITU-R P.1411-9], [ITU-R P.2108-0] and [ITU-R P.2109-0]). They are required for compatibility and sharing studies that are now conducted in ITU-R with the major contribution of ITU-R WP 5D. ITU-R WP 5D and WP 5C that are responsible for the determination of the parameters to be used in sharing and compatibility studies concerning the implementation of 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: ITU, ECC, ETSI, 3GPP. According to the current agreement the first priority frequency bands are 3.4-3.8 GHz and

24.25-27.5 GHz. In Figure 2, the current schedule of the work on the 5G international mobile telecommunications 2020 (IMT-2020) system is presented.



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(Source: 5GPPP. (2015, 24-09-2015). 5G Vision)

Figure 2 – 5G international deployment agenda

8 Overview of RF EMF exposure limits

5G systems will use frequencies that are already addressed by international radio-protection standards. Two international bodies; 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 frequencies band. These exposure guidelines form the basis of policy and regulation in many countries. However, the exposure limits differ in some countries, and in some cases are more restrictive. ITU recommend that if radio frequency electromagnetic field (RF EMF) limits do not exist, or if they do not cover the frequencies of interest, then ICNIRP limits should be used.

Basic 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 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 it; basic restrictions are used mainly for mobile handsets and in cases when exposure exceeds those reference levels.

In Table 1 basic restrictions and reference levels for ICNIRP and IEEE C.95.1-2005 are presented. Average limits values shall be measured over a six minute time. Note that there is a difference between ICNIRP and IEEE at 6 GHz. In IEEE 95.1 frequency ranges between 3-6 GHz are considered as transition frequencies meaning that exposure metrics may be SAR or power density.

Table 1 – EMF international whole body exposure limits

Frequency band	ICNIRP limit	IEEE limit C.95.1-2005
10 MHz < *f* < 3 GHz	0.08 W/kg	0.08 W/kg
3 GHz < *f* < 10 GHz	0.08 W/kg	10 W/m^2
10 GHz < *f* < 300 GHz	10 W/m^2	10 W/m^2
400 MHz < *f* < 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 radiofrequency exposure. To test compliance with respect to 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 the real life exposure.

9 RF EMF 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 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 mm-wave frequencies goes back many decades and is continuing. These opinions are based on the scientific research and considerable research has been conducted on the mobile phone frequencies. There are fewer biological studies about high frequencies above 24 GHz. Some countries plan to support a research on biology, epidemiology and dosimetry in this area. In terms of research specifically on 5G frequency range, the WHO and EMF Portal database lists approximately 350 studies on mm-wave 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 the building 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. The three ranges are: Sub-1 GHz, 1-6 GHz and above 6 GHz.

