# THE IMPACT OF RADIATION FROM TELECOMMUNICATION DEVICES AND TECHNOLOGIES ON HUMAN HEALTH AND THE ENVIRONMENT WHICH SURROUNDS US (4G, 5G, ETC.)

Gajšek Peter Kuhar Andrijana Raković Valentin Černe Tomaž Valič Blaž

Scientific monograph

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- The Impact of Radiation from Telecommunication Devices and Technologies on Human Health and the Environment which Surrounds Us (4G, 5G, etc.)

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**Note:**

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# List of Acronyms

**3GPP** – 3rd Generation Partnership Project
**AC** – Antenna Connector
**AEC** – Agency for Electronic Communication
**AMF** – Access and Mobility management Function
**AMPS** – Advanced Mobile Phone System
**AuC** – Authentication Centre
**BEREC** – Body of European Regulators for Electronic Communications
**BSC** – Base Station Subsystem
**BSS** – Basic Safety Standards
**CN** – Core Network
**DECT** – Digital Enhanced Cordless Communications
**EC** – European Commission
**EIR** – Equipment Identity Register
**ELF** – Extremely Low Frequency
**EMF** – Electromagnetic Fields
**EMW** – Electromagnetic Wave
**EPC** – Evolved Packet Core
**EU** – European Union
**GMSK** – Gussian Minimum Shift Keying
**GSM** – Global System for Mobile Communications
**HLR** – Home Location Register
**HSPA** – High Speed Packet Access
**IARC** – International Agency for Research on Cancer
**ICNIRP** – International Commission on Non-ionizing Radiation Protection
**IEEE** – Institute of Electrical and Electronic Engineers
**IF** – Intermediate Frequency
**IMEI** – International Mobile Equipment Identity
**IMSI** – International Mobile Subscriber Identity
**ITU** – International Telecommunication Union
**LEC** – Law on Electronic Communications
**LTE** – Long Term Evolution
**MEC** – Mobile Edge Computing
**MME** – Mobility Management Entity
**MMS** – Multimedia Message Source
**MNO** – Mobile Network Operators
**MRI** – Magnetic Resonance Imaging
**MS** – Mobile Station
**MSC** – Mobile services Switching Centre
**NFV** – Network Function Virtualization
**NOBP** – National Operation Broadband Plan
**OFDMA** – Orthogonal Frequency Division Multiple Access
**RF** – Radio Frequency
**SAE** – System Architecture Evolution
**SAR** – Specific Absorption Rate
**SCENIHR** – Scientific Committee on Emerging and Newly Identified Health Risks
**SC – FDMA** – Single Carrier Frequency Division Multiple Access
**SDN** – Software Defined Networks

**SIM** – Subscriber Identity Module
**SMS** – Short Message Source
**TDMA** – Time Division Multiple Access
**UE** – User Equipment
**UMTS** – Universal Mobile Telecommunication System
**UPF** – User Plane Function
**VLR** – Visitor Location Register
**WHO** – World Health Organization
**WLAN** – Wireless Local Area Network

# Chapter 1

## 1 Introduction

The number of **electromagnetic fields (EMF)** sources is rapidly increasing in our environment. In proportion to their increase, public concern about the possible health consequences of exposure to EMF is growing.

Concerns about the possible health consequences of exposure to EMF date back to World War II, when military personnel were exposed to relatively high-amplitude fields derived from high-frequency radar systems and video communications. Other claims about the negative effects of high-frequency sources of EMF, such as radar units used by the police, military antenna systems, cordless and mobile phones, microwave ovens, and other home appliances, have emerged. In modern life, as a consequence of the rapid development of technology, the exposure of the human environment to EMF is increasing daily, so the public concern about human safety is increasing proportionally.

In the last few decades we have witnessed a rapid increase in the number and capabilities of mobile telecommunications devices. With the emergence and development of new generations of mobile networks that operate at **radio frequency (RF)** part of the EMF spectrum, the discussion about RF EMF exposure and possible health risks becomes more and more intense. There is tension in the public that often results in protests as well as damage to communication infrastructure facilities. While most people in the world use mobile phones and wireless LANs, protests against this type of communication took place in the late 1990s, especially against the construction of mobile phone base stations. Nowadays this kind of resistance is present in relation to the establishment and construction of the structure of the new 5G generation of mobile networks.

This scientific monograph aims to provide scientifically substantiated answers to the most frequently asked questions in the public on the topic of EMF exposure of living organisms, with special emphasis on the RF band, i.e. mobile communication systems. The public is often asked whether the new technology of mobile networks, 5G, will increase the exposure to RF EMF in the immediate human environment. Therefore, in this monograph, special attention is paid to the analysis and comparison of the transmitted and received power of 5G technology with previous technologies of mobile communication systems. The following is a brief description of the content of the separate chapters in this scientific monograph.

Starting with the definition of the basic quantities in the field of EMF, the **second** chapter of the study explains the ways in which different types of fields from the human environment interact with biological tissues and systems. In the **third** chapter of this scientific monograph, through a thorough analysis of the key scientific publications, an attempt was made to make scientifically substantiated, objective conclusions about the potential health consequences for human health that could result from exposure to low frequency and radio frequency EMF based on current state of the science. From the multitude of technologies that use the RF spectrum, the emphasis is on mobile communication technologies. The scientific settings are explained on the basis of which the international expert bodies set the exposure limit values of the RF EMF and the European and international standards and recommendations regarding the exposure of the RF EMF are presented in detail.

The **fourth** chapter provides an overview of the different generations of mobile networks - 2G, 3G and 4G, in terms of radio interface and design at the physical level. The technical specification of 5G technology and the differences with the previous generations of mobile communication systems are described. The **fifth** chapter focuses on the requirements of the standards defined by the international telecommunications organizations 3GPP and ITU for the performance of mobile communication systems, for the generations from 2G to 5G. Guidelines are given for operators for setting up the mobile infrastructure in a way that will provide quality signal, i.e., quality mobile communication services to the users, and during the sizing the limit values of expressed power and RF EMF exposure defined in world standards are taken into account.

The **sixth** chapter of the study provides an overview of the development of existing mobile communication networks in North Macedonia. The role of the Agency for Electronic Communications (AEC) as a regulatory body in terms of giving guidance to the operators in the construction of networks and monitoring their impact on the environment is explained. The regulatory legal and sub-legal framework is explained in detail, with interpretation of specific parts of the Law on Electronic Communications and bylaws for construction of mobile networks. In the **seventh** chapter, the spatial aspect of the installation of the new infrastructure elements by the mobile operators is elaborated. The importance of spatial planning, design, and construction for sustainable development of mobile infrastructure is emphasized. Detailed results from the performed RF EMF exposure assessment for the Skopje area are presented. The measurements on a total of 21.705 locations are compared with permissible exposure limit values. In the last, **eighth** chapter of the study an overview is given of the aspects of communication between all stakeholders in the construction of mobile communication systems, as a multi-stage process. Emphasis is placed on key barriers to the construction of new mobile networks such as 5G technology, with proposed guidelines for proactive communication and precautions regarding exposure to RF EMF. Recommendations are given regarding the installation of new infrastructure by mobile operators in the environment.

# Chapter 2

## 2 Physical laws, sources, and exposure assessment of Electromagnetic Fields

In our daily life we are exposed to electromagnetic fields (EMF) from many sources, at different frequencies. From static to low frequency EMF ranging from power lines, electrical domestic appliances, machinery, etc. to the most widespread radiofrequency (RF) EMF originating from telecommunications networks including mobile phones, radio and television transmitters, electrical devices, medical equipment, and many other devices. This chapter will first explain the basic theoretical premises in the analysis of electromagnetic fields and give an overview of the main sources of EMF in the environment. The focus in this chapter is on the methodology for assessing the impact of RF EMF on humans and the human environment.

### 2.1 Theoretical basics of electromagnetics

An electric field is a special physical state of space in the vicinity of electric charges that is manifested by the appearance of a mechanical force acting on an electric charge introduced into the field. The characteristics of the electric field are described by the vector quantity of electric field strength vector, $\vec{E}$ with the unit of measure Volt / meter (V/m) and the scalar quantity of electric potential, φ, with the unit of measure Volt (V). Magnetic field is a physical state of space in the vicinity of a magnet or conductor through which current flows and is manifested through: force acting on an object of ferromagnetic material or conductor through which electric current enters the field and induction of electromotive force in a conducting loop which moves in the field. The characteristics of the magnetic field are described by the vector quantities magnetic field strength vector, $\vec{H}$, measured in Ampere/meter (A/m) and magnetic flux density vector, $\vec{B}$, with intensity measured in Tesla (T).

Electric and magnetic fields can be considered as separate quantities only in static conditions, i.e., when they do not change over time. In case these quantities are variable over time, their analysis can only be performed by applying the complete set of Maxwell equations. According to Maxwell's theory of the electromagnetic field, the electric and magnetic fields are parts of the electromagnetic field as a single physical phenomenon (Janev 2002; Sadiku 2014). The solution of Maxwell's equations is a wave function that mathematically describes the phenomenon of electromagnetic wave (EMW), i.e., a fast-changing electromagnetic field that propagates in the form of a wave. As a more general approach, only the term EMF will be used in the following sections of the study. The term electromagnetic radiation refer to the process of generating electromagnetic waves, which occurs when alternating current is passed through a metal object (antenna). The basic characteristics of time changing EMF (i.e., waves) are their frequency f, with a unit of measure Hertz (Hz) or wavelength λ with a unit of meter (m). The wavelength is inversely proportional to the frequency: $\lambda = c/f$, where c is the speed of light. When the electric field strength vector and the magnetic field strength vector lie in a plane normal to the direction of propagation of the wave, it is referred to as a plane EMW. Figure 2.1 shows the propagation of a plane EMW.

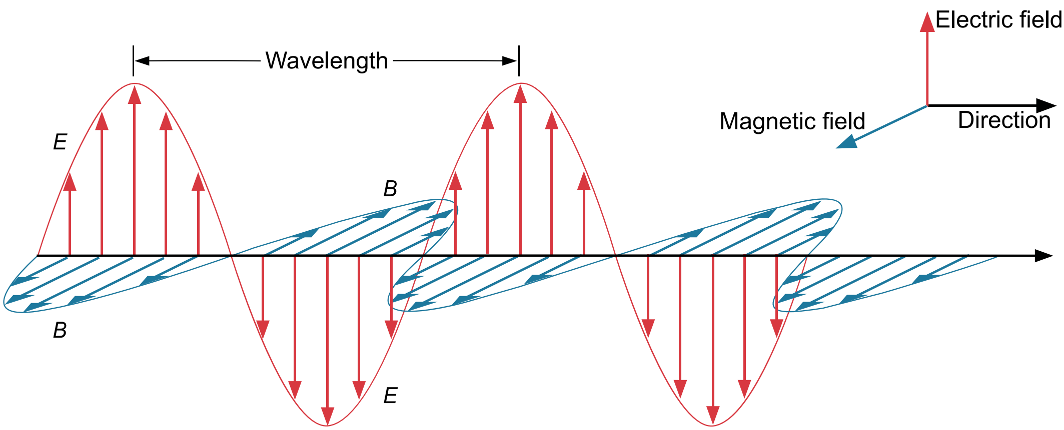


Figure 2.1: Plane electromagnetic wave

The full range of frequencies (or wavelengths) of natural and anthropogenetic electromagnetic fields is called the electromagnetic “spectrum”. The electromagnetic spectrum extends from the static fields, extremely low frequencies present in the household electrical network (50 – 60 Hz), through RF electromagnetic waves ($10^3$ – $10^{10}$ Hz), microwaves ($10^{10}$ – $10^{12}$ Hz), infrared radiation ($10^{12}$ – $10^{14}$ Hz), visible light ($10^{14}$ Hz), ultraviolet (UV) radiation ($10^{15}$ Hz), up to X-rays and gamma rays (>$10^{16}$ Hz).

The frequency distribution of the different types of EMF is given in Figure 2.2. As the wave propagates through space it transmits power from the source, which is measured in watts (W) and is equivalent to Joules (J, unit of energy) per unit time. The electromagnetic energy carried by each of the mentioned types of EMF from the electromagnetic spectrum increases with increasing frequency. For example, the energy carried by a high-energy X-ray beam is billions of times higher than the energy of a 1 GHz electromagnetic wave.

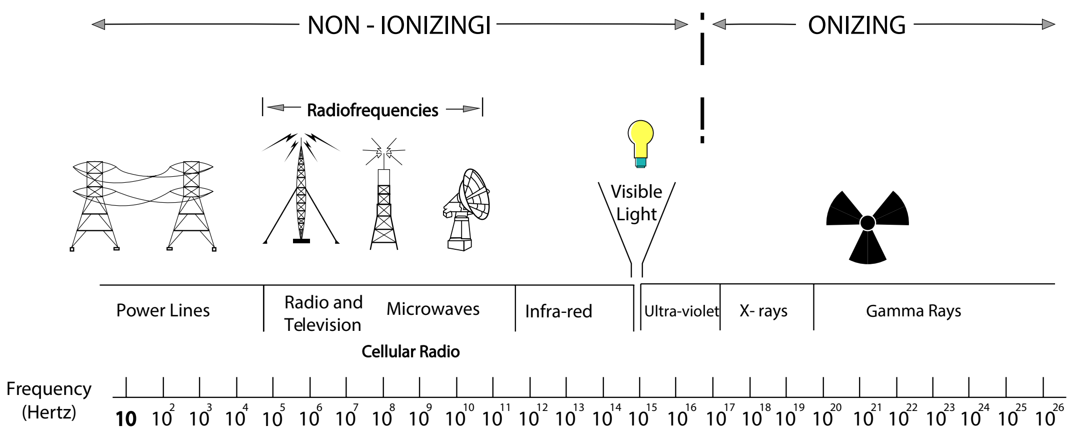


Figure 2.2: Frequency band distribution of the electromagnetic spectrum
[figure taken from (Cleveland and Ulcek 1999)]

The Hertz dipole is the basic antenna structure used in the mathematical analysis of electromagnetic fields. In the study of RF EMF, the simplified form of expressions that determine the field at long distances is of particular importance. The fields of the elementary Hertz dipole at such distances are expressed as

Equation 2.1: $H = j\beta \frac{Il}{4\pi} \frac{e^{-j\beta r}}{r} \sin\theta$ and $E = j2\pi f \frac{\mu Il}{4\pi} \frac{e^{-j\beta r}}{r} \sin\theta$

where

- $\mu$ is the magnetic permeability of the medium,
- $I$ is the current through the Hertz dipole,
- $l$ is its length,
- $r$ is the distance from the dipole to the receiving point,
- $\theta$ is the angle occupied by the vector at the position of the receiving point with the dipole axis,
- $\beta$ is called the phase constant and equals 2π/λ.

The area in which these terms can be used is called the "radiation area" or so-called "far field zone". It can be estimated that it extends over distances greater than about 15 wavelengths from the dipole. The wave created by the Hertz dipole, except for the spherical shape, has the same properties as the plane wave. This conclusion is reached by comparing the mathematical form of Equation 2.1 with the shape of the electric and magnetic field of a plane EMW. In cases where there are small areas of interest compared to the distance from the dipole, the curvature of the wave can be neglected. This practically means that the field emanating from the RF EMF source can be considered as a plane wave.

In order to characterize the RF EMF, in addition to the electric and magnetic field, the power flux density (S) is often used. The power flux density is defined as power per unit area and is expressed in watts per square meter (W/m2), but milli-watts per square centimeter (mW/cm2) and micro-watts per square centimeter (μW/cm2) are also used (Janev 2006).

The power flux density of the electromagnetic wave is most precisely defined at points that are far enough away from the RF EMF source, i.e., located in so-called far field zone. In that zone the relationship between the quantities is well known, so it is sufficient to measure either the intensity of the electric or that of the magnetic field, and the power flux density is calculated using the mathematical relation

Equation 2.2: $S = \frac{1}{2}\sqrt{\frac{\varepsilon}{\mu}} \cdot |E|^2$

where

- $\varepsilon$ is the dielectric constant of the medium,
- $E$ is electric field strength and
- $\mu$ is the permeability of the medium.

## 2.2 EMF in the environment

Living organisms are exposed to EMF on a daily basis from a variety of sources, at different frequencies. The sources of these fields originate partly from natural phenomena, and the rest are a consequence of the technological activities of man. Depending on the field type, intensity and duration of exposure, there are different mechanisms of field influence on biological systems.

According to their influence on biological tissues, the electromagnetic fields present in the human environment are divided into two basic groups: ionizing and non-ionizing. In the complete electromagnetic spectrum, only EMF with frequencies above about 1016 Hz carry a sufficient amount of electromagnetic energy to cause an ionization effect. Ionizing radiation is high-frequency EMF that carries enough energy to break molecular bonds and ionize atoms in tissues. Under the action of ionizing radiation in the nucleus of the cell are created secondary charged particles and free radicals that cause damage to its DNA. Examples of this type of radiation are gamma rays, X-rays, etc. (Kaplan 1960). Non-ionizing radiation do not have enough energy to ionize atoms. Therefore, the mechanisms of interaction of non-ionizing radiation with biological systems are substantially different from those of ionizing radiation. Examples of non-ionizing radiation – EMF include static fields, extremely low-frequency EMF, intermediate frequency (IF) EMF, RF EMF, infrared radiation, visible light and ultraviolet (UV) radiation. Artificially generated static fields are mainly found in occupational settings, such as close to MRI scanners. In nature, a magnetic field at extremely low frequencies (from 0.001 Hz to 5 Hz) is constantly present, which originates from electric currents from the movement of molten iron in the earth's core and is called a geomagnetic field. The intensity of the geomagnetic magnetic flux density ranges between 25 and 65 μT (IAGA 2010). The direct effects of this field are generally harmless to human health. Some living organisms use the geomagnetic field in their life processes, such as some species of migratory birds during navigation, some species of whales during migration. Another natural phenomenon of this kind is a high-intensity variable magnetic field (magnetic flux density can reach up to 0.5 μT) that occurs due to solar storms. Also, in the daily period, there are slowly changing magnetic fields with a magnetic flux density intensity of about 30 nT that originate from the solar influence on ionic currents in the upper layer of the atmosphere (Polk 1995).

Artificially generated electric and magnetic fields in the extremely low frequency (ELF) range in the human environment originate mainly from power transmission systems (transmission lines, etc.), household and office electrical appliances, and some types of public transportation. In offices, ELF magnetic field levels typically exceed those present in the home, especially for certain devices, such as photocopiers etc. In industrial areas, significantly higher ELF magnetic field levels are measured near metal processing plants. This chapter will review the mechanisms and consequences of the impact of artificial ELF magnetic field on biological systems.

Applications generating **intermediate frequency (IF)** fields are still relatively limited but have been increasing in recent years. Examples are some anti-theft devices operating at the shops exits, induction cookers, computer and television screens which use cathode ray tubes, as well as some radio transmitters. Such fields are also generated by some industrial applications such as welding. In most cases exposure is limited, but for radio transmitters and welding, exposure can be above the recommended limits, so safety precautions should be taken.

Some medical applications lead to exposures in this frequency range, like electrosurgery that uses an electric current to cut or remove tissues and magnetic resonance imaging (MRI) that provides three-dimensional images of internal body structures.

A potential source in this IF range that may expose the general public and professionals to magnetic fields higher than the reference levels are induction cookers that generate magnetic fields in the range between 20 kHz and 100 kHz. The person located near the induction cooker would be exposed to a stray magnetic field if the cooking zone is not completely covered by the cooking vessel.

Gajšek et al. (2016) systematically reviewed the literature of exposure assessment studies done in European countries on the exposure of the general public to low frequency electric and magnetic fields of various frequencies. The review showed that outdoor average extremely low frequency magnetic fields in public areas in urban environments range between 0.05 and 0.2 μT in terms of flux densities, but stronger values (of the order of a few μT) may occur directly beneath high-voltage power lines, at the walls of transformer buildings and at the boundary fences of substations. In the indoor environment, high values have been measured close to several domestic appliances (up to the mT range), some of which are held close to the body, e.g., hair dryers, electric shavers. Common sources of exposure to intermediate frequencies (IF) in EU include induction cookers, compact fluorescent lamps, inductive charging systems for electric cars and security or anti-theft devices. The authors concluded that the low frequency electric and magnetic fields levels to which the European population is exposed are, in general terms, significantly below both exposure limits in Europe and the 0.3–0.4 μT level used to cluster the exposure data for epidemiological purposes.

Since the beginning of the 20$^{th}$ century, as a result of rapid technological development in the environment, there has been an extremely rapid increase in the number of artificial (anthropogenetic) RF EMF sources which include mobile telecommunications, other types of wireless communication systems (for example wireless local area networks - WLAN), television and radio distribution, RF communication of police and fire brigades, electrical devices, medical equipment, and many other everyday appliances. The number and types of RF EMF sources have rapidly increased and the ways of human interaction with the devices emitting RF EMF are constantly changing.

In the electromagnetic spectrum, RF EMF range from 3 kHz ($3 \cdot 10^3$ Hz) to 300 GHz ($3 \cdot 10^9$ Hz). In terms of wavelengths, a typical RF wave with a frequency of about 100 MHz ($100 \cdot 10^6$ Hz) has a wavelength of about 3 m. Main sources of exposure for the general population and professionals are the ones located relatively close to the human body. For example, the main source of exposure of the human brain are mobile phones since they are used at the surface of the ear. Another similar source located close to the ear are Digital Enhanced Cordless Telecommunications (DECT) phones. Recently there has been a development of the assessment methods for other parts of the body than ear and head, which requires organ-specific exposure assessment. This is due to sources used next to the whole body like smartphones, tablets and laptop computers.

Mobile communication systems occupy the largest share in the multitude of sources of RF EMF. Therefore, the next section will provide an overview of the different generations of mobile communication networks and some results from environmental exposure measurements.

Average exposures to RF EMF of the general public in Europe are difficult to summarize, as exposure levels have been reported differently in different studies, and a large proportion of reported measurements were very low, sometimes falling below detection limits of the measurement equipment.