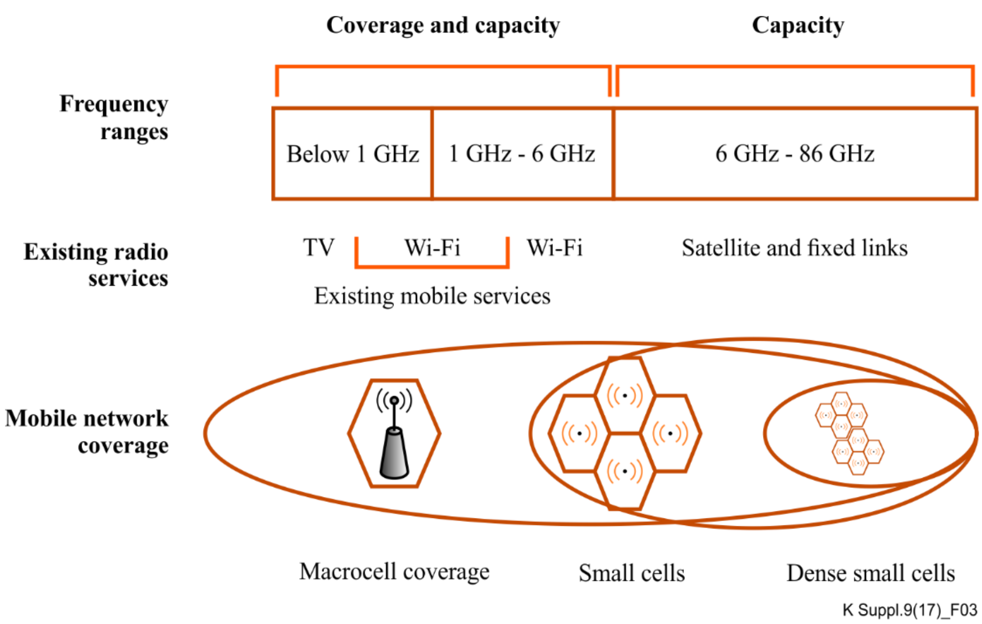
– Sub-1 GHz will support widespread coverage across urban, suburban and rural areas and help support IoT services through better in-building coverage.
– 1-6 GHz offers a good mixture of coverage and capacity benefits. This includes spectrum within the 3.3-3.8 GHz range which is expected to form the basis 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. 26 GHz band is considered in 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 3G and 4G mobile technologies typically operate in several bands between 700 MHz and 2.7 GHz. 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, the 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 which rely on very good coverage (for example for connected car) and is already used for 4G and 4G+.

Spectrum around 3.6 GHz offers enhanced capacity over dense urban areas, perhaps delivering 1 Gbit/s depending on the radio frequency (RF) channel width available. Many countries have already carried out work in this frequency band and trial of new antennas in anticipation of the deployment of the 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 millimeter (mmWaves) frequency ranges are under special interest for application of 5G mobile systems. They will allow, at least as complementary bands, substantially increase system capacity. Their use is now under study for short range areas and indoor applications.



(Source: Orange)

Figure 3 – Frequency band allocation

These high frequencies are also known as *millimeter waves*. At such frequencies RF energy is absorbed superficially by the body, mostly by the skin. Some studies are already underway using these millimeter wave exposures. The millimeter wave frequencies will be used in conjunction with increased small cell deployments.

All experiments and future deployment are using frequencies already addressed by existing standards. The 5G networks for the wireless part will be using frequencies comparable to legacy networks like 2G, 3G or 4G.

9.3 Assessment of RF EMF 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 are developed and updated by International Standardization Organizations (i.e., IEC, ITU, IEEE and CENELEC).

– IEC 62232:2017 has been published and extends frequency band up to 100 GHz.
– A case studies Technical Report IEC TR 62669 supporting IEC 62232:2017 for 5G compliance assessment is under development.

9.4 Expected RF EMF 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 the questions raised by the public and provide information on likely exposure.

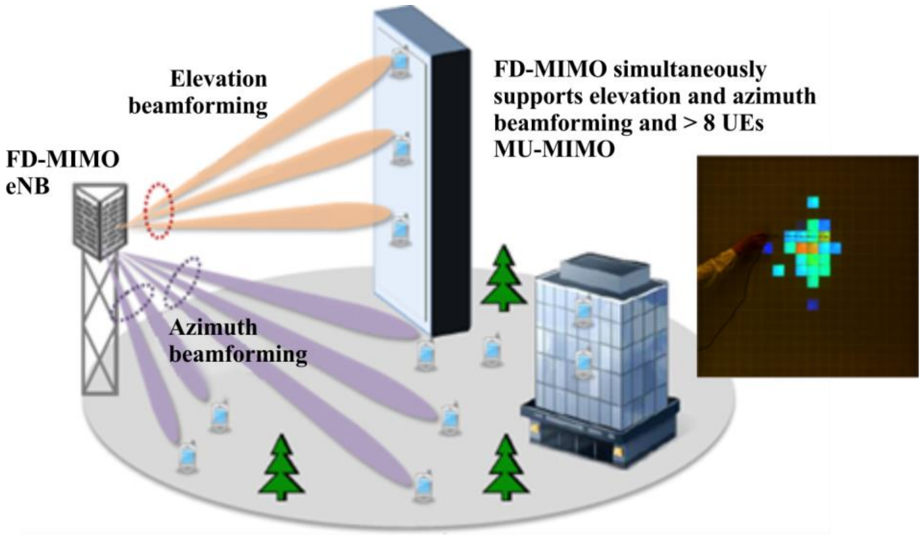
5G networks are specifically designed to minimize transmitter power, even more than existing 4G networks. 5G networks use a new advanced radio and core architecture which is very efficient and minimizes transmissions which results in lower EMF levels.