A comparative analysis (Gajšek et al. 2016) of the results of spot or long-term RF EMF measurements in the EU indicated that mean electric field strengths were between 0.08 V/m and 1.8 V/m. The overwhelming majority of measured mean electric field strengths were <1 V/m. It is estimated that less than 1 % of the measurements were above 6 V/m and less than 0.1 % of measurements were above 20 V/m. No exposure levels exceeding European Council recommendations were identified in these surveys. The exposures from radio and television broadcasting towers were observed to be low because these transmitters are usually far away from populated areas and are spatially sparsely distributed. On the other hand, the contribution made to RF EMF exposure from wireless telecommunications technology is continuously increasing and its contribution was above 60% of the total exposure.

### 2.2.1 Overview of RF EMF sources in the environment and results from exposure measurements, with emphasis on mobile communication systems

The **first generation** of mobile communication network is the so called 1G technology. This designation refers to wireless telephony, or analogue telecommunications technology, which was introduced in 1979, before the advent of digital telecommunications technologies (2G generation).

In the 1990s the technology with 2G label was introduced, which is used for the **second generation** of mobile communication networks – the beginning of digital telecommunication standards. The benefits of the new technology are in the digital encryption of the signals, significantly higher efficiency in the use of the frequency band and data services for mobile phones such as short message service (SMS), as well as multimedia messages (Multimedia Message Service - MMS). European GSM (Global System for Mobile communications) technology belongs to the second generation of mobile networks. In America, the IS-54 and IS-136 standards belong to the second generation of mobile telephony (2G) systems, known as the Digital Advanced Mobile Phone System (AMPS), and the IS-95 standard, known as CDMA.

3G (**third generation** mobile network) technology appears at the end of the last century and its main feature is the speed of digital data transmission of at least 144 kilobits per second (kbit/s). Further newer variants of 3G technology, often referred to as 3.5G and 3.75G, already provide broadband mobile data flow at speeds of up to several megabits per second (Mbit/s). As a result, this technology, in addition to voice calls and multimedia messaging, is also being used for the first time for mobile internet access, video calling and mobile television.

The first standard of the **fourth generation** of mobile telecommunications (4G) was launched in Norway and Sweden in 2009 and is called LTE (Long Term Evolution). While LTE technology achieves a maximum speed of 32.5 Mbit/s, ITU4G standards technology is designed to include a maximum speed of 100 Mbit/s for "high mobility" connections (for example, a mobile device used in a moving car) and a maximum speed at 1 gigabit per second (Gbit/s) for "low mobility" connections (for example, a mobile device used by pedestrians).

10 years after the introduction of 4G standards, the next - **fifth generation** (5G) of mobile telecommunications standards begins to be implemented. This technology is not intended to directly replace the previous ones - for a period of time it will coexist with 4G/LTE

technologies. The 5G standards are defined by the consortium 3rd Generation Partnership Project (3GPP) which provides data transfer speeds between 1 and 10 Gbit/s.

In parallel with the **six generations** of mobile networks, **wireless local area networks (WLAN)** have been functioning since the 90s of the last century. Network protocols for wireless local area networks are based on the IEEE 802.11 family of standards.

In order to calculate and compare the received power (in the space of daily living), the values of the measured amplitude and the average value of the electric field for different generations of mobile networks should be analyzed and compared (Imtiaz 2019). The report (ANACOM 2021) shows the results of measurements made in Portugal at a distance of 100 m from a 5G base station. From the results the following can be noticed: the average value of the electric field is several times lower compared to other technologies. This is to be expected because at higher frequencies the absorption of EMF from the surrounding objects is greater. In addition, the number of connected devices at these distances is smaller than the total number in the space covered by the antenna radiation, which means that due to advanced beamforming[1] protocols, other beams would receive more "attention". This conclusion is confirmed in the same publication and in the measurements performed at a distance of 80 m and 50 m in cases where the base stations belong to different mobile operators. The same conclusion can be drawn by analyzing the results of measurements at multiple locations in the UK, exposed in (OFCOM 2020) - measurements show levels many times lower than the allowable limit and similar to those measured in existing mobile technologies (such as 3G and 4G).

The results from measurements performed in Serbia (Djuric et al. 2020) and the Republic of North Macedonia (AEK 2019) show that the exposures are several times lower than the limit values in the standards and comparable to the exposure from existing technologies.

For the purpose of this monograph, RF EMF exposure assessment for the existing technologies in the Skopje area has been performed and detailed results presented in chapter 7 Importance of spatial management in the context of EMF. The measurements on a total of 21.705 locations have been conducted yielding results for the average exposures with a total value being only 0.2 % of permissible exposure limit values. The most important contributor to the average EMF values is the FM radio frequency band.

Naturally, the measurements of 5G levels still do not give the full picture due to the smaller number of connected devices on the 5G network compared to other networks. However, with the increase in the number of devices, no drastic changes in the receiving power are expected because although the data flow would increase, the radiation would be distributed across all the beams with so called techniques for smart beamforming. This is confirmed in the paper (Colombi et al. 2020) where measurements of the electric field around base stations that serve a large number of customers over a larger area were made. The research covers the operation of 25 massive 5G base stations within 24 hours in urban areas in Australia with over 100,000 potential users. Each base station changes the radiation depending on the number of users and their location relative to the station. The conclusion from such measurements shows that by increasing the number of connected devices, and thus the radiated power of the base station, a significant increase in radiation in one beam

[1] Beamforming - a technique for focusing wireless signals towards a specific receiving device, which results in a faster and more reliable direct link. More on this technique can be found in Chapter 4 of this scientific monograph.

can still be successfully avoided using the 5G techniques of smart beamforming.

## 2.3 Interaction of EMF with biological tissues and systems. Methodology for impact assessment

As explained previously, non-ionizing EMF do not have enough energy to ionize atoms. Therefore, the mechanisms of interaction of non-ionizing EMF with biological systems are substantially different from those of ionizing radiation. Static and low frequency EMF (up to 100 kHz) cause induced intracorporeal electric fields that may arouse biological effects such as cellular stimulation. In the RF range EMF energy absorption and subsequent tissue heating is the main interaction mechanism. In the following sections of this chapter we will focus on the mechanisms of interaction of ELF magnetic fields and RF EMF with biological tissues and systems.

### 2.3.1 Mechanisms of interaction of ELF fields with biological tissues and systems

The effect of ELF electric fields (similar to static electric fields) on uncharged objects is redistribution of electric charges and thus charging the object's surface. When human body and hair is charged, this can cause minor annoyance to affected persons. The redistribution of charge can also lead to uncomfortable periodic discharges (micro-electroshocks) at the body surface or to grounded objects.

ELF magnetic fields originating from transmission lines, electrical appliances, machinery, etc., cause induced intracorporeal electric fields and currents. As a result, for very high field intensities, nerve and muscle stimulation and changes in nerve cell excitability including peripheral and central nerve stimulation and induction of retinal phosphenes can be caused (SCENIHR 2015; ICNIRP 2010). This is why the relationship between the exposure of living organisms to ELF magnetic fields and the increased risk of adverse health consequences is of particular interest. In static conditions (when fields do not change over time) or at extremely low frequencies, the electric and magnetic fields may be considered as separate parts of the EMF. In the following we will focus on the impact of ELF magnetic field on biological systems.

As previously discussed, many man-made sources of ELF magnetic field are present in homes, at workplaces, public transportation and other public places. These sources include power lines, long-range military communication systems and a wide range of devices, tools and machines used at homes, in offices and in industry. For example, from a 765 kV three-phase power line that transmits a current of 2 kA, the magnetic flux density intensity measured at 1 m above the earth's surface is 33 μT. For a 500 kV line that transmits current of 1.5 kA, the measured magnetic flux density is 28 μT (Kaune 1993; NRC 1997). These high voltage power lines end with transformers that reduce the voltage to values usually less than 35 kV. Usually, the energy is further transmitted locally with lines that are shorter than a few km. In locations that are close to the end users, the voltage is reduced again with transformers to values from 110 to 480 V and is transmitted over short distances with the so-called secondary lines. Due to the lower values of voltages and currents through the secondary conductors, the intensity of the magnetic flux density below them is less than 2 μT.

In home environments we are exposed to ELF magnetic fields generated by a number of household electrical appliances. In Figure 2.3 the magnetic flux density measured near several types of household electric stoves, as well as 3 types of hair dryers is depicted (Polk 1995).

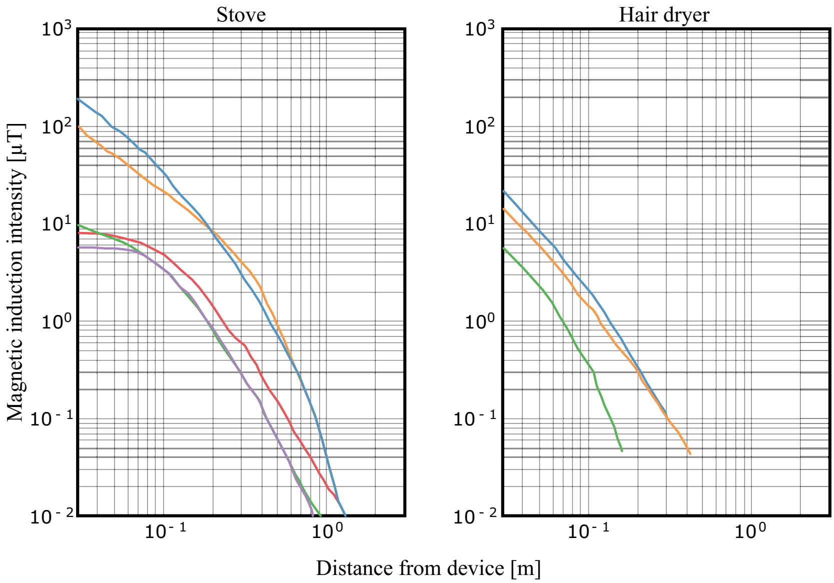


Figure 2.3: Magnetic flux density intensity measured near several types of household electric stoves and from 3 types of hair dryers.

Figure 2.4 shows the numerically calculated distribution of the current density induced in a human body under the action of the ELF magnetic field originating from some type of electric blanket (Polk 1995).

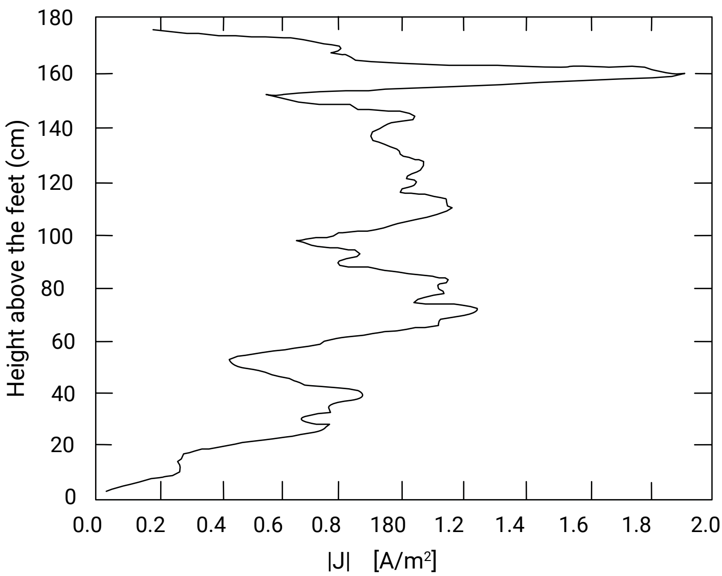


Figure 2.4: Calculated value of the ELF induced current density in a human body model by the electric blanket.

In offices ELF magnetic field levels typically exceed those present in the home, and certain devices, such as photocopiers, produce magnetic flux density intensities of about 1 μT. Of course, with increasing human distance from the devices, this value decreases significantly. In industrial areas, significantly higher magnetic field levels are measured near metal processing plants (magnetic flux density can reach up to 70 mT near smelting furnaces). Another important source of ELF magnetic field in the environment is the electric city transport. For example, at the place where the electric train operator sits, but also in the passenger compartment, tens of μT have been measured.

Low frequency magnetic field affects living organisms through two types of mechanisms: 1. induced electric field (according to Faraday's law of electromagnetic induction) and 2. direct effect of magnetic field on magnetic particles, such as magnetic crystal particles ($Fe_3O_4$) which are present in certain organisms (Polk 1995).

#### 2.3.1.1 Induced electric field

The ELF magnetic field in biological tissues induces currents that circulate along paths in a plane normal to the direction of incidence of the field. Tissue-induced circulating electric field increases proportionally to the frequency and cross-sectional area. As a result, the intensity of induced electric fields increases from zero at the inner part of the body to the maximum at the body surface. The process can be expressed by Faraday's law of electromagnetic induction:

Equation 2.3: $$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

where

- $\nabla \times \vec{E}$ is the rotor of the electric field vector, and
- $\frac{\partial \vec{B}}{\partial t}$ is the change of incident magnetic flux density in time.

Induced electric currents can also be obtained from this relation using Ohm's law:

Equation 2.4: $$\vec{J} = \sigma \vec{E}$$

where

- $\vec{J}$ is the vector of the induced current density (in amperes per square meter, $A/m^2$) and
- $\sigma$ is the specific conductivity of the tissue and is measured in Siemens per meter (S/m).

In the present case: a loop with radius *R* in tissue in the presence of a time-varying magnetic field perpendicular to the loop, the maximum induced electric field that is tangential to the loop can be obtained from Faraday's law:

Equation 2.5: $$E_{\max} = \frac{dB}{dt}(R/2)$$

If the magnetic field is sinusoidal with magnetic flux density amplitude B0, and frequency *f*, then, using expressions Equation 2.4 and Equation 2.5 the maximum current density value can be obtained

Equation 2.6: $$J_{max} = \sigma R \pi f B_0 \sin(2\pi f t)$$

Using Equation 2.6 one can calculate the amplitude of magnetic flux density of an ELF magnetic field that would be expected to interfere with the function of certain biological tissues, such as the heart and brain tissue. Current densities derived from the electrical activity of the human brain and heart are estimated at minimums of 1 mA and 10 mA, respectively (Bernhardt 1979).

Obstruction of the normal functioning of these organs could be expected when induced currents in these tissues due to magnetic fields are higher than mentioned typical values of endogenous currents:

- for brain tissue: $R$ = 0.1 m and σ = 0.1 S/m, according to Equation 2.6 the current density with the amplitude of 1 mA/m2 will be induced by a magnetic field of 0.5 mT at 60 Hz;
- for cardiac tissue: $R$ = 0.06 m and σ = 0.2 S/m, according to Equation 2.6 the current density with the amplitude of 10 mA/m2 will be induced due by a magnetic field of 4.4 mT at 60 Hz.

The obtained values of the magnetic flux density of ELF magnetic field of several mT are present near some of the industrial machines and devices. It can be concluded that in these cases there is a danger that the normal function of the heart and / or brain of people exposed to the magnetic field will be disrupted due to induced circulatory currents.

#### 2.3.1.2 Health risks related to ELF magnetic field

The potential link between exposure to ELF magnetic fields and the negative consequence for human health is certainly of interest to people. In this context, numerous epidemiological studies have been prepared in which the human exposure at the workplace and home has been analyzed. In most of the mentioned studies, assumptions and determinations have been published for a potentially negative impact of the continuous exposure of man to a ELF magnetic field on several factors such as human reproductive health, association with malignancy (cancer) and other.

Regarding the **human reproductive health** evidence has been published those seasonal changes in fetal development and the frequency of abortions in Springfield, Oregon, are due to 60 Hz magnetic field emanating from electric heaters built into the ceiling in the home (NRC 1993). The measured values of the magnetic flux density amplitude of the mentioned field are about 1 μT. There are many publications that suggest correlation between male and female reproductive health and exposure to ELF magnetic fields (Polk 1995).

An **association between leukemia** in children (376 out of a control group of 590 children) living near power lines has been reported in Yorkshire, England (Myers et al. 1985; Ahlbom et al. 2000). There are other publications that present a correlation between the incidence of malignancies (especially in children) and exposure to ELF magnetic fields (Polk 1995).

In 2001 ELF magnetic fields were evaluated as possibly carcinogenic to humans (Group 2B) by the International Agency for Research on Cancer (IARC). The following two types of carcinogens can be classified in Group 2B: factors for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity because of laboratory experiments performed on animals, and factors for which no there is adequate evidence of carcinogenicity in humans but there is sufficient evidence of carcinogenicity as a result of laboratory experiments performed on animals (IARC 2002).

The past conclusions made by IARC that **extremely low frequency** magnetic fields are possibly carcinogenic are still valid. This was concluded based on studies indicating that children exposed to relatively strong magnetic fields from power lines were more likely to develop leukemia. These results have not been confirmed or explained by experiments on animals and cell cultures. In European countries the proportion of children exposed to such levels is less than 1%. Whether recommended exposure limits ought to be changed is a risk management decision.

#### 2.3.1.3 Steps taken by standardization bodies

ELF magnetic field exposure is regulated by the standards and recommendations of international organizations - the World Health Organization (WHO) and the International Commission on Non-Ionizing Radiation Protection (WHO 2007; ICNIRP 2010). The ICNIRP recommendations for so-called basic restriction levels for the induced electric field for human exposure to time-varying electric and magnetic fields are presented in Table 2.1. Basic restrictions refer to physical quantities that are closely related to the harmful effects of exposure to EMF.

| Exposure characteristic [V/m] | Frequency range | Internal electric field | |
|---|---|---|---|
| | | Occupational exposure | General public exposure |
| Central Nervous System (CNS) tissue of the head | 1 Hz–10 Hz | $0.5/f$ | $0.1/f$ |
| | 10 Hz–25 Hz | 0.05 | 0.01 |
| | 25 Hz–400 Hz | $2 \times 10^{-4}f$ | $4 \times 10^{-4}f$ |
| | 400 Hz–1000 | 0.8 | $4 \times 10^{-4}f$ |
| | 1000 Hz–3 kHz | 0.8 | 0.4 |
| All tissues of head and body | 1 Hz–3 kHz | 0.8 | 0.4 |
| | 3 kHz–10 MHz | $2.7 \times 10^{-4}f$ | $1.35 \times 10^{-4}f$ |

Table 2.1: Basic restriction levels for the induced electric field for human exposure to time-varying electric and magnetic fields (ICNIRP 2010).

However, most of the basic restrictions values refer to phenomena inside biological systems and therefore cannot be easily measured. For these reasons, new type of limit values called “reference levels” has been introduced. The reference level values are derived from the basic restriction values to ensure their more practical use. The reference levels are derived in such a way as to provide an equivalent degree of protection as the basic restrictions and can be applied equally with them. The reference levels define limit values for electric and magnetic fields that must not be exceeded during continuous human exposure to low-frequency EMF.

### 2.3.2 Mechanisms of interaction of RF EMF with biological tissues and systems

RF EMF do not carry enough energy and do not have the ability to break molecular bonds and thus, ionize atoms in tissues. As a result, a complex distribution of EMF is generated inside the biological tissues which depends on its electromagnetic characteristics, as well as on the geometry and physical characteristics of the biological system.

RF EMF can efficiently transmit part of their electromagnetic energy to water molecules, thereby causing heating (the so-called thermal effect of RF EMF). The main component of RF EMF that has an impact on biological systems is the electric field. The biological tissues are dielectrics dominated by water and electrolytes and contain several polar molecules. Under the action of the incidental RF EMF so-called induced electric fields are generated inside the tissue. Induced electric fields can affect biological systems in ways that are potentially relevant to their health.

The induced electric field acts with electric force on the polar molecules of water and on the free charged particles (electrons and ions). In both cases part of the electromagnetic energy is converted into kinetic energy, with the polar molecules rotating and directing, and the charged particles begin to move in the same direction - the direction of the field, creating a current field. In the process of rotation of polar molecules and the movement of charged particles, they collide with other molecules and particles in their environment, whereby their kinetic energy is converted into heat. This is the basis of the thermal interaction of RF EMF with biological systems.

The generated heat can affect the state of biological systems in many ways. For example, if the induced field is at a frequency lower than 10 MHz and carries enough energy, it can exceed the levels of electrical forces sufficient to stimulate the nerves. At strong RF EMF, a huge amount of thermal energy could be generated that could cause even death of the exposed organism.

In addition to the thermal effects of RF EMF, more recent research has focused on "non-thermal effects", i.e., possible effects of low-level RF EMF (below reference limit values) on biological systems (Adey 1981; Bernhardt et al. 1997; Belpomme et al. 2018).

One phenomenon that is rarely registered is the non-thermal so-called "sound effect" of RF EMF. Under certain strictly observed conditions in terms of frequency, modulation and intensity of the RF EMF, a human or animal can perceive a certain type of buzzing or throbbing sound. The scientifically accepted explanation for the origin of this effect is that the RF EMF produces thermoelastic pressure in the head which is perceived as sound by the auditory apparatus in the ear. This effect is not recognized as a risk to human health and the probability of the conditions under which it may occur to be satisfied in the human everyday environment is quite small. There is no evidence that this effect can be produced within the functioning of telecommunications operators as well as TV distribution operators. Therefore, this phenomenon can be declared irrelevant to the safety of the public population.

For people with implanted pacemaker or other types of biomedically active electrical implants there is a potential risk of some type of non-thermal impact to the RF EMF. Although modern pacemakers have protection against electromagnetic interference under certain conditions their conductors can play as receiving antennas in relation to the incident RF wave - that is, to induce an electromotive force in them. For these reasons international standardization bodies have published specific recommendations for the use of mobile phones by persons with a built-in pacemaker - to keep a minimum distance of 15 cm (Cleveland and Ulcek 1999).

### 2.3.3 RF EMF Exposure assessment methodology

The interaction mechanisms of the RF EMF with biological tissues are complex and depends on many parameters. RF EMF in the free space is characterized by their frequency, electric (*E*, [V/m] and magnetic (*H*, [A/m]) field intensities, direction of propagation and polarization. All the mechanisms of influence of the RF EMF inside biological tissues, even the induced currents due to the changing magnetic field can be expressed through the electric field. But the tissues have an imperfect geometric shape and the characteristics of an inhomogeneous dielectric with losses (due to their specific conductivity); therefore, the process of formulating wave equations is not simple. The level of exposure is a function of the power carried by the wave and its frequency, as well as the distance of the object from the source and the duration of the exposure. From the aspect of potential health risk of biological systems, the part of EMF energy that is absorbed in their tissues should be analyzed.

For frequencies below about 6 GHz RF EMF penetrate deeper into the tissues (and this depth is subject to calculations). This process is explained by the quantity **Specific Absorption Rate (SAR)**. SAR is one of the most important quantitative measures of the interaction of EMF with biological tissues. It is defined as a time derivative of the change of the energy *dW*, in an elementary mass, *dm*, located in an elementary volume *dV* (in units of measure m3), with a given density ρ (measured in kilograms per cubic meter - kg/m3) (NCRPM 1981):

Equation 2.7: $$\mathrm{SAR} = \frac{d}{dt}\frac{dW}{dm} = \frac{d}{dt}\left[\frac{dW}{\rho \cdot dV}\right]$$

Equation 2.7 is used to calculate the SAR of whole-body. The localized SAR in the extremities is closely related to the density of current flowing through them. Its value is practically immeasurable and is therefore performed mathematically using Pointing's theorem for sinusoidal variable electromagnetic fields (Janev 2006). Thus Equation 2.7 gives a relation for the local SAR depending on the current in the extremities (*I*), which is measured relatively simply:

Equation 2.8: $$\mathrm{SAR} = \frac{\sigma}{\rho}\left|E_i\right|^2 = \frac{1}{\sigma\rho}\left|J\right|^2 = \frac{1}{\sigma\rho A^2} I^2$$

where

- $E_i$ is the maximum value of the internal electric field in the extremities,
- *J* is the current density [A/m2] and
- *A* is the effective area [m2].

SAR is expressed in watts per kilogram [W/kg] and is a measure of the rate at which electromagnetic energy is converted to thermal energy in tissue. This quantity allows comparison of experimentally observed biological effects on different tissue types under different field exposure conditions. For now, this is the only way to assess the potential risk to human health from exposure to RF EMF through available experimental animal tissue data (Polk 1995). Figure 2.5 presents the results of numerical calculations for SAR in the human head originating from the RF EMF at a frequency of 900 MHz.

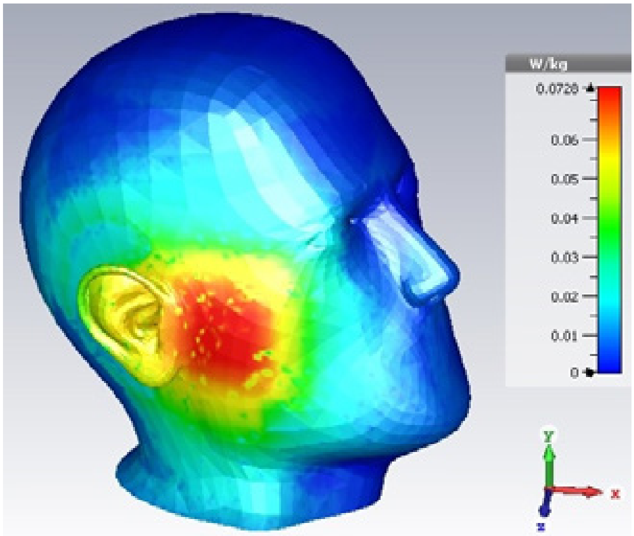


Figure 2.5: Simulated SAR values in human head from RF EMF at 900 MHz

When determining the limit values of exposure to RF EMF, the ability of the body to dissipate heat from the tissues that absorb energy from mobile phones is considered. The limit value is set at a level much lower than the levels shown in research on biological systems (Cleveland and Ulcek 1999) equal to 1.6 W/kg (FCC 2020). The limit of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) for the SAR value in the human head derived from the use of a mobile phone is 2 W/kg (ICNIRP 2020). For orientation, a SAR value of 4 W/kg causes a human temperature to rise by less than 1 °C (Swerdlow et al. 2011). Measurements performed in the framework of scientific studies show that the levels of RF fields in the human environment are far lower than those that would achieve significant warming and increase in body temperature (Mantiply et al. 1997).

Since at very high frequencies EMF are absorbed superficially and the skin depth becomes irrelevant, the exposure is usually described by the magnitude of the absorbed surface power density, $S_{ab}$ (for frequencies higher than 6 GHz).

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# Chapter 3

## 3 Health risks, limit values and legislation on RF EMF exposure

Assessing the impact of EMF on biological systems is a complex process. There is a vast base of published research papers on the possible impact of EMF on biological systems, with an emphasis on radio frequency (RF) EMF. However, the numerous research studies that have been done on this topic are not aimed at a common theory that should be established or refuted and therefore the results are divergent. In addition, during research exact same conditions of exposure of experimental subjects are not always maintained, which leads to conflicting views and conclusions of experts in the field. In this chapter, by a thorough analysis of the most influential scientific publications an attempt will be made to draw scientifically substantiated, objective conclusions about the potential health risk that could result from exposure to RF EMF. From the multitude of technologies that use the radio frequency spectrum, the emphasis will be focused on mobile communication technologies. The scientific basis on which the international expert bodies set the exposure values of the RF EMF will be explained and the European and international standards and recommendations regarding the exposure of the RF EMF will be presented in detail.

### 3.1 Scientific basis for setting limit values for RF EMF and review of international standards and recommendations

The influence of external factors on biological systems is registered by measuring a certain change in the biological system after its interaction with the external factor. However, the registration of the influence of a certain factor does not necessarily lead to the conclusion that the phenomenon is dangerous for the biological system. This conclusion can be made only in cases when the impact is manifested by registered damage to the health of the individual or the offspring of the individual.

The changes that are registered due to the thermal impact of RF EMF on biological systems have long been known in the scientific community. After exceeding a certain threshold of the intensity of the RF EMF, thermal energy begins to be absorbed in the biological tissues, and consequently there is a rapid local increase in kinetic energy and temperature. The minimum power flux density limit value to which the biological tissue should be exposed to register its heating (but not damage) is between 10 and 100 W/m2, depending on the conditions under which the tissue is exposed. The heating rate depends on several factors such as the frequency of the EMF, the size, shape and orientation of the exposed object, the duration of the exposure, the environmental conditions and the heat dissipation efficiency of the tissue and body. One of the main mechanisms for thermoregulation of living organisms is blood circulation. Different human organs have different ability to dissipate heat because they have different blood perfusion. In humans, for example, two organs are particularly susceptible for heating under the influence of RF EMF due to poor blood perfusion: the eye and the testicles. Laboratory experiments showed that exposure of rabbits to very high levels of RF EMF (power densities of 1000 to 2000 W/m2) lasting 30 to 60 minutes can cause cataracts. It should be noted that any other mode of energy transfer that would cause a comparable local increase in thermal energy in the rabbit's eye would give a similar consequence. The temperature gradients in the tissue, when exposed to RF EMF, are fundamentally different from the gradients that appear during ambient heating. With an extreme increase in the intensity of the RF EMF, the thermoregulatory mechanisms can be subdued, and this can lead to tissue damage and even death of the exposed organism (ICNIRP 2020 b). Apart from the scientific publications in which the thermal impact is analyzed there is also a few research papers in the field of the impact of the RF EMF on a non-thermal level (Barnes 2006; Imtiaz 2019). There is currently no scientific consensus on whether these impacts could pose a risk to human health, especially for long-term exposure. A review and analysis of the published papers will be provided in section 3.2 of this chapter.

Precisely to rule out the possibility of any potential health risks, international organizations set exposure limit values that are far below the minimum levels required for any known risks. This fact has been proven in scientific studies: the levels of RF EMF in the human environment are far lower than those that would achieve significant warming and increase in body temperature (Petersen and Testagrossa 1992; Mantiply et al. 1997). Regarding the exposure to significantly higher levels of RF EMF found in certain workplaces (for example near high power sources of RF EMF) it is necessary to take certain protective measures such as restrictions of the duration of exposure of workers etc. In addition to the intensity of the RF EMF, its frequency also plays a role in the quantitative estimation of the amount of electromagnetic energy that would be absorbed by the biological system. In the far region of the RF EMF source (for example at a distance of several wavelengths) the SAR is the highest at a frequency between 80 and 100 MHz, depending on the height, volume and shape of the body of the object. Due to this “resonant” phenomenon the most restrictive values for the minimum levels of allowable RF EMF exposure in the safety standards are set in this frequency range. At relatively low levels of exposure to RF EMF, i.e., at an intensity of RF EMF much lower than the one that would cause significant and measurable heating of biological tissues, there is no unequivocal evidence for harmful (non-thermal) effects on biological systems.

In addition, the conclusions from the analysis of the existing research on the effects of RF EMF on humans by the World Health Organization (WHO) is presented as follows:

> *“There is no convincing evidence that RF EMF with intensities lower than those specified in international standards cause genetic damage or an increased likelihood of cells becoming malignant. Extensive studies have not found that RF EMF affect the initiation or development of cancer and there is no consistent evidence of effects on the brain and nervous system, nor on the hearing apparatus and reproductive organs. Evidence suggests that exposure to RF EMF below the maximum allowable intensity does not cause acute symptoms in humans. Well-conducted studies found no association between exposure to RF EMF and acute cognitive changes. There is evidence that exposure to RF EMF may affect EEGs and other markers of brain function. However, this evidence is not consistent in various studies. The changes in brain function reported in the studies are often small compared to normal physiological changes, and it is unclear whether they are a symptom of deteriorating health.*
>
> *Although research into the long-term effects of exposure to RF EMF below the level allowed in the standards is limited, the literature does not provide strong evidence for impact on the cardiovascular system, reproductive function, or mortality from non-cancerous causes.*

*Epidemiological studies on the risk of cancer depending on the exposure to RF EMF in the workplace and at home have significant methodological shortcomings, especially around exposure assessment. From this research the investigated causality cannot be proved, but neither can it be concluded that it does not exist.*

*There is a significant number of published epidemiological research on the risks of cancer due to cell phone use. Although several studies have found a link, overall research does not prove that cell phone use causes tumors in the human brain or other cancers. It should be noted that the data under study in these studies are limited to exposure periods shorter than 15 years.*

*The World Health Organization will continue to promote and support research into the potential health effects of cell phone use on children and adults (Agnir 2012; WHO 2014).”*

## 3.2 Overview of the scientific research on the impact of exposure to RF EMF with emphasis on mobile communication systems

This section of the scientific study provides an analysis of relevant publications with research on potential health risks that could arise from RF EMF exposure. Of particular interest to the public is research on the health effects of exposure to RF EMF due to wireless networks on humans. Scientific research in this area intensified with the advent of GSM technology, and with the beginning of the implementation of 5G technology, their relevance is growing. Although there is a large database of publications exposing the results of scientific research in this field, there is a public consensus on the need for more systematic and comprehensive studies in order to understand the impact of RF EMF on biological systems (Repacholi 1998). The wide range of publications in this area can be divided into two main parts - thermal and non-thermal effects of exposure to RF EMF. The consequence of thermal effects of RF EMF is a thermal heating of the biological tissues and an increase of the temperature as a noticeable effect. However, there is a growing public interest in the potential conclusions that could be drawn from research on the non-thermal (not heating related) effects of RF EMF, including sinusoidal (continuous) and non-sinusoidal (pulsating) fields.

The review of RF EMF impact studies given in this section addresses the effects on body systems and processes and specific disease groups. The research domains considered include experimental studies on cells, animals, and humans, assessing the correlation between RF EMF exposure and a range of potential adverse health effects. This section analyses research in the field of nervous system and cognition, cardiovascular and endocrine system, reproductive system and fertility, cancer diseases, etc. Regarding the skeletal, muscular, respiratory, digestive, and excretory systems, there is not a sufficiently large base of research papers that could be considered and therefore these systems will not be considered in this section.

### 3.2.1 Impact on the nervous system and cognitive functions

There is public concern about the potential adverse effects of cell phone RF EMF on the central nervous system due to the proximity of these devices to the human head. Research into these effects considers five main aspects: nervous system morphology, brain function, electrophysiology, behavior, and development. In laboratory tests of cognition in animals, special care is taken to avoid incorrect registration of adverse effects arising from stressful conditions in the treatment of animals, and not from the impact of the RF EMF being examined.

Several papers have been published in this field of research. Some of these papers report minor transient effects (both positive and negative) on encephalogram (EEG) findings, sleep structure, and cognitive processes in human subjects, as well as certain biochemical changes in neurotransmitters in animals (D'Costa et al. 2003; Cook et al. 2002; Hossmann and Hermann 2003; Sienkiewicz et al. 2005). Some of these findings cannot be obtained even by repeated experimental tests (Besset et al. 2005). The electroencephalogram frequency bands of 8-13 and 10-14 Hz have been shown to change under the influence of RF EMF exposure with a specific absorption rate (SAR) of less than 2 W/kg, but there is no evidence that these changes are with negative health consequences (Loughran et al. 2012).

Given the fact that the human ear is very close to the source of RF EMF (during telephone conversations), some studies deal with the study of the hearing aid under the cumulative influence of RF EMF. No effect on the auditory apparatus was observed in these studies (Ozturan et al. 2002; Arai et al. 2003; Aran et al. 2004; Parazzini et al. 2005; Uloziene et al. 2005).

A few studies have been performed on the impact of RF EMF on the brain barrier. This barrier serves to isolate the central nervous system from the rest of the body, to control the flow of molecules, and to protect the brain (Purves et al. 2001). Changes in cerebral barrier permeability at low levels of specific rate of absorption (SAR) (Salford et al. 2003; Ushiyama et al. 2007) have been reported in some scientific papers, while no changes have been reported in other publications (Finnie 2001), even by repeating the exposure over a period of two years (Finnie et al. 2002).

The correlation between the development of multiple sclerosis in rats and exposure to RF EMF has been investigated and no evidence has been found (Anane et al. 2003).

Nervous system morphological effects have not been reported below the RF EMF thermal impact threshold (D'Andrea et al. 2003).

An analysis of the above and many other scientific studies cannot conclude the existence of any effects of RF EMF on the nervous system and cognition. Changes recorded on the EEG and neurotransmitters have no effect on cognitive processes, behavior, or memory, and cannot be considered a danger that may cause pathological consequences (Bromen 2007).

### 3.2.2 Impact on the reproductive system and fertility

The base of scientific papers dealing with experimental examination of the possible effects of RF EMF on human reproduction and embryo development is small. Most studies in this group focus on the hormonal system and there is no evidence that exposure to RF EMF has any effect on it (ICNIRP 2020 b).

Epidemiological studies have been performed on adverse pregnancy outcomes under the influence of RF EMF: miscarriages, neonatal weight and genetic abnormalities. Some of the results of the studies show that this impact is limited to people who are exposed at the professional level, while other results do not lead to a common conclusion (Verschaeve and Maes 1998; Heynick and Merritt 2003; Feychting 2005).

Numerous studies have been conducted to assess the impact of RF EMF on the development of mammals, birds, and other species. From them it can be concluded that RF EMF with intensity below the recommended limit values does not cause a negative impact on the development of these animals (Heynick and Merritt 2003; ICNIRP 2004).

Extensive studies have been performed in the field of fetal malformations and abnormalities in mice for SAR values up to 4 W/kg, in which no effect of RF EMF on embryos has been identified. For example, (Sommer et al. 2009) examined a group of 4 generations of mice with SAR values up to 2.34 W/kg, and found no adverse effects of RF EMF on embryos and fetuses.

### 3.2.3 Cancer

Studies on the correlation of the incidence of cancer with respect to RF EMF exposure are mainly focused on intracranial[2] tumors. This is because the transmission of electromagnetic energy from mobile phones is done to the human skull. Part of the research considered the exposure of the whole human body and examined other forms of cancer.

Of particular interest to researchers because of their location is the type of tumors that appear on Schwann cells[3] that line the vestibuloclechial[4] nerve. They are benign tumors that develop very slowly and are called “acoustic neuromas”. Studies in Sweden have shown some relative increase in the risk of acoustic neuromas (Hardell et al. 2006). The results of Danish and Japanese studies on the risk of acoustic neuromas (Christensen 2004; Takebayashi et al. 2006) do not show any correlation between the relative risk and the use of mobile phones in the respondents. In 2010, the Interphone study was launched by the International Agency for Research on Cancer (IARC). This study did not provide evidence of an increased risk of developing brain tumors, acoustic neuromas, or airway tumors among regular cell phone users (IARC 2010, 2011b). Similar results were obtained by the research published in (Röösli et al. 2019).

In 2011, exposure to RF EMF was classified as a potential human carcinogen by group 2B by the International Agency for Research on Cancer (IARC). The findings were based on findings for an increased risk of glioma - a malignant type of brain cancer associated with the use of cordless phones (IARC 2011a). As previously stated, the following two types of carcinogens can be classified in Group 2B: 1. factors for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity because of laboratory experiments performed on animals, and 2. factors for which no there is adequate evidence of carcinogenicity in humans but there is sufficient evidence of carcinogenicity because of laboratory experiments performed on animals. In some cases, group 2B may include phenomena for which there is insufficient evidence of carcinogenicity in humans and there is less than sufficient evidence of carcinogenicity because of laboratory experiments performed on animals but classified solely on the basis of mechanical or oth-

[2] Intracranial tumors - tumors located in the head.
[3] Schwann cells - cells that secrete myelin and thus form the myelin sheath of the nerve.
[4] Vestibulocchlear nerve - makes up the eighth cranial nerve and its function is necessary to maintain balance.

er type of relevant data. In the following period, other results were published which indicate a certain indirect correlation between the exposure to the RF field and the occurrence of malignant diseases (Duhaini 2016; Romanenko et al. 2017).

There is a considerable body of literature in the field of molecular processes that are particularly relevant to cancer. These areas include cell proliferation, differentiation, proto-oncogenic expression, genotoxicity, increased oxidative stress, and DNA strand breakage. Although there are claims of RF EMF influences on some of the mentioned molecular processes, there is no scientifically substantiated evidence for this (Vijayalaxmi and Prihoda 2018).

Several studies on the impact of RF EMF on the incidence of cancer in animals have registered positive effects, but the studies have methodological shortcomings and the results have not been confirmed in subsequent independent studies. Most studies show the absence of carcinogenic effects in the results of numerous animal experiments (ICNIRP 2020b).

Two recent extensive studies on the carcinogenic impact of long-term exposure of animals to RF EMFs associated with mobile phones and mobile communication base stations were conducted in 2018 in the United States and Italy (NTP 2018a, 2018b; Falcioni et al. 2018). Although both studies use many animals, excellent laboratory practice, and exposure of animals throughout their lives, they also contain drawbacks and significant limitations that affect the usability of the results obtained. The statistical methods used in these studies cannot distinguish between the conditions of treatment of animals - the interpretation of the data is problematic due to large changes in body temperature in animals because of very high levels of RF EMF. Additionally, there is no consistency between the results of the two mentioned studies.

For these reasons, by analyzing research on carcinogenicity of exposure to RF EMF exclusively (ICNIRP 2020 a) or in the context of other studies on human carcinogens and (HCN 2014, 2016), the findings do not show that RF electromagnetic fields are carcinogenic.

In addition, some of the other changes in biological tissues and systems that have been published as a result of research on the influence of RF EMF include: changes in the chromosomes of various types of plant and animal cells; Kinetic functional and biochemical changes in cells as well as disorders in embryonic development. A common feature of these publications is that no definite conclusion can be drawn from the results obtained. Most often the reasons for this are the high levels of exposure used in research, representative sample of examined subjects. The main reason for the unreliability of the results is the fact that scientists fail to reproduce the experimental results published in the mentioned scientific papers by repeating the experiments.

In the few studies that have reported effects at low-level (nonthermal) exposure levels (i.e., below the exposure reference limits), the findings are generally inconsistent with each other, as well as with the larger body of evidence reporting no effects at these exposure levels (IEEE 2019). The conclusion that can be drawn from these findings is that although a certain possibility of RF EMF non-thermal influences is not excluded, the analysis of the previous research does not lead to a conclusion that they pose a danger to human health (USGA 1994; Bromen 2007). What scientists agree on is that further research is needed to determine the legitimacy of these impacts and whether they are potentially relevant to human health. The world standardization bodies continuously follow the latest experimental discoveries to determine the set limit values or to change them to protect the public health.

The research presented in this chapter deals with EMF from the radio frequency spectrum - from 3 kHz to 300 GHz. The experiments used base stations and mobile phones from the generations of 2G, 3G and 4G mobile networks as EMF sources. The introduction of new technology that uses existing radio frequencies does not change the characteristics of the frequencies. This means that the conclusions from the analysis of publications covering frequencies up to 300 GHz remain valid in relation to the new technology (5G), if the exposure to RF EMF is within the exposure limit values and reference levels defined in international standards (ICNIRP 2020).

## 3.3 International Standards and Recommendations for RF EMF

Countries around the world adhere to the recommendations of various (national and international) standardization bodies and organizations and therefore apply different exposure limit values. In Russia and some other Eastern European countries, for example, more restrictive exposure standards are in place than those in North America and Western Europe.

The differences are due to the different philosophy/approach in determining the limit levels of exposure:

- levels of exposure that are believed to have no effect on biological systems and
- levels of exposure that are believed to have no adverse effect on biological systems.

However, the largest number of countries in the world form their legislation in consultation with relevant international bodies that regulate standardization in relation to the protection of human and the environment from exposure to EMF.

In the last few decades, several international bodies and organizations have been functioning in the world that set limit (maximum) values of human exposure to EMF, based on contemporary scientific knowledge. In this section we have selected the most influential scientific and standardization bodies:

- World Health Organization (WHO),
- International Commission on Non-Ionizing Radiation Protection (ICNIRP),
- International Committee on Electromagnetic Safety at the Institute of Electrical and Electronics Engineers (IEEE),
- European Commission (EC) - Scientific Committee on Emerging and Newly Identified Health Risks (SCENHIR),
- International Telecommunication Union (ITU).

In 1996, the World Health Organization (WHO) established the **International EMF Project**, whose task was to analyze scientific publications dealing with the effects of EMF on biological systems, to detect deficiencies in human knowledge in this field, to recommend guidelines for further research that are necessary to answer globally questions about the safety of the use of RF technologies.