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 the overall exposure levels will remain similar and will be a small fraction of the international exposure limits.

9.5 RF EMF exposure from massive MIMO and smart antennas

Some deployments of 5G will use 'massive' MIMO (multiple input, multiple output) antennas that have multiple elements or connections to send and receive more data simultaneously. 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 the desired direction.



(Source: Orange)

Figure 4 – Massive MIMO antenna (3.4-3.8GHz)

Moreover, new measurement techniques shall be introduced and evaluated into dosimetry standards (such as [IEC 62232:2017]) for assessing the exposure induced by moving beams taking into account time averaging as defined in the international exposure limits.

9.6 Compliance boundaries

Compliance boundaries are zones around antennas outside of which the electromagnetic field (EMF) levels are at or below the 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 dimension are harmonized and computed using an 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

The future networks will rely on a heterogeneous network of macro-cells and small cells (radio transmitters of low powers) that will ensure capacity. Nowadays, small cells are important for 4G networks for some countries. They will increase the 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 (for example buildings, street lights, bus shelters and so on) as well as simplified permit procedures for successful deployment.

Small cell antennas are low-power access points (for example 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 reach up to 10 small cells per macro site in dense urban area.

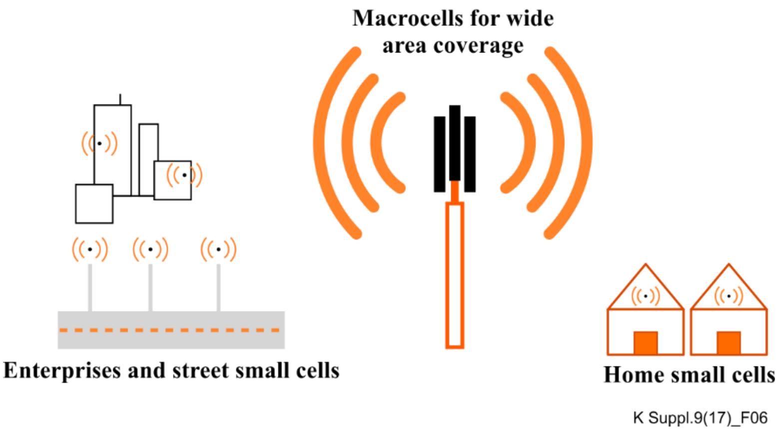


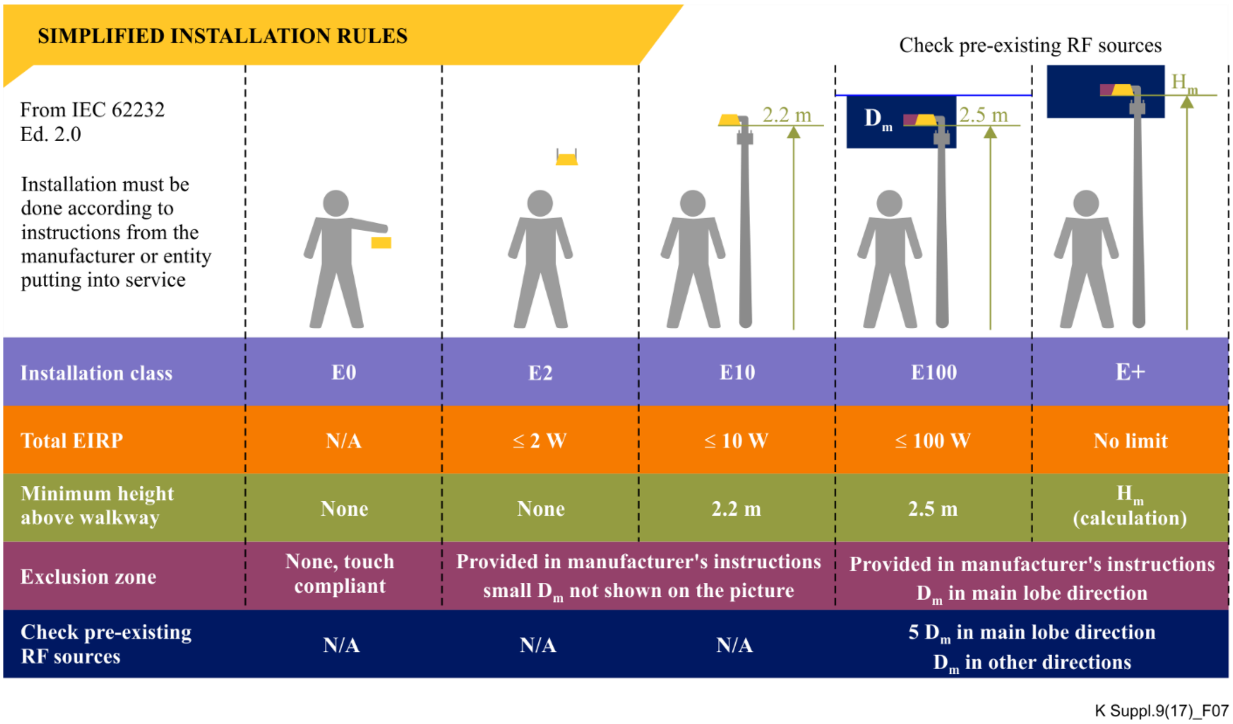
Figure 6 – Heterogeneous network integrating macro antennas supplemented by small antennas

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 the mobiles phones and the total EMF exposure.

Outdoor small cells also have little visual impact, one can hardly see them and they 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 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 much more in the higher frequency bands $f > 24$GHz to bring data capacities.

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



(Source: Small Cells Forum and GSMA)