In 1992, the **International Commission on Non-Ionizing Radiation Protection (ICNIRP)** was established in Munich, Germany. This commission continues the work of the International Committee for Non-Ionizing Radiation, which originates from the International Radiation

Protection Association (IRPA), which dates back to 1973. The purpose of this international body is to publish expert opinion and guidelines for limiting the levels of EMF to protect humans and their environment from the negative effects of ionizing radiation. ICNIRP is a non-profit organization engaged in the development and analysis of scientific research in order to provide scientifically substantiated evidence on the basis of which recommendations are made for limit values of exposure to non-ionizing radiation. The ICNIRP recommendations are taken into account by the World Health Organization and the European Commission.

The **International Telecommunication Union (ITU)** is a specialized agency for information and communication technologies within the United Nations. It was founded in 1865 to facilitate international connectivity between communication networks, allocate radio frequency and satellite spectra and develop technical standards.

The **Scientific Committee on Emerging and Newly Identified Health Risks (SCENHIR)** has been functioning within the European Commission (EC) since 2004, whose task is to provide an expert assessment and opinion on new developments based on the analyzed scientific research risks to human health and the environment, including exposure to RF EMF.

Another world standardization body in this area is the **International Committee for Electromagnetic Safety at the Institute of Electrical and Electronics Engineers (IEEE)**. The IEEE Institute is the largest technical professional organization in the world and was founded in 1884 when electricity began to have a significant impact on the world economy. Table 3.1 gives a list of the websites of the international organizations exhibited in this section where the public can be informed about the latest recommendations regarding the exposure from the RF EMF.

| Standardization body / organization | Website |
|---|---|
| WHO | https://www.who.int |
| ICNIRP | https://www.icnirp.org |
| IEEE | https://www.ieee.org |
| ITU | https://www.itu.int |
| EC | https://ec.europa.eu |

Table 3.1: List of international organizations and their websites, where additional information regarding the exposure to RF EMF can be found

When preparing the national legislation, most of the countries in the world adhere to either The International Commission on Non-Ionizing Radiation Protection (ICNIRP) or to International Committee for Electromagnetic Safety at the Institute of Electrical and Electronics Engineers– IEEE guidelines and standards for exposure of the RF EMF. Accordingly, in the next section limit and reference values of the above standardization bodies are present.

### 3.3.1 Principles for limiting the exposure to RF EMF

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) bases its recommendations on a thorough analysis of published scientific research in the field of the impact of the RF EMF exposure to the biological systems. There are those influences that have proven to be harmful to human health and there is scientific evidence for those influences. For each of the selected adverse effects ICNIRP identifies the so-called "harmful effect threshold", i.e., the lowest level of exposure that can cause the harmful effect. The mentioned harmful impact thresholds are strictly defined and cover most of the possible exposure situations. The limit values recommended by ICNIRP for restriction of exposure to RF EMF are derived from the thresholds of harmful impact by applying safety factors (reduction factors). Safety factors consider the biological diversity of the population, such as age and sex, environmental factors such as temperature, humidity, etc., as well as some inaccuracies in the medical assessment of the adverse effect. Thus, obtained limit values are called "basic restrictions". They refer to physical quantities that are closely related to the harmful effects of RF EMF. Some of these values refer to phenomena inside biological systems and therefore cannot be easily measured. For these reasons, new types of limit values called "reference levels" have been introduced. As discussed previously, the reference level values are derived from the basic restriction values to ensure their more practical use. The reference levels are derived in such a way as to provide an equivalent degree of protection as the basic restrictions and can be applied equally with them, i.e., to check whether the exposure is in accordance with the guidelines (whether it is lower than the reference levels). There are other factors that may affect the adequacy of the equivalence of the basic restriction levels with the reference levels.These include the frequency of the RF EMF, the physical dimensions of the source, the distance of the source from the measuring point, the variation of the field levels in the space that would occupy the human body, and so on. Considering these uncertainty factors, the reference levels define more conservative limit values than basic restrictions (ICNIRP 2020 b).

### 3.3.2 Basic restriction values and reference level values recommended by ICNIRP and IEEE

Table 3.2 shows the basic restriction values recommended by **ICNIRP** in terms of specific absorption rate – SAR for occupational and public exposure to the RF EMF at frequencies from 100 kHz to 300 GHz (ICNIRP 2020 b). The internationally accepted basic restriction criteria for exposure to RF EMF defines limits for the maximum permissible exposure (MPE) that relate to exposure averaged over a period. This means that it is permissible to exceed the MPE in a short period of time, but the average exposure must be kept below the threshold level. For example, in Table 3.2 for a frequency between 100 kHz and 6 GHz the recommended maximum SAR level is 0.4 W/kg with the averaging time of 6 minutes for occupational/controlled exposure. The local SAR refers to 10 g of contiguous tissue. It can be noticed that for frequencies higher than 6 GHz beside SAR, the last column of the table gives MPE values in terms of local absorbed power density, $S_{ab}$. The given values for $S_{ab}$ refer to the square body area of 4 $cm^2$.

| Exposure | Frequency range | Whole body average SAR [W/kg] | Local SAR head and torso [W/kg] | Local SAR limbs [W/kg] | Local $S_{ab}$ [W/m2] |
|---|---|---|---|---|---|
| Occupational | 100 kHz – 6 GHz | 0.4 | 10 | 20 | -- |
| | 6 – 300 GHz | 0.4 | -- | -- | 100 |

| | | | | | |
|---|---|---|---|---|---|
| General Public | 100 kHz – 6 GHz | 0.08 | 2 | 4 | -- |
| | 6 t– 300 GHz | 0.08 | -- | -- | 20 |

Table 3.2: Basic restriction values for SAR and $S_{ab}$ (ICNIRP 2020 b).

Table 3.3 shows the basic SAR limit values and local absorbed power density, Sab, for professional / controlled and general / uncontrolled exposure of the public population of RF EMF with frequencies from 100 kHz – 6 GHz, included in the current IEEE standard (IEEE 2019).

| Exposure | Frequency range | Whole body average SAR [W/kg] | Local SAR head and torso [W/kg] | Local SAR limbs [W/kg] | Local $S_{ab}$ [W/m2] |
|---|---|---|---|---|---|
| Occupational | 100 kHz – 6 GHz | 0.4 | 10 | 20 | -- |
| | 6 – 300 GHz | -- | -- | -- | 100 |
| General Public | 100 kHz – 6 GHz | 0.08 | 2 | 4 | -- |
| | 6 t– 300 GHz | -- | -- | -- | 20 |

Table 3.3: Basic SAR constraint values of the current IEEE standard (IEEE 2019).

The concept of time averaging can be explained as follows: the sum of the products of the actual exposure levels multiplied by the actual exposure times must not be greater than the permissible (limit) average exposure time multiplied by the specified averaging time. This concept can be illustrated by the following example of RF EMF exposure in the workplace: for frequencies between 100 kHz and 6 GHz, exposure with a SAR value of 0.8 W/kg is allowed for 3 minutes in any 6-minute period, if the remaining 3 minutes of that period the exposure is close to 0.

Mathematically this situation can be expressed as 0.8 W/kg × 3 minutes + 0 W/kg × 3 minutes = 0.4 W/kg × 6 minutes.

The exposed situation is not the only one that can be equated with 6-minute mediation, there are several other combinations of exposure and time intervals. It is very important to emphasize that temporal averaging is only necessary in situations where temporary exposure to power density levels and/or electric and magnetic field amplitudes higher than recommended is possible. This can only happen in a work environment where exposure can be measured and controlled. For residential areas where the public moves, there are no conditions to control the duration of human exposure to RF EMF. In those situations, the MPE levels refer to continuous exposure, ie, if the limit levels are not exceeded, the permitted duration of exposure is unlimited.

Table 3.4 and Table 3.5 show the reference levels recommended by ICNIRP in terms of the effective values of the electric and magnetic field and the received power density, averaged over a period of 6 and 30 minutes respectively (ICNIRP 2020 b). The power density is calculated for a plane electromagnetic wave, and the designation f means frequency in MHz. The values in Table 3.4 represent the reference levels for local exposure. Table 3.5 presents the reference levels that refer to whole body exposure.

| Exposure | Frequency range | Electric field strength *E* [V/m] | Magnetic field strength *H* [A/m] | Power density *S* [A/m] |
|---|---|---|---|---|
| Occupational | 0.1 – 30 MHz | 1504 / $f^{0.7}$ | 10.8 / *f* | –– |
| | 30 – 400 MHz | 139 | 0.36 | 50 |
| | 400 – 2000 MHz | 10.58 $f^{0.43}$ | 0.0274 $f^{0.43}$ | 0.29 $f^{0.86}$ |
| | 2 – 6 GHz | –– | –– | 200 |
| | 6 – 300 GHz | –– | –– | 275 / $f^{0.177}$ |
| | 300 GHz | –– | –– | 100 |
| General Public | 0.1 – 30 MHz | 671 /$f^{0.7}$ | 49 / *f* | –– |
| | 30 – 400 MHz | 62 | 0.163 | 10 |
| | 400 – 2000 MHz | 4.72 $f^{0.43}$ | 0.0123 $f^{0.43}$ | 0.058 $f^{0.86}$ |
| | 2 – 6 GHz | –– | –– | 40 |
| | 6 – 300 GHz | –– | –– | 55 / $f^{0.177}$ |
| | 300 GHz | –– | –– | 20 |

Table 3.4: ICNIRP reference levels for local exposure (ICNIRP 2020 b)

| Exposure | Frequency range | Electric field strength *E* [V/m] | Magnetic field strength *H* [A/m] | Power density *S* [A/m] |
|---|---|---|---|---|
| Occupational | 0.1 – 30 MHz | 660 / $f^{0.7}$ | 4.9 / *f* | –– |
| | 30 – 400 MHz | 61 | 0.16 | 10 |
| | 400 – 2000 MHz | 3 $f^{0.5}$ | 0.008 $f^{0.5}$ | *f*/ 40 |
| | 2 – 300 GHz | –– | –– | 50 |
| General public | 0.1 – 30 MHz | 300 / $f^{0.7}$ | 2.2 / *f* | –– |
| | 30 – 400 MHz | 27.7 | 0.073 | 2 |
| | 400 – 2000 MHz | 1.375 $f^{0.5}$ | 0.0037 $f^{0.5}$ | *f* / 200 |
| | 2 – 300 GHz | –– | –– | 10 |

Table 3.5: ICNIRP reference levels for whole body exposure (ICNIRP 2020 b)

Table 3.6 and Table 3.7 show the reference levels recommended by the **IEEE** in terms of effective electric and magnetic field values and received power density[5], mediated over a period of 6 and 30 minutes respectively (IEEE 2019). The power density is calculated for a plane electromagnetic wave, and the designation *f* means a frequency expressed in MHz. The values in Table 3.6 represent the reference levels for local exposure. Table 3.7 presents the reference levels that refer to the whole-body exposure.

| Exposure | Frequency range [MHz] | Electric field strength *E* [V/m] | Magnetic field strength *H* [A/m] | Power density *S* [A/m] | |
|---|---|---|---|---|---|
| | | | | *SE* | *SH* |
| Professional | 0.1 – 1.34 | 4119 | 36.4 / *f* | 45000 | 500000 / $f^2$ |
| | 1.34 – 30 | 4119 / *f* | 36.4 / *f* | 45000 / $f^2$ | 500000 / $f^2$ |
| | 30 – 100 | 137.3 | 36.4 / *f* | 50 | 500000 / $f^2$ |
| | 100 – 400 | 47.3 $f^{0.232}$ | 0.125 $f^{0.232}$ | 5.93 $f^{0.463}$ | |
| | 400 – 2000 | –– | –– | 5.93 $f^{0.463}$ | |
| | 2000 – 6000 | –– | –– | 200 | |

[5] $S_E$ and SH are power densities for a plane wave based on the intensity of an electric or magnetic field.

| | | | | | |
|---|---|---|---|---|---|
| General public | 0.1 – 1.34 | 1373 | 36.4 / $f$ | 5000 | 500000 / $f^2$ |
| | 1.34 – 30 | 1842 / $f$ | 36.4 / $f$ | 9000 / $f^2$ | 500000 / $f^2$ |
| | 30 – 100 | 61.4 | 353 / $f^{1.668}$ | 10 | 47000000 / $f^{3.336}$ |
| | 100 – 400 | 21.2 $f^{0.232}$ | 0.0562 $f^{0.232}$ | 1.19 $f^{0.463}$ | |
| | 400 – 2000 | -- | -- | 1.19 $f^{0.463}$ | |
| | 2000 – 6000 | -- | -- | 40 | |

Table 3.6: IEEE reference levels for local exposure (IEEE 2019)

| Exposure | Frequency range [MHz] | Electric field strength *E* [V/m] | Magnetic field strength *H* [A/m] | Power density *S* [A/m] | |
|---|---|---|---|---|---|
| | | | | *SE* | *SE* |
| Professional | 0.1 – 1.34 | 1842 | 16.3 / $f$ | 9000 | 100000 / $f^2$ |
| | 1.34 – 30 | 1842 / $f$ | 16.3 / $f$ | 9000 / $f^2$ | 100000 / $f^2$ |
| | 30 – 100 | 61.4 | 16.3 / $f$ | 10 | 100000 / $f^2$ |
| | 100 – 400 | 61.4 | 0.163 | 10 | |
| | 400 – 2000 | -- | -- | $f$ / 40 | |
| | 2000 – 300000 | -- | -- | 50 | |
| General public | 0.1 – 1.34 | 614 | 16.3 / f | 1000 | 100000 / $f^2$ |
| | 1.34 – 30 | 823.8 /$f$ | 16.3 / f | 1800 / $f^2$ | 100000 / $f^2$ |
| | 30 – 100 | 27.5 | 158.3 / $f^{1.668}$ | 2 | 9400000 $f^{3.336}$ |
| | 100 – 400 | 27.5 | 0.0729 | 2 | |
| | 400 – 2000 | -- | -- | $f$/ 200 | |
| | 2000 – 300000 | -- | -- | 10 | |

Table 3.7: IEEE reference levels for whole body exposure (IEEE 2019)

## 3.4 European Recommendation 1999/519/EC

In the EU there is no mandatory legislation regarding the exposure of public to EMF. It is therefore at the discretion of each member state to freely regulate the exposure of general population to EMF with national legislation. However, in 1999 the recommendations regarding the exposure of public to EMF were published: 1999/519/EC: Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz) (EC 1999). The intention of the 1999/519/EC recommendation is to establish a non-binding regulatory frame for national policies regarding the exposure of general public to EM to achieve high protection of all EU citizens in all EU countries and it provides minimum protection of all EU citizens: *"It is imperative to protect members of the general public within the Community against established adverse health effects that may result as a consequence of exposure to electromagnetic fields"* (1999/519/EC recommendation, 4. paragraph of introduction). However, each Member state can provide higher level of protection than that set in 1999/519/EC recommendation (1999/519/EC recommendation, 15. paragraph of introduction). This coupled by the fact that the 1999/519/EC recommendation is non-binding, lead to considerable differences between legislation in different EU countries.

1999/519/EC recommendation is based on the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) from 1998 (ICNIRP 1998). The ICNIRP guidelines from 1998 are now obsolete, as they have been surpassed by updated guidelines covering low frequency (ICNIRP 2010) and RF (ICNIRP 2020) EMF exposures. However, the

1999/519/EC recommendation still provides adequate protection levels for public, as the limit values for low frequency EMF exposure in 1998 ICNIRP guidelines and 1999/519/EC recommendation are lower than those in ICNIRP 2010 recommendation and for RF exposure the limit values in 1998 ICNIRP guidelines and 1999/519/EC recommendation are very similar to those in 2020 ICNIRP guidelines.

Both ICNIRP guidelines and 1999/519/EC recommendation are based on scientifically proven biological effects, mainly induced currents for low frequency fields and energy absorption for RF EMF. It is important to note that a large safety factor of 50 is incorporated in 1999/519/EC recommendation basic restrictions. This large safety factor covers all categories or groups of general publics like children, elderly, or people with different diseases as well as possible variations among the individual susceptibility of some people to risks emerging from EMF. 1999/519/EC recommendation define two types of limit values, one called basic restrictions and the other called reference levels.

In EU recommendations, basic restrictions are defined for internal current density [mA/m2] for low frequency EMF exposure and for specific absorption rate - SAR [W/kg] and plane wave power density S [W/m2] for RF exposure, the same as in 1998 ICNIRP guidelines. However, 2010 ICNIRP guidelines for low frequency exposure define basic restrictions on internal electric field strength (E in situ) [V/m] instead on current density. Quantities limited by basic restrictions are directly related to biological effects – stimulation of muscle and nerve tissue due to induced current and increase of tissue temperature due to energy absorption. If the exposure is below basic restriction values, there are no known harmful effects to the exposed people. Unfortunately, these quantities are not easy to determine, as they are defined inside the human body. Therefore, second type of limit values, called reference levels are defined for quantities outside the human body that can be directly measured, like external electric field or external magnetic field and plane wave power density.

Basic idea with two types of limit values is that you have two possibilities to demonstrate the compliance, with the benefit that demonstrating compliance using reference levels is usually much simpler than with basic restrictions. However, reference level limit values are conservative, they are defined for worst case exposure scenario. This means that compliance with reference levels guarantee compliance with basic restrictions, however if exposure is not compliant with reference levels, it might still be compliant with basic restrictions, but this compliance must be proven directly to basic restriction values. One example of such situation is mobile phone compliance. Electric field values close to mobile phone can exceed reference levels, so measurements of SAR value on human phantom is used to demonstrate the compliance to basic restrictions as defined in standards.

| Frequency range | Magnetic flux density B [mT] | Current density J [mA/m2] | Whole body average SAR [W/kg] | Local SAR head and torso [W/kg] | Local SAR limbs [W/kg] | Power density S [W/m2] |
|---|---|---|---|---|---|---|
| 0 Hz | 40 | | | | | |
| >0 – 1 Hz | | 8 | | | | |
| 1 – 4 Hz | | 8/f | | | | |
| 4 – 1000 Hz | | 2 | | | | |
| 1000 Hz – 100 KHz | | f / 500 | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 100 kHz – 10 MHz | | f / 500 | 0.08 | 2 | 4 | |
| 10 MHz – 10 GHz | | | 0.08 | 2 | 4 | |
| 10 – 300 GHz | | | | | | 10 |

Table 3.8: Basic restrictions from 1999/519/EC recommendation

f is frequency in Hz.

| Frequency range | Electric field strength *E* [V/m] | Magnetic field strength *H* [A/m] | Magnetic flux density B [mT] | Power density S [W/m2] |
|---|---|---|---|---|
| 0-1 Hz | | 3.2 104 | 4 104 | |
| 1-8 Hz | 10000 | 3.2 104 / $f^2$ | 4 104 / $f^2$ | |
| 8-25 Hz | 10000 | 4000 / *f* | 5000 / *f* | |
| 0.025-0.8 kHz | 250 / *f* | 4/f | 5/f | |
| 0.8-3 kHz | 250 /*f* | 5 | 6.25 | |
| 3 Hz-150 KHz | 87 | 5 | 6.25 | |
| 150 kHz – 1 MHz | 87 | 0.73 / *f* | 0.92 / *f* | |
| 1 MHz – 10 MHz | 87 / $f^{1/2}$ | 0.73 / *f* | 0.92 / *f* | |
| 10 MHz – 400 MHz | 28 | 0.073 | 0.092 | 2 |
| 400 MHz – 2000 GHz | 1.375 $f^{1/2}$ | 0.0037 $f^{1/2}$ | 0.0046 $f^{1/2}$ | *f* / 200 |
| 10-300 GHz | 61 | 0.16 | 0.20 | 10 |

Table 3.9: Reference levels from 1999/519/EC recommendation

f is frequency in range as indicated in frequency column.

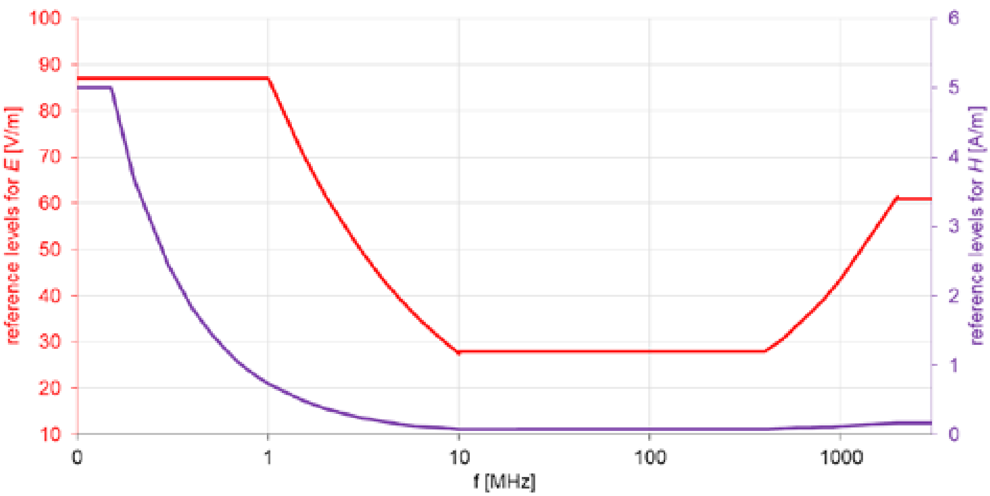


Figure 3.1: Reference levels are frequency dependent. They are shown for frequency range from 0.1 MHz up to 3 GHz, however reference levels from 2 GHz up to 300 GHz are the same

## 3.5 European Directive 2013/35/EU

Occupational exposure to EMF in EU is regulated. There is Directive 2013/35/EU of the European Parliament and of the Council of 26 June 2013 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (20th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) and repealing Directive 2004/40/EC (U) (EC 2013), which sets the minimum requirements for protection of workers from risks emerging from EMF exposure at workplace. However, as stated in paragraph 8 from introduction, *"Member States are given the option of maintaining or adopting more favorable provisions for the protection of workers, in particular by fixing lower values for the action levels (ALs) or the exposure limit values (ELVs) for electromagnetic fields."*

Similar to 1999/519/EC recommendation there is two tier limit values, but basic restrictions are called exposure limit values and reference levels are called action values.

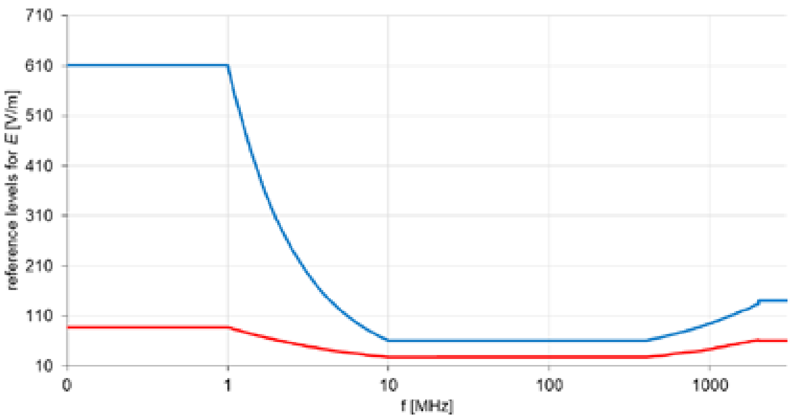


Figure 3.2: Action values (blue) are frequency dependent, and they are higher than reference levels from 1999/519/EC recommendation (red).

The implementation date of the directive was set to 1. July 2016. As the implementation of the directive and obligations for workers are not easy to carry, the European Commission published non-binding guide to good practice for implementing Directive 2013/35/EU Electromagnetic Fields with three volumes: Practical guide (EC 2015-1), Case studies (EC 2015-2) and Guide for SME (EC 2015-3).

Non-binding guides provide comprehensive overview of the directive requirements, obligations of all stakeholders, assessment methods (including simplified assessment for employers without dangerous EMF sources, case studies and other aspects of directive implementation.

## 3.6 EMF Recommendations and standards published by International Telecommunication Union (ITU)

The International Telecommunication Union (ITU) is main international organization in the field of telecommunications. It is the United Nations agency specialized for information and communication technologies – ICTs. The main objective of ITU is to ensure seamless interoperability of ICT around the globe like managing and allocating radio spectrum, developing technical standards for technology interconnection, coordinating satellite orbits. Members of the ITU are either states or other stakeholders like companies, universities, and international and regional organizations.

Inside the ITU the Study Group 5 develops recommendations and standards on electromagnetic compatibility, lightning protection and environmental issues including energy efficiency, clean energy, climate change, circular economy, e-waste, and human exposure to RF EMF due to ICT technologies. ITU the Study Group 5 recommendations on human exposure to EMF are joined in the K-series of recommendations. The K-series recommendations covering RF EMF are given in Table 3.10. They cover all aspects of RF EMF, like exposure of public, occupational exposure, test methods to assess the exposure.

For other telecommunication areas additional ITU RF EMF recommendations may exist like ITU-R BS.1698 Evaluating fields from terrestrial broadcasting transmitting systems operating in any frequency band for assessing exposure to Non-ionizing radiation for radio transmission.

| Number | Name | Last updated |
|---|---|---|
| K.52 | Guidance on complying with limits for human exposure to electromagnetic fields | 01.2018 |
| K.61 | Guidance on measurement and numerical prediction of electromagnetic fields for compliance with human exposure limits for telecommunication installations | 01.2018 |
| K.70 | Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations | 12.2020 |
| K.83 | Monitoring of electromagnetic field levels | 06.2020 |
| K.91 | Guidance for assessment, evaluation and monitoring of human exposure to radio frequency electromagnetic fields | 12.2020 |
| K.100 | Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service | 07.2019 |
| K.113 | Generation of radiofrequency electromagnetic field level maps | 11.2015 |
| K.121 | Guidance on the environmental management for compliance with radio frequency EMF limits for radiocommunication base stations | 12.2016 |
| K.122 | Exposure levels in close proximity of radiocommunication antennas | 12.2016 |
| K.145 | Assessment and management of compliance with radio frequency electromagnetic field exposure limits for workers at radiocommunication sites and facilities | 12.2020 |
| K.Sup 1 | ITU-T K.91 - Guide on electromagnetic fields and health | 05.2020 |
| K.Sup 4 | ITU-T K.91 - Electromagnetic field considerations in smart sustainable cities | 09.2018 |
| K.Sup 9 | 5G technology and human exposure to radiofrequency electromagnetic fields | 05.2019 |
| K.Sup 13 | Radiofrequency electromagnetic field (RF-EMF) exposure levels from mobile and portable devices during different conditions of use | 05.2018 |
| K.Sup 14 | The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment | 09.2019 |
| K.Sup 16 | Electromagnetic field compliance assessments for 5G wireless networks | 05.2019 |
| K.Sup 19 | Electromagnetic field (EMF) strength inside underground railway trains | 09.2019 |
| K.Sup 20 | ITU-T K.91 - Supplement on radiofrequency exposure evaluation around underground base stations | 05.2020 |

Table 3.10: List of ITU K-series recommendations covering RF EMF

The aim of **ITU-T K.52 Guidance on complying with limits for human exposure to EMF** is to help with compliance of telecommunication installations, such as base stations, and wireless communication devices, such as mobile handsets or other radiating devices used next to the ear or close to the body, with safety limits for human exposure to RF EMF. The recommendation does not provide safety limits, but it provides techniques and procedures for assessing the exposure of public and workers. The recommendation suggests three possible compliance categories for emitter installations:

- inherently compliant: inherently compliant low power installations emit RF EMF that comply with relevant exposure limits a few centimeters away from the source,
- normally compliant: normally compliant installations emit RF EMF that comply with relevant exposure limits at the accessible locations under normal conditions. The RF EMF exposure close to the emitters can exceed relevant exposure limits, therefore precaution is needed in case of close exposure (maintenance workers on towers, construction workers on roofs),
- provisionally compliant: provisionally compliant installations require individual assessment to determine compliance.

The **ITU-T K.61 Guidance on measurement and numerical prediction of EMF for compliance with human exposure limits for telecommunication installations** defines tools, methods, and procedures for measurements as well as numerical calculations that are suitable to determine the levels of the RF EMF emitted by telecommunication installations. The requirements for measurements are like requirements given in international standards dealing with RF EMF measurements (IEC 2017, CENELEC 2008), but international standards are more precise and detailed than the recommendation.

The **ITU-T K.70 Mitigation techniques to limit human exposure to EMFs in the vicinity of radiocommunication stations** provides guidance for telecommunication operators on mitigation techniques for limiting the RF EMF exposure in the vicinity of transmitting antennas. Different mitigation methods and their effectiveness are provided which allow minimization of the RF EMF exposure, for example decreasing down tilt, increasing antenna gain, changing vertical or horizontal radiation pattern.

The **ITU-T K.83 Monitoring of EMF levels** recommendation is covering the aspects of RF EMF monitoring, which is used in some countries mainly because of the public concerns. RF EMF monitoring requires long-term measurements, which are usually performed by automated measurement systems. The recommendation specifies the methods as well as the necessary characteristics of the measurement system used for long-term measurements of RF EMF. At the end of the recommendation the links are given to monitoring campaigns in different countries around the globe including the presentation of monitoring systems implemented in Serbia, Republic of Korea, Panama, Uruguay, Colombia, France, Greece, Italy, and Spain.

The **ITU-T K.91 Guidance for assessment, evaluation, and monitoring of human exposure to RF EMF** provides guidance on how to assess and monitor public exposure to RF EMF emitted ty radiocommunication installations. The recommendation does not cover only fixed installations but also devices used near the human body like mobile phones, where SAR is used to determine the compliance of the exposure and vehicle mounted antennas. The recommendation provides step by step guidance for the compliance check. Especially the part covering exposure assessment methods is comprehensive, covering measurement and calculation methods to determine electric and magnetic field in free space as well as SAR values in human body.

The **ITU-T K.100 Measurement of RF EMF to determine compliance with human exposure limits when a base station is put into service** covers the measurement techniques and procedures to assess compliance of the RF EMF emissions of new base stations after they are put into service. Different assessment methods are proposed depending on the technical characteristics of the equipment under test as well as the exposure conditions. The recommendation emphasis that estimating highest exposure using actual transmitted power avoids the unrealistic over-estimation of other approaches like using rated or maximum transmitted power. Measurement procedures are given for different generations of base stations, in Appendix V the reasoning for reduction of averaging times for measurements of base stations is given, as it is demonstrated that reduction of averaging time has minimal effect on the final value of the fields.

The **ITU-T K.113 Generation of RF EMF level maps** describes methods and tools for the development of map of the RF EMF exposure on a large-scale territories like cities or countries either by measurements (drive test measurements) or by calculations. RF EMF maps have proven to be a good communication tool, as visible information about the RF EMF exposure in the environment helps provide simple and understandable information to general population about their exposure to RF EMF.

The **ITU-T K.121 Guidance on the environmental management for compliance with RF EMF limits for base stations** provides general guidance how to manage the compliance of mobile base stations with RF EMF exposure standards. Management of compliance must consider not only all national, regional or local specifics regarding the exposure standards and environmental protection legislation but also variety of installations, constant development of radiocommunication technologies and growth of their use. The recommendation proposes that mobile network operators manage compliance with relevant regulations for RF EMF exposure, but it also recommends that national authorities provide enough information to municipal authorities, so they can understand national compliance assessment methods. The recommendation advises against adopting stricter municipal RF EMF policies than national policies. Compliance assessment must consider all relevant data about the source and about the location. During design stage compliance can be assessed with numerical calculations or based on similar mobile base station, during the operation the compliance is usually assessed by measurements.

The **ITU-T K.122 Exposure levels in close proximity of radiocommunication antennas** is intended for workers safety. The values of the RF EMF for typical configurations of transmitting antennas are given which provides general information about expected exposure of workers near the broadcasting and radiocommunication antennas.

The **ITU-T K.145 Assessment and management of compliance with RF EMF exposure limits for workers at radiocommunication sites and facilities** is also intended for workers safety. Based on their working tasks the recommendation splits workers in different groups and provides basic protective measures and risk assessment procedures that shall be implemented to guarantee safe working environment.

The **ITU-T K.Sup 1 ITU-T K.91 - Guide on EMF and health** provides answers to the most common questions from the public about the RF EMF health effects. The information can be useful as an education resources suitable for all communities, stakeholders, and governments. The supplement supports the World Health Organization (WHO) position regarding the RF EMF health effects. It includes the introduction to RF EMF, the overview of RF EMF (where positions of WHO, ICNIRP and IEEE are given), current safety limits and standards from ICNIRP, ICES/IEEE, ITU and IEC, explanation how mobile network works as well as FAQ chapters about mobile phones, base stations, and exposure limits. The supplement ends with the links, where additional resources about RF EMF and health are available.

The **ITU-T K.Sup 4 ITU-T K.91 - EMF considerations in smart sustainable cities** provides details for RF EMF considerations and guidance on implementation and deployment of wireless networks in smart cities. A special 'Smart sustainability city EMF checklist' is included in the supplement to support wireless network planes and city officials to efficiently deploy wireless networks.

The **ITU-T K.Sup 9 5G technology and human exposure to RF EMF** deals with 5G mobile network. It provides general information about 5G technology as well as new functionalities affecting the RF EMF exposure levels. Supplement summarizes that *"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"*.

The **ITU-T K.Sup 13 RF EMF exposure levels from mobile and portable devices during different conditions of use** gives information to users of various mobile devices such as mobile phones, cordless phones, tablets, phablets and satellite phones about the exposure to RF EMF. Several factors and conditions that determine the exposure of the user to RF EMF are analyzed, such as the power control implemented in mobile phones, services used, distance to base station, hands free use or speaker use, usage in cars, buses, and trains, use by children, pregnant woman, workers with medical devices…

The **ITU-T K.Sup 14 The impact of RF EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment** analyses the influence of the stricter limits for RF EMF exposure than the International Commission for Non-Ionizing Radiation Protection (ICNIRP) or Institute of Electrical and Electronics Engineers (IEEE) guidelines on the future deployment of wireless networks. There are several countries, such as China, India, Poland, Russia, Italy, and Switzerland (and Slovenia – remark by authors) that have significantly stricter limit values for general public exposures. The supplement provides an overview of some of the challenges they will face when deploying 4G or 5G infrastructures and urges to begin a process to harmonize RF EMF standards worldwide. Analysis of the case of Poland showed that stricter limit values could prevent the use of additional frequency bands (700 MHz, 3,5 GHz…), as the cumulative exposure can exceed stricter limit values. Beamforming can be problematic, as it narrows antenna beam and increase the distance, where stricter RF EMF exposure limits are exceeded. Deploying small cells can be hampered. All this will limit the possibility to densify network and limit future 5G deployment. This can prevent growing data traffic demand and the launching of new services on existing mobile networks being addressed.

The **ITU-T K.Sup 16 EMF compliance assessments for 5G wireless networks** provides guidance on the RF EMF compliance assessment for 5G networks. The supplement stresses out the importance of maximum transmitted power when assessing the 5G wireless equipment, as due to time division duplexing, scheduling time and spatial distribution of radiated power due to location of current users and current traffic load the actual maximum transmitted power is significantly lower than rated maximum transmitted power. In the case study for an 8x8 m MIMO antenna the actual maximum transmitted power is 25% of rated maximum transmitted power. The case study shows that for a 200 W rated (50 W actual) transmitted power at 3.5 GHz the ICNIRP reference levels are exceeded up to 9.6 m in front of the antenna and up to 2.2 m below the antenna.

The **ITU-T K.Sup 19 EMF strength inside underground railway trains** gives RF EMF exposure analysis inside the trains when passing tunnels. Due to the proximity of repeaters installed on the walls of the tunnels the RF EMF sources are close to passengers under these conditions. Measurements done in Seoul, Korea on 9 different lines shows that the maximum average value for one line was 2.09 V/m, which represents 4.95% of the ICNIRP reference levels.

The **ITU-T K.Sup 20 ITU-T K.91 - Supplement on RF exposure evaluation around underground base stations** contains the measurements of RF EMF and human exposure due to underground base stations. Underground base stations are base stations mounted in a hole and covered with reinforced plastic cover that allows the transmission of RF EMF. Such base stations are used where there are no suitable places for installation of classic antennas. Their coverage is limited and therefore they are suitable to provide coverage on small areas where a lot of people can be, like tourist and scenic spots.

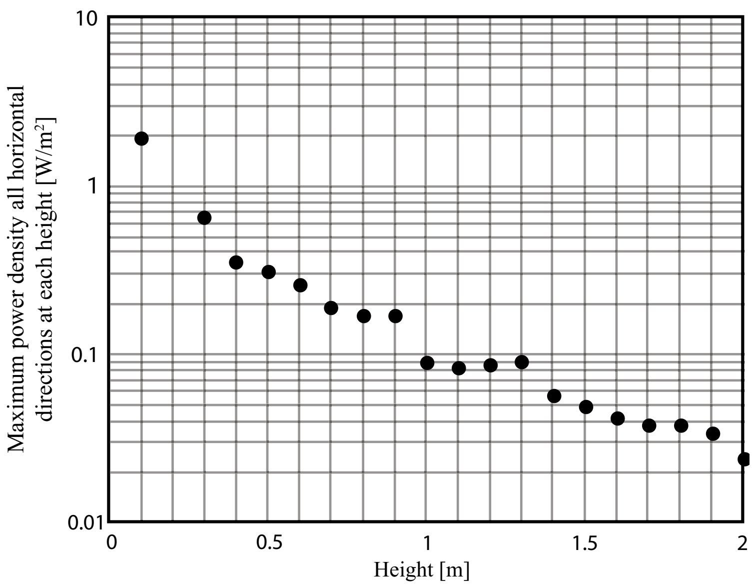


Figure 3.3: Maximum power density in vertical direction above the underground base station with the EIRP of 1 W per one MIMO (MIMO setup :2×2)

## 3.7 International Standards for Non-Ionizing Radiation Protection proposed by the World Health Organization (WHO)

Several national and international organizations have formulated guidelines establishing limits for occupational and residential EMF exposure. The exposure limits for EMF fields developed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) – a non-governmental organization formally recognized by WHO, were developed following reviews of all the peer-reviewed scientific literature, including thermal and non-thermal effects. The standards are based on evaluations of biological effects that have been established to have health consequences. The main conclusion from the WHO reviews is that EMF exposures below the limits recommended in the ICNIRP international guidelines do not appear to have any known consequence on health.

The WHO has compiled a database which includes worldwide standards for countries who have legislation on exposure to electromagnetic fields (www.who.int/emf-peh).

Because disparities in EMF standards around the world has caused increasing public anxiety about EMF exposures from the introduction of new technologies, WHO commenced a process of harmonization of electromagnetic fields (EMF) standards worldwide. With 54 participating countries and 8 international organizations involved in the International EMF Project, it provides a unique opportunity to bring countries together to develop a framework for harmonization of EMF standards and to encourage the development of exposure limits and other control measures that provide the same level of health protection to all people.

The development of International Standards for Non-Ionizing Radiation Protection has been initiated by WHO in 2016 using the example of the IAEA International Ionizing radiation Basic Safety Standards (BSS) developed as a collaborative approach between eight international organizations. The request reflects the fact that WHO Member States are increasingly interested in clear guidance based on harmonized standards and their application within a national framework of protection.

It is intended that the International Standards for Non-Ionizing Radiation Protection will be developed as a collaborative approach to reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of Non-ionizing radiation. The main target audience of the voluntary Standards are policy makers, regulators, and relevant employers. The scope of the proposed work covers the whole NIR spectrum, including EMF, optical radiation, and acoustic ultrasound and infrasound.

Like the IAEA Fundamental Safety Principles, it was decided to underpin this work with another document providing overarching “Fundamental Safety Principles for Protection against Non-Ionizing Radiation” (FSP), which are meant to provide a common safety philosophy across all areas of applications of non-ionizing radiation.

The work is ongoing, and standards will be prepared in a few years.

## 3.8 Overview of the situation in the EU and some countries that have already developed 3G, 4G and 5G networks

As already mentioned, there is no mandatory legislation in the EU regarding the exposure of public to RF EMF. Therefore, legislation in each member state can differ from international guidelines or EU Recommendation (EU, 1999) regarding the EMF exposure of public. If we extend the scope to the world, there are even bigger differences between the countries. Still limit values in most of the countries do follow either ICNIRP guidelines or IEEE standards, however there are some countries with stricter limit values.

Analysis presented in the ITU-T K.Sup 14 (ITU 2019-4) shows that stricter limit values could prevent the use of additional frequency bands (700 MHz, 3.5 GHz), limit the use of beamforming and deployment of small cells.

EMF policy in member states can be divided in three different approaches. In the first group of member states the EU Recommendation has been transposed in binding national legislation. This means that the basic restrictions and reference levels must be applied. Member states in this group are Cyprus, Czech Republic, Estonia, Finland, France, Hungary, Ireland, Malta, Poland, Portugal, Romania, and Spain. Catalonia has RF EMF exposure limits that are 65% of those in the EU Recommendation (44% for power density). In some EU member states (e.g., Germany and Slovakia) the reference levels have become de facto exposure limits.

In the second group of member states, the national limits based on the EU Recommendation or ICNIRP are not binding, there are more lenient limits or there is no regulation. Member states in this group are Austria, Denmark, Latvia, Netherlands, Sweden, and United Kingdom. In the United Kingdom telecommunication companies have signed up to a voluntary code to respect the provisions in the EC Recommendation.

In the third group of member states, there are stricter basic restrictions and/or reference levels based on the precautionary principle or due to public pressure. The limits chosen are sometimes based on the principle 'as low as reasonably achievable without endangering service' (e.g., Bulgaria, Lithuania) or precautionary policy (e.g., Slovenia, Luxembourg, Italy). In other countries, the reasons for limits are unclear or arbitrary (e.g., Greece). In some member states these stricter reference levels are applied as exposure limits that may not be exceeded.

**Belgium:** A national decision on precautionary limits for transmitters between 10 MHz and 10 GHz was declared unconstitutional and regulation left to regional government. Subsequent Flemish and Wallonia legislation limits the electrical field strength per antenna for telecommunication to 3 V/m per antenna and 20.6 V/m to limit for cumulative exposure from multiple antennas in residence areas like homes, schools, rest homes and nurseries. The Brussels Region limits cumulative exposure in residences for frequencies between 100 kHz and 300 GHz form multiple antenna locations to 6 V/m.

**Bulgaria:** Fixed limits for electrical field strength and power density are set. Their percentage of the reference levels in the Recommendation decreases with frequency. It is 2 % for power density at 900 MHz and less than 2% for higher frequencies.

**Croatia:** For public spaces in general, fixed limits for the electric and magnetic fields are applied which are 95% of the reference levels in the EU recommendation (90% for power density). For 'sensitive areas' (homes, offices, schools, playgrounds, kindergartens, maternity wards, hospitals, homes for the elderly and disabled and tourist accommodations), the limits for the electric and magnetic field are 40% of the reference levels in the EU recommendation (16% for power density).

**Greece:** The law on electronic communications sets basic restrictions of 70% of those in the Recommendation and 60% when antenna stations are located closer than 300 meters from the property boundaries of schools, kindergartens, hospitals, or eldercare facilities.

Installation of mobile phone antenna stations is not allowed within the property boundaries of aforementioned facilities. Reference levels calculated from these two basic restrictions are 84% and 77% of the reference levels in the EU Recommendation (70% and 60% for power density).

**Italy:** Under Italian law, reference levels have become de facto exposure limits that may not be exceeded. In contrast with the limits in the Recommendation, these are fixed (not frequency dependent) between 3 MHz and 3 GHz. The exposure limit for magnetic field strength at 900 MHz is 45% of the reference level in the EU Recommendation (22% for power density). In homes, schools, playgrounds, and places where people may stay for longer than 4 hours, an 'attention value' for magnetic field strength applies that is 14% of the reference level in the EU Recommendation at 900 MHz (2% for power density). The 'quality goal' for new installations is identical to the attention value.

**Lithuania:** There are limits for EMF with frequencies between 10 MHz and 300 GHz inside and surrounding residential and public buildings which may not be exceeded and are lower than the reference levels in the EU recommendation. The percentage varies with frequency, but for power density the limit is 10% of the EU reference level at 900 MHz.

**Luxembourg:** Precautionary policy is applied to mobile telephony through a law on classified locations and technical standards. These set a fixed exposure limit for the electrical field strength of 3 V/m per antenna which is 7% of the reference level in the EU recommendation at 900 MHz. The limit for the total number of antennas in one location equals the reference level in the EC Recommendation.