Figure 7 – Simplified installation rules

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 (Hm) and exclusion zones (Dm) must be considered. These site design parameters are generally provided in the product's technical documentation.

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

9.8 IoT in 5G technologies

Figure 8 – General picture showing IoT emitters

The Internet of things (IoT) concerns a coordination of multiple machines, devices and appliances connected to the Internet through multiple fixed and wireless networks. These include everyday objects such as sensors, wearable devices, vehicles, buildings, actuators, monitors and other items 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 in the lower frequency bands.

Basically, the 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 the IoT devices will usually be much lower than from other devices and systems. Additionally IoT devices will communicate on the event-based, periodic and automatic communication modes. So usually the amount of data that should be exchange will be very small and periodic. The 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, the 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 are more accustomed to the existence of radio antennas and the use of mobile devices is fairly ubiquitous. Notwithstanding this, it is recommended that some communication materials are written in order to educate and inform about the new 5G technology and human exposure to radiofrequency electromagnetic fields.

Key messages about 5G RF EMF exposure:

– 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 wireless fidelity (Wi-Fi).

– In the short-term, the 5G network is not intended to replace existing networks but it 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 refarming strategy, the 5G network will increase the 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 the 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.

The ITU website dedicated to EMF https://www.itu.int/en/ITU-T/emf and the ITU EMF Guide http://emfguide.itu.int/emfguide.html will be updated with information about 5G in order to answer any questions about this new service.

There are existing good channels of communication and information available through operators' 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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