**Slovenia:** For frequencies higher than 10 kHz exposure limits for electric and magnetic field strength of 31% of the reference levels in the EU Recommendation (10% for power density) apply in 'sensitive areas' (homes, schools, hospitals etc.). In all other locations the reference levels in the EC Recommendation are applied as de facto exposure limits that may not be exceeded.

**Switzerland** is often presented as role model for applying the precautionary principle regarding EMF emitted from mobile communications installations. The relevant sources of EMF regulation in Switzerland are the "Ordinance relating Protection from Non-Ionising Radiation" (ONIR), which entered into force on February 1st, 2000, and was slightly adapted in 2008 as well as the 'Implementation Recommendation', adapted in 2013 (technology neutrality). ONIR codifies the EMF exposure limits as recommended by the ICNIRP and the EU recommendation. These limits shall be kept at all places accessible to persons regardless for how long these places are accessible. In addition, lower "installation limit values" are set when an installation provides radio service in or nearby a "place of sensitive use". These places are deemed to be rooms in buildings that are regularly occupied by persons for prolonged periods and children's playgrounds designated in spatial planning legislation. In these places the "installation limit value" which is 10-times stricter than ICNIRP exposure limits needs to be kept.

As can be seen from Figure 3.4, most of the European countries have the reference levels from ICNIRP guidelines and 1999/519/EC recommendation, however there are some countries with stricter limits, for example Bulgaria, Croatia, Italy, Latvia, Slovenia, and Switzerland. But studies have shown that legislation with more restrictive exposure limits do not mean better protection of public.

The measurements of RF EMF in Poland (at the time when stricter limits were still in place in Poland) were compared to measurements in France (where ICNIRP limits are used) and it was found that the average exposure to RF EMF is very similar (ITU 2019-4).

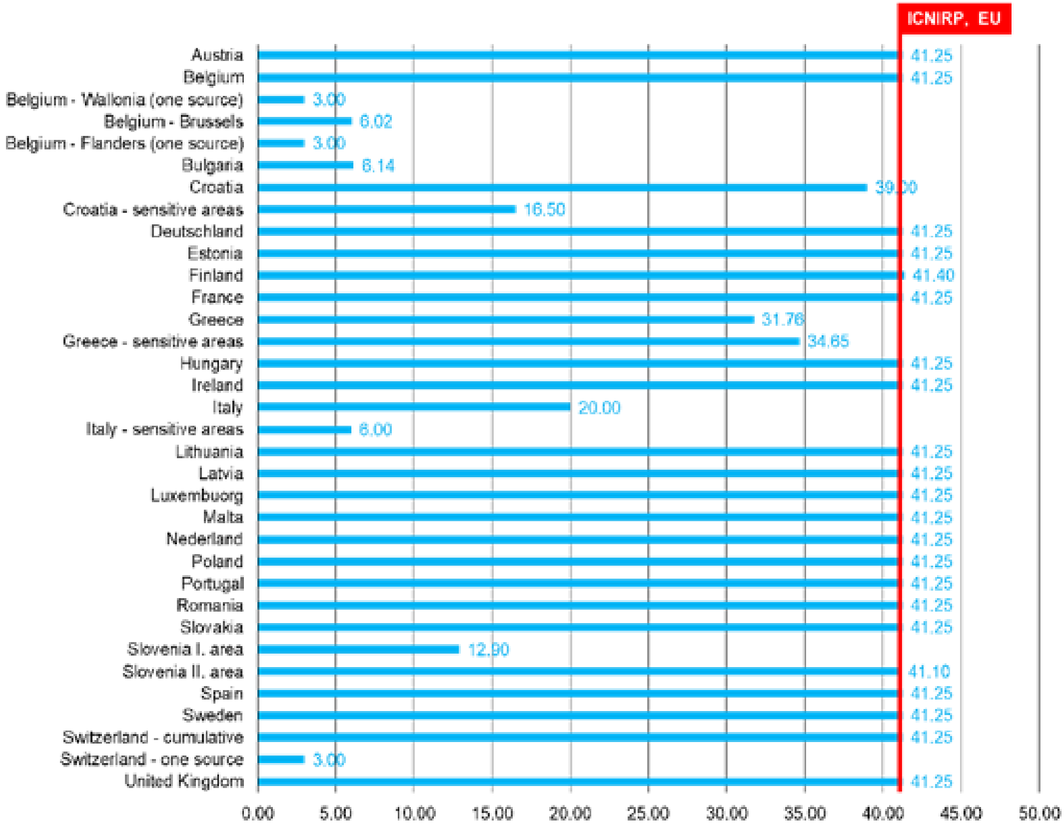


Figure 3.4: Comparison of reference levels for electric fields at 900 MHz in different European countries. Most have the reference levels from ICNIRP guidelines and 1999/519/EC recommendation.

However, stricter limits do pose limitations for new installations. In Slovenia there is legislation with stricter exposure limits. In general, for so called II. area of protection, the limit values are very similar to ICNIRP guidelines and 1999/519/EC recommendation. However, for the I. area of protection, the limit values are 10 times stricter (for power density). In I. area of protection is valid for areas where prolonged exposure exists (living areas, areas of schools, kindergartens and other similar institutions, hospitals and other similar institutions, recreation areas).

For a typical 2G – 4G mobile base station using 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, and 2600 MHz frequency bands, mounted on a 20 m tower, the compliance zone for I. area of protection (yellow) and for II. area of protection (red) is shown in Figure 3.5. We can see that the compliance zone is quite larger for the I. area of protection, as it extends up to 33 m from the antennas of the base station, whereas for the II. area of protection, it extends to about 9.5 m from antennas.

For current generations of mobile technologies lower limit values do present problems when placing such installations, but they are manageable. However, due to beamforming and higher maximum gains of 5G networks, this will become much more difficult. As can be seen from Figure 3.6 the compliance zone for the I. area of protection is up to 68m from the antennas of the base station, whereas for the II. area of protection, it extends to about 22m from antennas. This however is more problematic, as in urban areas such large compliance zones can pose severe limitations when placing new 5G antennas, especially considering that compliance zone extends to more than 10m below the antennas, whereas for the II. area of protection it extends only 2.5m below the antennas. This means that a building with the height of 10m at the distance of 50m of base station extends in the compliance zone for the I. area of protection.

Figure 3.5: Compliance zone for a typical 3G – 4G base station according to Slovenian legislation: yellow for I. area of protection, red, for II. area of protection. Limit values for II. area of protection is similar to ICNIRP guidelines and 1999/519/EC recommendation, for the I. area of protection, the limit values are 10 times lower (for power density).

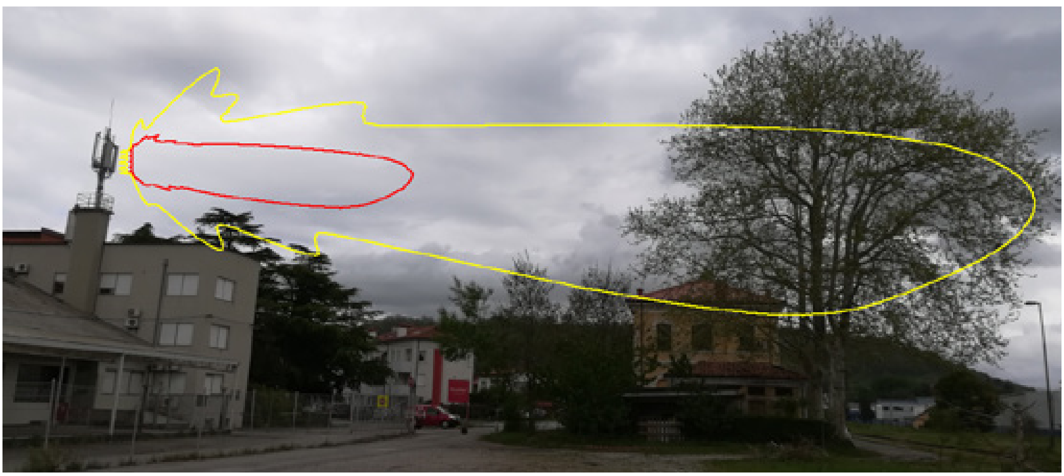

Figure 3.6: Compliance zone for a typical 3G – 5G base station according to Slovenian legislation: yellow for I. area of protection, red, for II. area of protection. Limit values for II. area of protection is similar to ICNIRP guidelines and 1999/519/EC recommendation, for the I. area of protection, the limit values are 10 times lower (for power density).

Situation becomes even worse if the antennas do have higher down tilts – the main beam is oriented more towards the ground. For the base station with the down tilt of 10°, the compliance zone for the I. area of protection reach ground and therefore such base station is non-compliant, for the II. area of protection, it extends to about 21m from antennas and 5.5m below the antennas, meaning that there is still 14.5m height margin to the ground.

Analysis for micro cells (Jevremovic 2020) showed that for a typical indoor base station the compliance zone according to USA legislation is 18.15 cm, according to Slovenian legislation it is 56.5 cm and according to Russian federation legislation it is 175.5 cm.

Figure 3.7: Compliance zone for a typical 3G – 5G base station with a 10°downtilt according to Slovenian legislation: yellow for I. area of protection, red, for II. area of protection. Limit values for II. area of protection is similar to ICNIRP guidelines and 1999/519/EC recommendation, for the I. area of protection, the limit values are 10 times lower (for power density).

As such differences in EMF legislation around the world causes more questions than answers to the public regarding the EMF exposures and associated risks on one hand and problems with implementation of new technologies, currently there is process to support harmonization of the EMF legislation around the world lead by WHO.

## 3.9 Conclusions

The international recommendations and standards set out in this Chapter do not apply to specific technologies. The exposure limit values shown in the different sections of this Chapter refer to the frequency bands that make up the spectrum of RF EMF. The maximum covered frequency is 300 GHz which includes the frequencies used by the 5G technology. The question arises in the public whether the higher frequencies (above 20 GHz - millimeter waves) covered by 5G technology automatically mean greater or more intense exposure to RF EMF. But the 5G frequency band is not new and has been used for a long time, for example in airport security scanners, car speed radars, microwave communication links, etc. With the addition of 5G equipment to the existing telecommunication networks, a small increase in the total exposure of RF EMF can be expected, but the total exposure is expected to remain low and far below the limit levels of the recommendations of the international standardization bodies.

The introduction of new technology that uses existing radio frequencies does not change the characteristics of the frequencies. This means that the recommendations of international organizations covering frequencies up to 300 GHz remain in force. It will be explained in the 4th chapter of this study that 5G technology has significant improvements in terms of wasted energy because the standard provides for sending a drastically smaller number of control signals for the radio interface. This allows components to be disconnected from the base station when there is little or no communication and enters one of the standby modes. As a result, the total consumption of base stations in 5G technology, and thus the radiated energy is like that of 4G-LTE technology, but with a significantly higher flow of information. In addition, with the new protocols for the formation of beamforming incorporated in 5G technology enables dynamic, directional shaping of base station antenna radiation that is necessary in environments where there are large numbers of users and densely spaced base stations. Innovations in beamforming techniques in this technology result in additional focusing of the signal in a concentrated beam directly aimed at the device, preventing it from scattering in all directions at once. This significantly improves the radiation efficiency of the antennas, i.e., the radiated power is reduced to a minimum level that is needed to ensure the signal flow to the users. Measurements performed in several countries show that the level of reception energy from the base stations of 5G technology is many times lower than the limit values in the standards and comparable to the RF EMF exposure from existing technologies. The conclusion from the measured values is that by increasing the number of connected devices, and thus the radiated power of the base station, using smart techniques for beamforming avoids a significant increase in RF EMF exposure in one beam. Therefore, there is no reason to believe that new effects on human health can be expected as a result of the new 5G technology, as long as the limit values and reference levels defined in international guidelines and standards are respected. International organizations have been constantly pointing out the need for extended research on the effects of EMF in general (SCENIHR 2015; ICNIRP 2020b). With the start of implementation of yet another generation of mobile communication systems (5G), additional research is needed on the effects of exposure to RF RMF, especially for frequencies around 26 GHz at levels below the ICNIRP limits. Fields with these frequencies do not penetrate the body any further than the skin and research should therefore focus on effects that originate in the skin, including effects on components of the immune system and nervous system that are located in the skin. Scenario studies for the future exposure of individuals as a result of wireless communications systems (3G, 4G and 5G) are also recommended (HCN 2020).

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# Chapter 4

## 4 Development of mobile technologies

The chapter provides an overview of the legacy wireless and mobile systems such as 2G, 3G and 4G, with respect to radio interface and physical layer design as defined in 3GPP standardization documents. It also describes the 5G technical specification and standardization specifics elaborate on the comparison and relation between 5G and legacy system specifics.

## 4.1 Global System for Mobile Communications (GSM)

The Global System for Mobile Communications (GSM) is the first digital mobile communication system. It is a standard developed by the European Telecommunications Standards Institute (ETSI) to describe the protocols for second-generation (2G) digital cellular networks used by mobile devices. GSM/2G mobile systems were developed as a replacement for first generation (1G) analog cellular networks. The GSM standard primarily focuses on digital, circuit-switched network, which is optimized for full duplex voice telephony. However, GSM evolved over time to include IP-based data communications, by its extensions, General Packet Radio Service (GPRS), and Enhanced Data Rates for GSM Evolution (EDGE).

A GSM network is composed of several system elements. Figure 4.1 depicts the layout of a generic GSM network (3GPP TS 23.002 1999). The GSM network can be divided into three broad parts. The *Mobile Station (MS)* is related to the subscriber. The *Base Station Subsystem* controls the radio link with the Mobile Station. The *Network Subsystem*, the main part of which is the Mobile services Switching Center (MSC), performs the switching of calls between the mobile users, and between mobile and fixed network users. The MSC also handles the mobility management operations. The Operations and Maintenance Center oversees the proper operation and setup of the network.

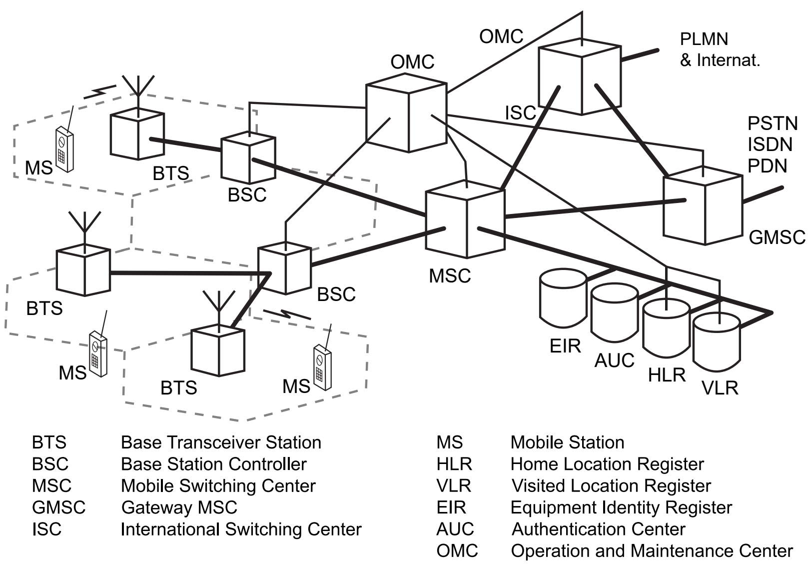



Figure 4.1: GSM system architecture (3GPP TS 23.002 1999)

The **mobile station** consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into another GSM terminal, the user can receive calls at that terminal, make calls from that terminal, and receive other subscribed services. The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity (IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information. The IMEI and the IMSI are independent, thereby allowing personal mobility.

The **Base Station Subsystem** is composed of two parts, the Base Transceiver Station (BTS) and the Base Station Controller (BSC). It is also known as the GSM EDGE Radio Access Network (GERAN). These communicate across the standardized Abis interface, allowing (as in the rest of the system) operation between components made by different suppliers. The Base Transceiver Station houses the radio transceivers that define a cell and handles the radio-link protocols with the Mobile Station. The Base Station Controller manages the radio resources for one or more BTSs. It handles radio-channel setup, frequency hopping, and handovers. The BSC is the connection between the mobile station and the Mobile service Switching Center (MSC).

The central component of the **Network Subsystem** is the Mobile services Switching Center (MSC). It acts like a normal switching node of the PSTN or ISDN, and additionally provides all the functionality needed to handle a mobile subscriber, such as registration, authentication, location updating, handovers, and call routing to a roaming subscriber. These services are provided in conjunction with several functional entities, which together form the Network Subsystem. The MSC provides the connection to the fixed networks (such as the PSTN or ISDN). Signaling between functional entities in the Network Subsystem uses Signaling System Number 7 (SS7), used for trunk signaling in ISDN and widely used in current public circuit-switched networks. The Home Location Register (HLR) and Visitor Location Register (VLR), together with the MSC, provide the call-routing and roaming capabilities of GSM. The HLR contains all the administrative information of each subscriber registered in the corresponding GSM network, along with the current location of the mobile. The location of the mobile is typically in the form of the signaling address of the VLR associated with the mobile station. The actual routing procedure is not of interest in this study. There is logically one HLR per GSM network, although it may be implemented as a distributed database. The Visitor Location Register (VLR) contains selected administrative information from the HLR, necessary for call control and provision of the subscribed services, for each mobile currently located in the geographical area controlled by the VLR. Although each functional entity can be implemented as an independent unit, all manufacturers of switching equipment to date implement the VLR together with the MSC, so that the geographical area controlled by the MSC corresponds to that controlled by the VLR, thus simplifying the signaling required. The other two registers are used for authentication and security purposes. The Equipment Identity Register (EIR) is a database that contains a list of all valid mobile equipment on the network, where each mobile station is identified by its International Mobile Equipment Identity (IMEI). The Authentication Center (AuC) is a protected database that stores a copy of the secret key stored in each subscriber's SIM card, which is used for authentication and encryption over the radio channel.

### 4.1.1 GSM radio interface

All specific subsystems in GSM are interconnected between each other with standardized interfaces. This study primarily focuses on the radio interface, denoted as the Um interface, as the main source of EMF.

In GSM, the **Um interface** uses a hybrid access method based on time and frequency division, i.e., TDMA/FDMA (3GPP TS 45.001 2000). The time and frequency division/duplexing are organized into several layers. First, the Up Link and Down Link directions are spited in two separate spectrum bands of 25 MHz. Each 25 MHz band is divided into 200 KHz of smaller sub-bands, each carry one RF carrier, equating to 125 carriers per 25 MHz band. As one carrier is used as guard channel between GSM and other coexisting technologies in the adjacent frequency bands, only 124 carriers are unutilized for the GSM communication. Each GSM carrier is divided in a time-based frame structure of 8 slots. Every slot is allocated to a specific user. In GSM every slot is denoted as a physical channel. The TDMA frame has an approximate duration of 4.615 ms, resulting in a slot/channel duration of approximately 0.577 ms. Figure 4.2 provides a visual representation of the high-level radio interface organization and its TDMA/FDMA multiplexing approach.

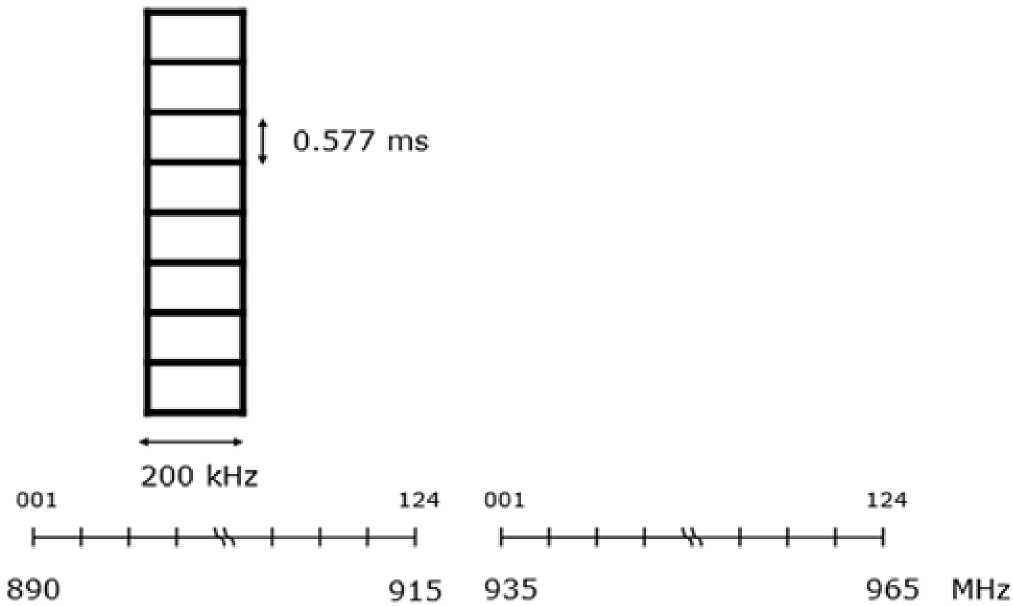



Figure 4.2: GSM Um interface organization (GSM 900 band)

The GSM frame structure (3GPP TS 45.005 2000) is designated as hyper frame, super frame, multifare and frame. The minimum unit being frame (or TDMA frame) which is made of 8 time slots. One GSM hyper frame is composed of 2048 super frames. Each GSM super frame is composed of specific number of multigrades, either 26 or 51 depending on the type of traffic, user, or control. Each GSM multifare is composed of frames, either 51 or 26 based on multifare type. Each frame is composed of 8 time slots. Hence there will be total of 2715648 TDMA frames available in GSM and the same cycle is repeated every 3.5 hours, Figure 4.3.

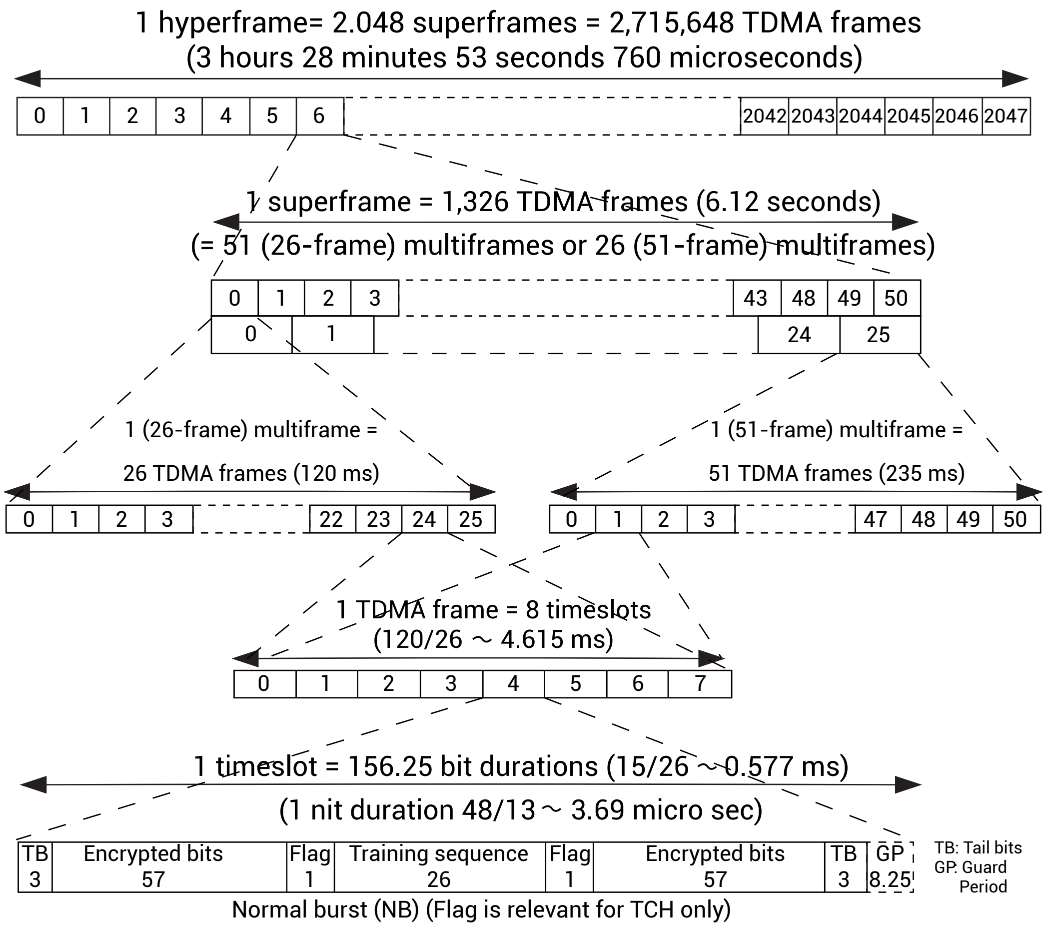


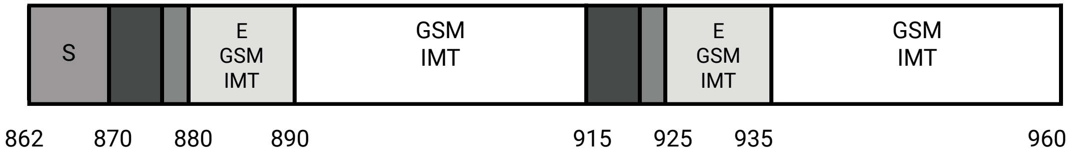

Figure 4.3: GSM Um interface frame organization

The GSM physical layer, that is used as the primary facilitator of the wireless transmissions, is based on several 3GPP Technical Specifications. The physical layer is specified in (3GPP TS 45.001 2000) and the logical channels in (3GPP TS 45.002 2000). The channel coding is specified in (3GPP TS 45.003, 2000) and the modulation is specified in (3GPP TS 45.004 2000). GSM utilizes a single carrier transmission based on the Gussian Minimum Shift Keying (GMSK). The same physical layer design is used in GPRS, whereas EDGE incorporates a modified physical layer. On top of GMSK, EDGE also incorporates 8PSK as a more efficient modulation, that provides improved data rates. The RF facet of GSM's physical layer is organized in several distinct spectrum bands, Table 4.1 (Agency for Electronic Communications 2021).

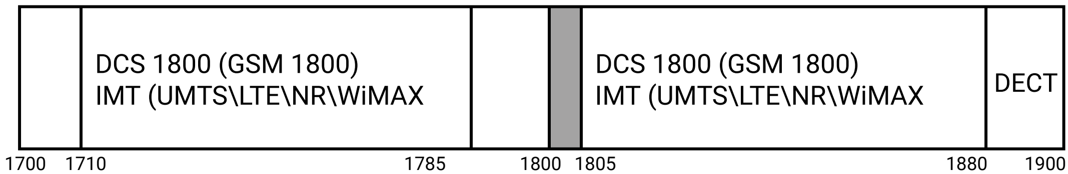
| | GSM 900 | GSM 1800 | GSM 1900 |
|---|---|---|---|
| Uplink | 890 – 915 MHz | 1710 – 1785 MHz | 1850 – 1910 MHz |
| Downlink | 935 – 960 MHz | 1805 – 1880 MHz | 1930 – 1990 MHz |

Table 4.1: GSM generic spectrum allocation

In N. Macedonia there are several allocated bands that can be used for GSM and are specific to the deployment type of the system. Specifically in N. Macedonia GSM can be deployed in the GSM 900 and GSM 1800 bands, based on the syntax from Table 4.1. The spectrum allocation for both bands is depicted in Figure 4.4 (Agency for Electronic Communications 2021).




a)




b)

Figure 4.4: GSM spectrum allocation in N. Macedonia:
a) 900 MHz band b) 1800 MHz band (Agency for Electronic Communications 2021)

## 4.2 Universal Mobile Telecommunications System (UMTS)

UMTS is an umbrella term for the third generation (3G) radio technologies, as a successor of 2G. UMTS is developed and maintained by the 3GPP (3rd Generation Partnership Project), providing new system design, offering several features. These features include support for circuit and packet switching, support for both voice and data applications, support for seamless mobility for both voice and data, improvement in spectral efficiency, legacy support for GSM/GPRS systems, increase in voice quality, low round trip packet delay etc. UMTS incorporates two evolutions of the technology, i.e., High Speed Packet Access (HSPA) and High-Speed Packet Access plus (HSPA+), that primarily foster significant improvements in terms of the system capacity and spectral efficiency and QoS support.

A UMTS network is composed of several system elements. UMTS specifies a complete network system, which includes the radio access network (UMTS Terrestrial Radio Access Network, or UTRAN), the core network (CN) and the user equipment (UE) cards. The UTRAN controls the radio link with the UE. The Core network is the main part that performs the switching of calls between the mobile users and between mobile and fixed network users as well as the data packet routing. The UE represents the mobile equipment, i.e., the terminal. Figure 4.5 depicts the layout of a UMTS system architecture (3GPP TS 23.002 1999).

The **User Equipment,** similarly, to the MS in GSM, consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into another UMTS terminal, the user is able to receive calls at that terminal, make calls from that terminal, and receive other subscribed services. The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity

(IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information. The IMEI and the IMSI are independent, thereby allowing personal mobility.

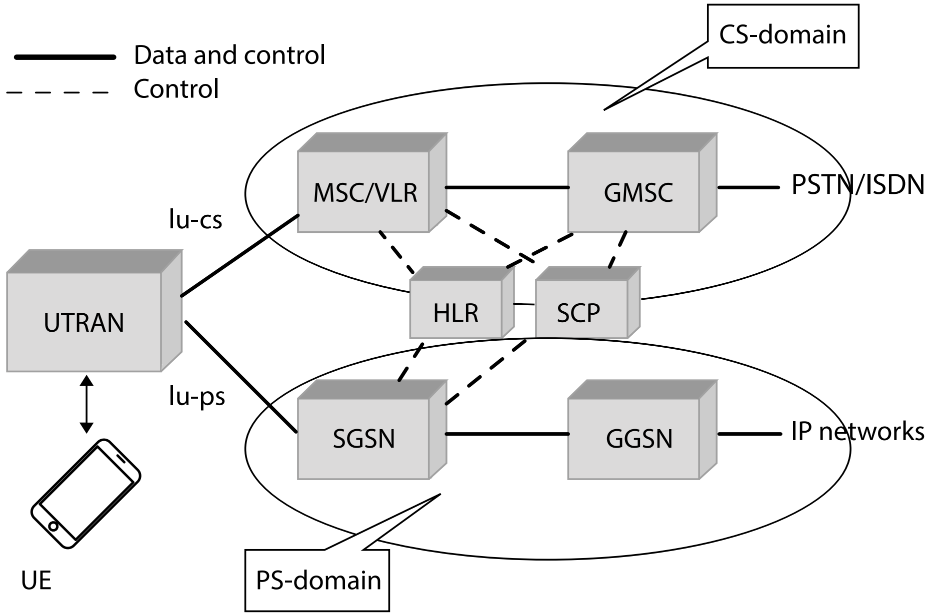



Figure 4.5: UMTS system architecture

The **UTRAN** is composed of two parts, the NodeB (i.e., the base station) and the Radio Network Controller (RNC). These communicate across the standardized Iub interface, allowing (as in the rest of the system) operation between components made by different suppliers. The NodeB houses the radio transceivers that define a cell and handles the radio-link protocols with the User Equipment. The Radio Network Controller manages the radio resources for one or more NodeBs. It handles radio-channel setup, and handovers. The RNC is the connection between the mobile station and the Core network.

The **Core Network** is composed of circuit switched and packet switched functional modules. For the Circuit switched (CS) operations, the CN incorporates the MSC and GMSC along with database modules such as VLR, HLR, etc. The GMSC node relates to PSTN/ISDN in the CS case and is used as a gateway between the UMTS network, and other CS networks. For the packet switched (PS) operations, the CN incorporates the SGSN and GGSN. The SGSN is responsible for the IP-based traffic management in the network. The GGSN acts as a gateway between the UMTS network and the Packet data Network (PDN) for the PS case.

### 4.2.1 UMTS radio interface

All specific subsystems in UMTS are interconnected between each other with standardized interfaces. This study primarily focuses on the radio interface, denoted as the Uu interface, as the main source of EMF in UMTS networks.

Compared to GSM's Um interface, UMTS's Uu interfaces introduces a completely novel design with respect to the signal waveforms and multiple access (3GPP TS 25.106 2001). UMTS uses a direct sequence spread spectrum approach, where the signal is artificially expanded with the utilization of PN sequences. The specific direct sequence spread spectrum solution used in UMTS is the so-called Wideband Code Division Multiple Access (W-CDMA) that operates on 5 MHz channel bandwidths. The radio access specifications facilitate both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) variants, and several chip rates are provided for in the TDD option, allowing UTRAN technology to operate in a wide range of bands and co-exist with other radio access technologies. Because of the W-CDMA approach, UMTS is a single frequency, network, where all users per cell and all cells operate on the same frequency. The orthogonalization between cell sites and users, is performed by the utilization of channelization and scrambling codes. The chip rate of the codes, in UMTS is fixed at 3.84 Mcps. Table 4.2 presents the code specification used in UMTS.

| | Channelization codes | Scrambling codes |
|---|---|---|
| Length | UL: 4-256 chips (1.0-66.7 μs)<br>DL: 512 chips | UL: (1) 10 ms = 38400 chips or<br>(2) 66.7 μs = 256 chips.<br>DL: 10 ms = 38400 chips |
| Number of codes | Depended on the current design and spreading factor | UL: several millions<br>DL: 512 |
| Code family | OVSF | Long 10 ms codes: Gold codes<br>Short codes: Extended S(2) code set |
| Spread spectrum effect | Yes | No |
| | Yes | |

Table 4.2: UMTS code specification

In UMTS the Physical transmission is organized in Radio Frames and Slots. The slots do not define physical channels but are used for periodic control. Each Radio Frame is consisted of 15 slots and has a duration of 10 ms, Figure 4.6, (3GPP TS 25.106 2001).

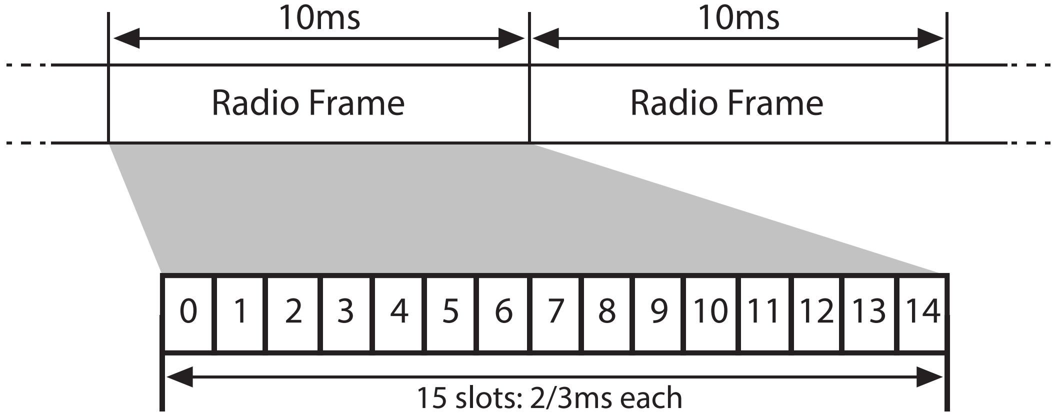



Figure 4.6: Radio frame format in UMTS

The UMTS physical layer that is used as the primary facilitator of the wireless transmissions, is based on several 3GPP Technical Specifications. The physical layer is specified in (3GPP TS 25.101 2001) for TDD and (3GPP TS 25.102 2001) for FDD. As discussed, UMTS utilizes a single carrier transmission based on W-CDMA. The same physical layer design is used in HSPA and HSPA+, with modifications that are primarily observed on the MAC layer. However, HSPA and HSPA+ also incorporates multiple antenna transceiver designs and higher order modulations that significantly improve the system's capacity. Specifically, UMTS utilizes QPSK as the core modulation for the radio transmissions, whereas HSPA/HSPA+ incorporate 16-QAM and 64-QAM modulations, in order to provide higher spectral efficiencies. Moreover, the multiple antenna design in HSPA/HSPA+ was initially designed for 2x2 antenna, systems. However, later designs incorporate higher number of antennas, e.g., 4x4. Also, HSPA+ incorporates the carrier aggregation concept, where the system can aggregate up to 4 x 5 MHz UMTS channels for improved system capacity. The RF facet of UMTS's physical layer is organized in several distinct spectrum bands, Table 4.3.

| | | Band II | Band III | Band IV | Band V | Band VI |
|---|---|---|---|---|---|---|
| Uplink | 1922.4 – 1977.6 MHz | 1852.4 – 1907.6 MHz | 1712.4 – 1782.6 MHz | 1712.4 – 1752.6 MHz | 826.4 – 846.6 MHz | 832.4 – 837.6 MHz |
| Downlink | 2112.4 – 2167.6 MHz | 1932.4 – 1987.6 MHz | 1807.4 – 1877.6 MHz | 2112.4 – 2152.6 MHz | 871.4 – 891.6 MHz | 877.4 – 882.6 MHz |

Table 4.3: UMTS generic spectrum allocation

In N. Macedonia there are several allocated bands that can be used for UMTS and are specific to the deployment type of the system (Agency for Electronic Communications 2021). Specifically in N. Macedonia UMTS can be deployed in the Band I and Band III, based on the syntax from Table 4.3. The spectrum allocation for the bands is depicted in Figure 4.7.

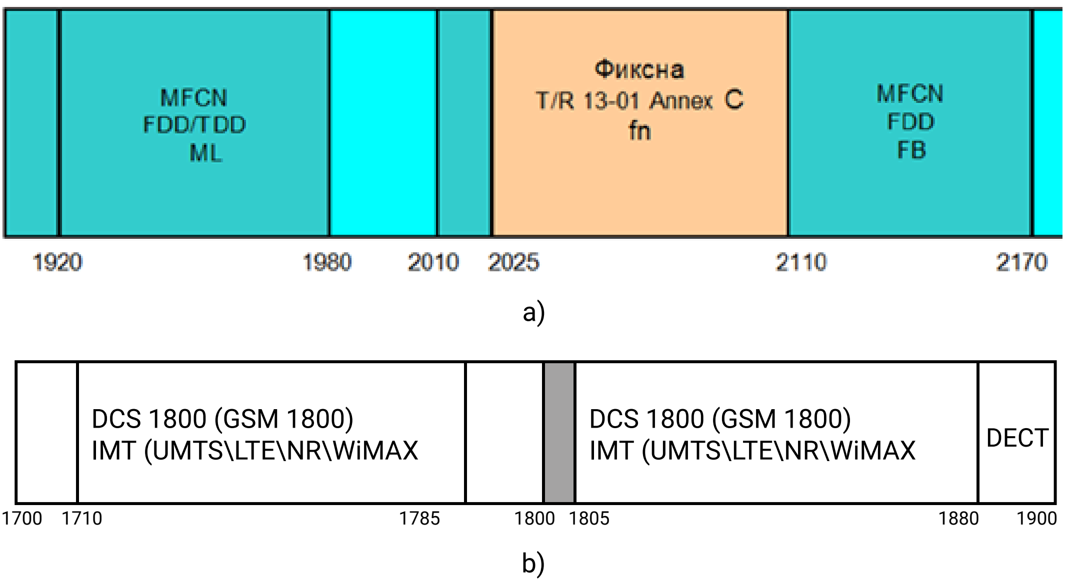



Figure 4.7: UMTS spectrum allocation in N. Macedonia:
a) Band I b) Band III (Agency for Electronic Communications 2021)

## 4.3 Long Term Evolution (LTE)

LTE (Long Term Evolution) is the name given to development of a new generation high performance cellular mobile communication systems. It is deemed as the last step toward the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile telephone networks. While the former generation of mobile telecommunication networks are collectively known as 2G or 3G, LTE is marketed as 4G, although the 4G ITU requirements are fulfilled by its evolution, i.e., LTE-Advanced.

The LTE standard has been developed by 3GPP as an extension of UMTS (based on 3GPP standard) and 1xEV-DO (base on 3GPP2 standard) technologies. LTE is mainly designed for high-speed data applications both in the uplink and downlink. LTE offers the possibility of supporting voice over LTE (VoLTE) as the first packet switched voice service in mobile systems. Based on the specific 3GPP standards for LTE, the technology provides several improvements compared to legacy 2G and 3G systems: i) Reduced cost per bit; ii) Increased service provisioning; iii) Flexibility of use of existing and new frequency bands; iv) Simplified architecture; v) Improved energy efficiency.

System Architecture Evolution (SAE) is a new network architecture designed to simplify LTE networks and establish a flat architecture like other IP based communications networks (3GPP TS 23.882 2007). SAE uses an eNB and Access Gateway (aGW) and removes the RNC and SGSN from the equivalent 3G network architecture to create a simpler mobile network. This allows the network to be built with an "All-IP" design. SAE fosters full inter-working with other related wireless non-3GPP technology (WiMAX, WLAN, etc.). It can manage and permit the non-3GPP technologies to interface directly with the network and be managed from within the same network. LTE system architecture (i.e., SAE) is consisted of three major building blocks, the Evolved-UTRAN (E-UTRAN), Evolved Packet Core (EPC), and the IMS/Internet subsystem, Figure 4.8.

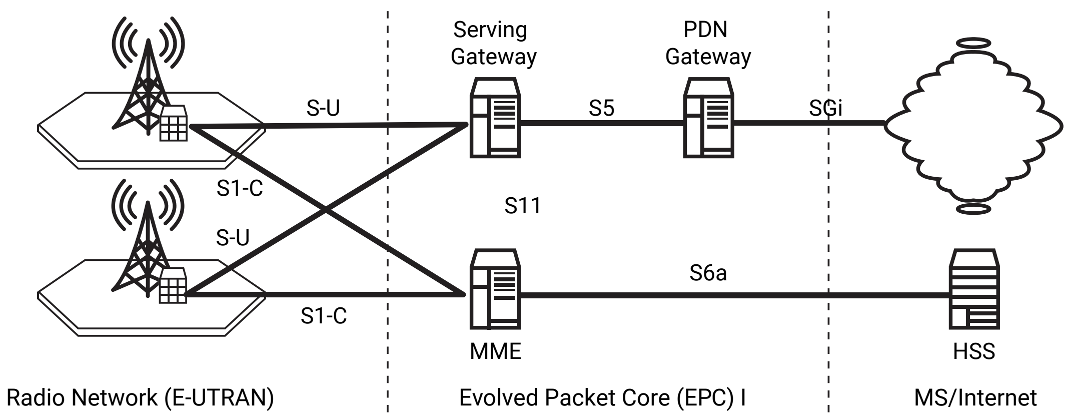



Figure 4.8: LTE SAE (System Architecture Evolution)

The **E-UTRAN** is composed the eNodeB (i.e., the base station). The eNodeB houses the radio transceivers that define a cell and handles the radio-link protocols with the User Equipment. It also manages the radio resources and handles the radio-channel setup. The eNodeB is directly connected to the core network (EPC) via the S1-C interface to the MME, and via the S1-U (or S-U) interface to the Serving Gateway. The eNodeB communicates via the radio interface with the user equipment. The **User Equipment**, similarly, to the UE in 3G, consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into another terminal, the user is able to receive calls at that terminal, make calls from that terminal, and receive other subscribed services. The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity (IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information. The IMEI and the IMSI are independent, thereby allowing personal mobility.

The **Evolved Packet Core** is a key part of SAE. Its main components include the MME, SGW, and PGW. The Mobility Management Entity (MME) is responsible for Idle mode UE (User Equipment) tracking; Paging procedure such as re-transmissions; Bearer activation and deactivation process; SGW selection for a UE at the initial attach; Intra-LTE handover with Core Network node relocation; User authentication with HSS. It is also responsible for the enforcement of UE roaming restrictions. The MME handles the ciphering/integrity protection for NAS signaling and the security key management. It supports lawful interception of signaling, and the control plane function for mobility between LTE and legacy networks with the S3 interface. The S6a interface connects the MME to the HSS for roaming UEs. The main function of the Serving Gateway is routing and forwarding of user data packets. It is also responsible for inter-eNB handovers in the U-plane and provides mobility between LTE and other types of networks, such as between 2G/3G and P-GW. The DL data from the UEs in idle state is terminated at the SGW, and arrival of DL data triggers paging for the UE. The SGW keeps context information such as parameters of the IP bearer and routing information and stores the UE contexts when paging happens. It is also responsible for replicating user traffic for lawful interception. The PDN Gateway (PGW) is the connecting node between UEs and external networks. It is the entry point of data traffic for UEs. To access multiple PDNs, UEs can connect to several PGWs at the same time. The functions of the PGW include: Policy enforcement; Packet filtering; Charging support; Lawful interception; Packet screening. Another important role of the PGW is to provide mobility between 3GPP and non-3GPP networks.

The **IMS/Internet** is the responsible for housing the Internet Multimedia Subsystem, which fosters the operation of the VoLTE service, as well as many other packed data facets. By definition the HSS is not part of the EPC, and it is located in the IMS/Internet block, as an external element.

### 4.3.1 LTE radio interface

All specific subsystems in LTE are interconnected between each other with standardized interfaces. This study primarily focuses on the radio interface, denoted as the X1 or the LTE-Uu interface (3GPP TS 36.201 2007), as the main source of EMF in LTE networks.

Compared to UMTS's Uu interface, LTE's Uu interface introduces a completely novel design with respect to the signal waveforms and multiple access. LTE uses mutli-carrier approach, based on the Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and a Single Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink. The physical layer in LTE allows for scalable bandwidths, ranging from 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, up to 20 MHz. Later evolutions of LTE, i.e., the LTE-A standard, allows carrier aggregation of up to 100 MHz of bandwidth.
In LTE the Physical transmission is organized in Radio Frames, Resource Blocks and slots. Each Radio Frame is consisted of 20 slots and has a duration of 10 ms, Figure 4.9. Each frame is spited in 10 sub-frames that are consisted of two consecutive slots and have du-

ration of 1 ms. Each slot has a duration of 0.5 ms and is consisted of either 6 or 7 OFDM symbols. Each of the OFDM symbols is transmitted over 12 consecutive OFDM subcarriers, with a bandwidth of 15 kHZ, resulting in a total of 180 kHz of occupied bandwidth per OFDM symbol. The 2-D organization of one slot, i.e., 0.5 ms and 180 kHz is referred to as a resource block, in LTE systems, and is the minimal quantum of resources that the network can allocate in the radio interface.

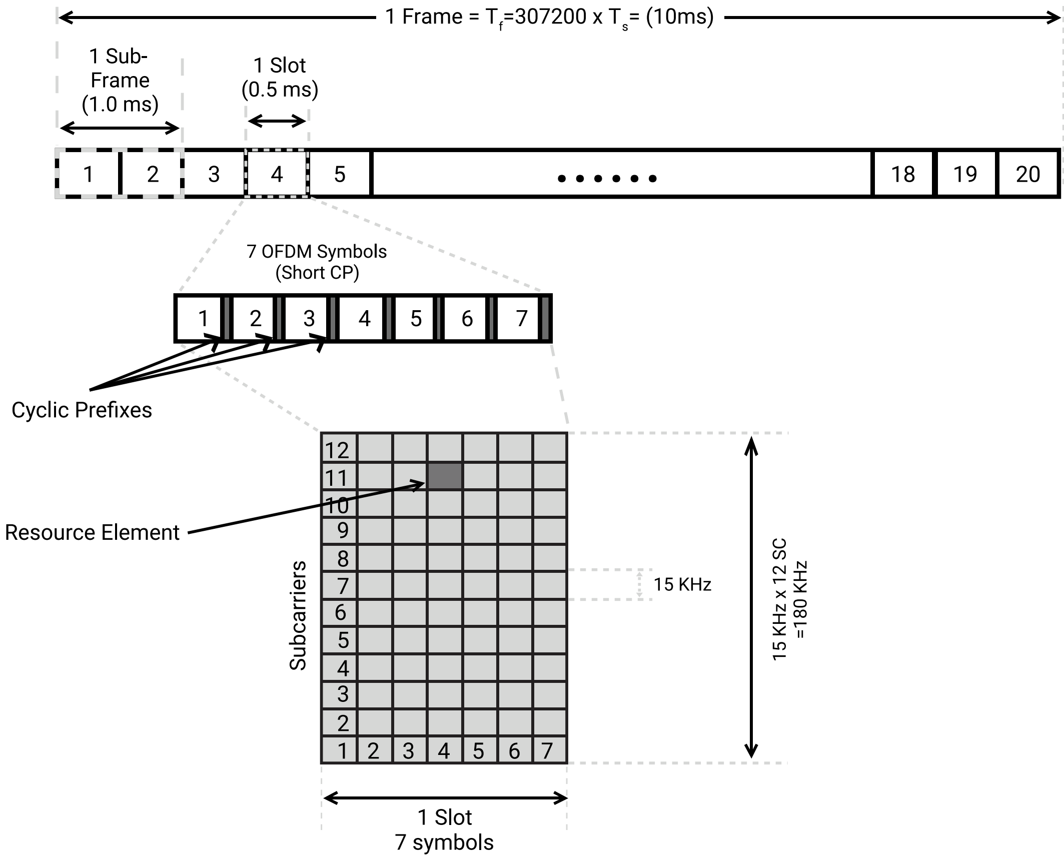



Figure 4.9: LTE physical transmission and radio frame format (3GPP TS 36.201 2007)

Between all adjacent OFDM symbols LTE inserts the Cyclic Prefix, as a mean to mitigate the inter-symbol interference that occurs in a wireless multipath channel. The smallest element in this radio structure is the resource element, which is defined as one OFDM subcarrier for one OFDM symbol. The multiple access in LTE is performed by allocating different resources blocks to different users on a slot basis. The number of resource blocks that a user is assigned to, is dependent on the users' requirements and application profile. For the uplink direction LTE uses SC-FDMA instead of OFDMA, to minimize the transmit power and the Peak to Average Power Ratio. In essence the Resource Block stays the same in dimensions, i.e., 0.5 ms and 180 kHz, however, one SC-FDMA is transmitted over shorter period with higher bandwidth, Figure 4.10.

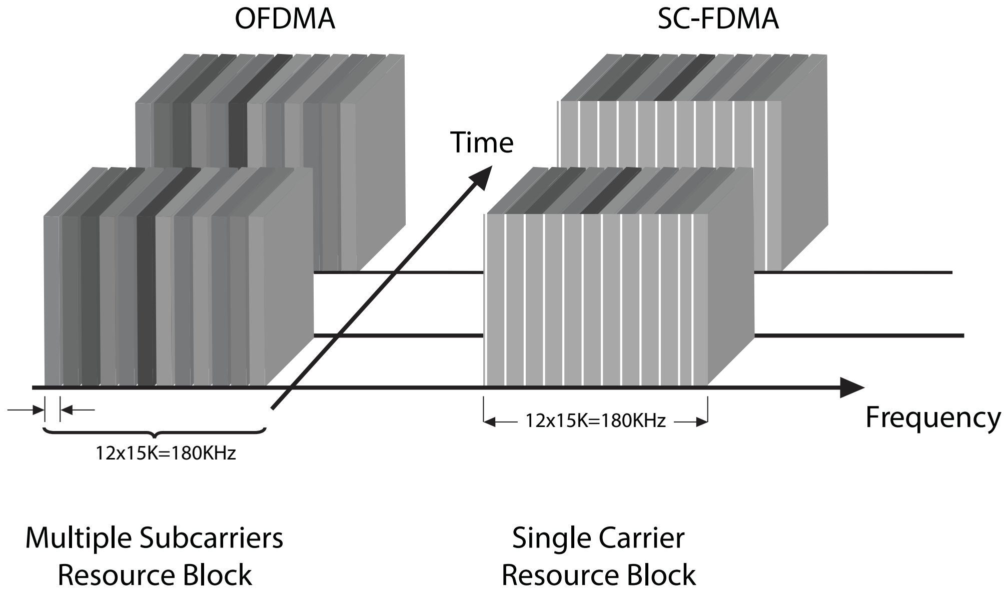



Figure 4.10: LTE OFDMA vs SC-FDMA format (3GPP TS 36.201 2007)

The LTE physical layer, that is used as the primary facilitator of the wireless transmissions, is based on several 3GPP Technical Specifications (3GPP TS 36.104 2017). As discussed, LTE utilizes a multi-carrier transmission based on OFDM. The same physical layer design is used in LTE-A, with modifications that are primarily observed on the MAC layer. However, LTE-A also incorporates higher order of multiple antenna transceiver designs and higher order modulations that significantly improve the system's capacity. Specifically, LTE utilizes QPSK, 16QAM and 64QAM as the core modulation for the radio transmissions, whereas LTE-A incorporate higher order modulations, up to 256QAM to provide higher spectral efficiencies. Moreover, the multiple antenna design in LTE was initially designed for 4x4 antenna, in downlink and now MIMO support for the uplink. LTE-Advanced supports Single-User MIMO (SU-MIMO) and Multi-User MIMO (MU-MIMO) schemes. The antenna array size can go up to 8-layer downlink MIMO (8x8 MIMO) and 4-layer uplink MIMO (4x4 MIMO). Using this update, LTE-A networks can achieve a theoretical peak spectral efficiency of 30 bit/s/Hz for downlink and 15 bit/s/Hz for uplink. The RF facet of LTE's physical layer is organized in several distinct spectrum bands, Table 4.4, Table 4.5, Table 4.6.

| LTE frequency bands | Uplink (UL) operating band BS receive UE transmit (fUL(low) – fUL(High)) [MHz] | Downlink (DL) operating band BS transmit UE receive (fDL(low) - fDL(High)) [MHz] | Duplex mode |
|---|---|---|---|
| 1 | 1920 – 1980 | 2110 – 2170 | FDD |
| 2 | 1850 – 1910 | 1930 – 1990 | FDD |
| 3 | 1710 – 1785 | 1805 – 1880 | FDD |
| 4 | 1710 – 1755 | 2110 – 2155 | FDD |
| 5 | 824 – 849 | 869 – 894 | FDD |
| 6 | 830 – 840 | 875 – 885 | FDD |
| 7 | 2500 – 2570 | 2620 – 2690 | FDD |

| | | | |
|---|---|---|---|
| 8 | 880 – 915 | 925 – 960 | FDD |
| 9 | 1749.9 – 1784.9 | 1844.9 – 1879.9 | FDD |
| 10 | 1710 – 1770 | 2110 – 2170 | FDD |
| 11 | 1427.9 – 1447.9 | 1475.9 – 1495.9 | FDD |
| 12 | 699 – 716 | 729 – 746 | FDD |
| 13 | 777 – 787 | 746 – 756 | FDD |
| 14 | 788 – 798 | 758 – 768 | FDD |
| 15 | Reserved | Reserved | FDD |
| 16 | Reserved | Reserved | FDD |
| 17 | 704 – 716 | 734 – 746 | FDD |
| 18 | 815 – 830 | 860 – 875 | FDD |
| 19 | 830 – 845 | 875 – 890 | FDD |
| 20 | 832 – 862 | 791 – 821 | FDD |
| 21 | 1447.9 – 1462.9 | 1495.9 – 1510.9 | FDD |
| ... | | | |
| 23 | 2000 – 2020 | 2180 – 2200 | FDD |
| 24 | 1626.5 – 1660.5 | 1525 – 1559 | FDD |
| 25 | 1850 – 1915 | 1930 – 1995 | FDD |
| .... | | | |
| 33 | 1900 – 1920 | 1900 – 1920 | TDD |
| 34 | 2010 – 2025 | 2010 – 2025 | TDD |
| 35 | 1850 – 1910 | 1850 – 1910 | TDD |
| 36 | 1930 – 1990 | 1930 – 1990 | TDD |
| 37 | 1910 – 1930 | 1910 – 1930 | TDD |
| 38 | 2570 – 2620 | 2570 – 2620 | TDD |
| 39 | 1880 – 1920 | 1880 – 1920 | TDD |
| 40 | 2300 – 2400 | 2300 – 2400 | TDD |
| 41 | 2496 – 2690 | 2496 – 2690 | TDD |
| 42 | 3400 – 3600 | 3400 – 3600 | TDD |
| 43 | 3600 – 3800 | 3600 – 3800 | TDD |

Table 4.4: LTE generic spectrum allocation: LTE (E-UTRA) Frequency Bands

| E-UTRA CA Band | E-UTRA Band | Uplink (UL) operating band BS receive UE transmit (fUL(low) – fUL(High)) [MHz] | Downlink (DL) operating band BS transmit UE receive (fDL(low) - fDL(High)) [MHz] | Duplex Mode |
|---|---|---|---|---|
| CA_1 | 1 | 1920 – 1980 | 2110 – 2170 | FDD |
| CA_40 | 40 | 2300 – 2400 | 2300 – 2400 | TDD |

Table 4.5: LTE generic spectrum allocation: Carrier Aggregation Intra frequency bands

| E-UTRA CA Band | E-UTRA Band | Uplink (UL) operating band BS receive UE transmit (fUL(low) – fUL(High)) [MHz] | Downlink (DL) operating band BS transmit UE receive (fDL(low) - fDL(High)) [MHz] | Duplex Mode |
|---|---|---|---|---|
| CA_1-5 | 1 | 1920 – 1980 | 2110 – 2170 | FDD |
| CA_1-5 | 5 | 824 – 849 | 869 – 894 | FDD |

Table 4.6: LTE generic spectrum allocation: Carrier Aggregation Inter frequency bands

In N. Macedonia there are several allocated bands that can be used for LTE and are specific to the deployment type of the system (Agency for Electronic Communications 2021). Specifically in N. Macedonia LTE can be deployed in multiple bands for both FDD and TDD based on the syntax from Table 4.4. The spectrum allocation for the bands is depicted in Table 4.7.

| Band | Operation |
|---|---|
| 694 – 790 MHz | Mobile Broadband |
| 790 – 862 MHz | Mobile Broadband |
| 880 – 960 MHz | Mobile Broadband |
| 1710 – 1785 MHz / 1805 – 1880 MHz | Mobile Broadband |
| 1900 – 2690 MHz | Mobile Broadband |
| 3400 – 3800 MHz | Fixed Wireless Access |

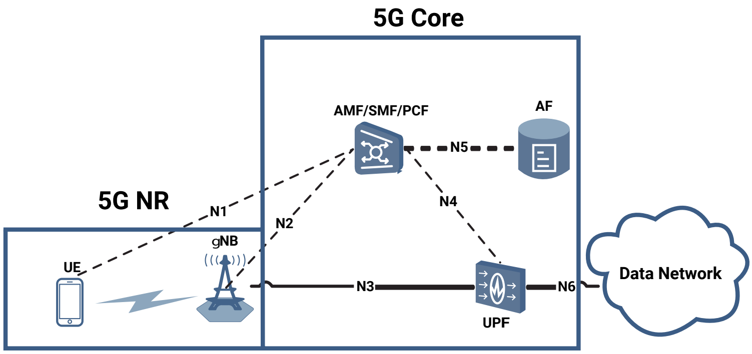
Table 4.7: LTE spectrum allocation in N. Macedonia

## 4.4 Fifth generation of mobile networks (5G)

5G is the 5th generation of mobile networks, a significant evolution of the legacy 4G LTE networks. 5G has been designed to meet the very large growth in data and connectivity of today's modern society. 5G will initially operate in conjunction with existing 4G networks before evolving to fully standalone networks in subsequent releases and coverage expansions. In addition to delivering faster connections and greater capacity, a very important facet of 5G is the minimized system latency, 10× lower than 4G LTE. 5G enables a new generation of applications, services and business opportunities that have not been seen before. There are three major categories of use case for 5G:

- **Massive machine to machine communications.** It is also known as the Internet of Things (IoT) and involves connecting large number of devices without human. This facet has the potential to revolutionize modern industrial processes and applications including agriculture, manufacturing, and business communications.
- **Ultra-reliable low latency communications.** Mission critical communication is of outmost importance in scenarios such as, real-time control of devices, industrial robotics, vehicle to vehicle communications and safety systems, autonomous driving and safer transport networks.
- **Enhanced mobile broadband.** Fostering significantly faster data speeds for new applications, such as fixed wireless internet access for homes, outdoor broadcast applications without the need for broadcast vans, and greater connectivity mobility-based scenarios.

The 5G system architecture is defined and specified by plethora of 3GPP technical specifications. The main pillars of the architecture are the 5G NR, i.e., the radio access network, and 5G Core, the core part of the system, Figure 4.11. (3GPP TS 23.501).




| | | | |
|---|---|---|---|
| AF | Application Function | UPF | User Plane Function |
| AMF | Access and Mobility Management Function | UE | User Equipment |
| SMF | Session Management Function | NB | NodeB |
| PCF | Policy Control Function | | |

Figure 4.11: 5G system architecture

The **5G-NR (NG-RAN)** is composed the gNodeB (i.e., the base station). The gNodeB houses the radio transceivers that define a cell and handles the radio-link protocols with the User Equipment (UE). It also manages the radio resources and handles the radio-channel setup. The gNodeB is directly connected to the 5G core network via N2 interface to the AMF, and via the N3 interface to the UPF. The gNodeB communicates via the radio interface with the user equipment. The **User Equipment**, similarly, to the UE in 3G/4G, consists of the mobile equipment (the terminal) and a smart card called the Subscriber Identity Module (SIM). The SIM provides personal mobility, so that the user can have access to subscribed services irrespective of a specific terminal. By inserting the SIM card into another terminal, the user is able to receive calls at that terminal, make calls from that terminal, and receive other subscribed services. The mobile equipment is uniquely identified by the International Mobile Equipment Identity (IMEI). The SIM card contains the International Mobile Subscriber Identity (IMSI) used to identify the subscriber to the system, a secret key for authentication, and other information. The IMEI and the IMSI are independent, thereby allowing personal mobility.

The **5G Core network** architecture is at the heart of the new 5G specification and enables the increased throughput demand that 5G must support. The new 5G core, as defined by 3GPP, utilizes cloud-aligned, service-based architecture (SBA) that spans across all 5G functions and interactions including authentication, security, session management and aggregation of traffic from end devices. The 5G core further emphasizes Network Function Virtualization (NFV) as an integral design concept with virtualized software functions capable of being deployed using the Mobile Edge Computing (MEC) infrastructure that is central to 5G architectural principles. Changes at the core level are among the myriad of architectural changes that accompany the shift from 4G to 5G. Among the other changes that differentiate the 5G core from its 4G predecessor are user plane function (UPF) to decouple packet gateway control and user plane functions, and access and mobility management function (AMF) to segregate session management functions from connection and mobility management tasks.

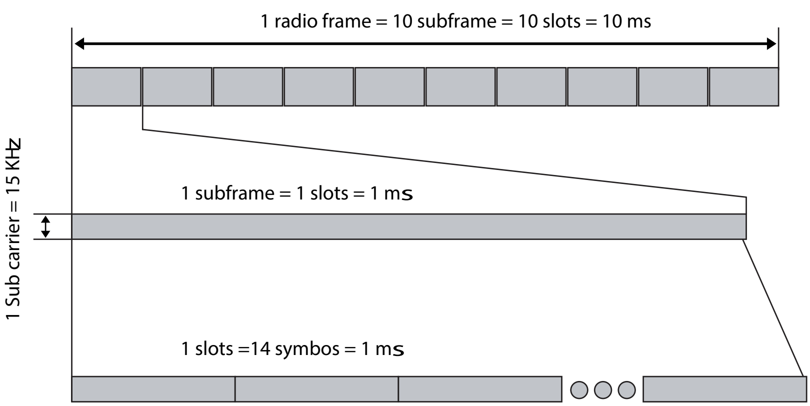
Bridging the gap between 4G and 5G will require incremental steps and a well-orchestrated deployment plan. Characteristic of this shift will be the gradual transition from **non-standalone** model to **standalone** model 5G architecture options. The 5G non-standalone deployment model utilizes existing LTE RAN and core networks as an anchor, with the addition of a 5G component carrier. The 5G standalone model is essentially 5G deployment from the ground up with the new core architecture and full deployment of all 5G hardware, features and functionality. As the non-standalone model gradually gives way to new 5G mobile network architecture deployments, careful planning and implementation will make this transition seamless for the user base.

### 4.4.1 5G radio interface

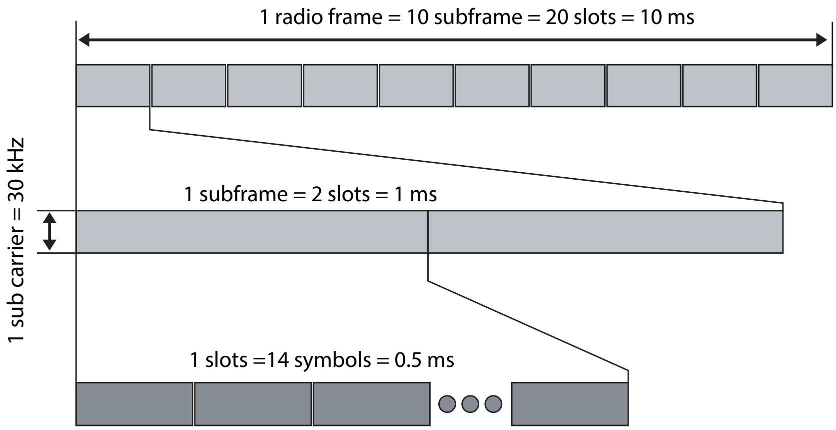
All specific subsystems in 5G are interconnected between each other with standardized interfaces. This study primarily focuses on the radio interface, denoted as the 5G or NR air interface (3GPP TS 38.202 2020), as the main source of EMF in 5G networks.

Compared to LTE's Uu interface, 5G's air interface introduces an updated design with respect to the signal waveforms and multiple access (3GPP TS 38.202 2020, 3GPP TS 38.212 2020). 5G also uses mutli-carrier approach, based on the Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink and CP-OFDM- and DFT-S-OFDM in the uplink. The physical layer in 5G allows for scalable bandwidths, ranging from 5 MHz, up to 400 MHz. One of the biggest differences in the waveform design between 5G and LTE is the scalable numerology applied in 5G. As such the OFDM sub-carriers in 5G can have different bandwidths ranging from 15 kHz up to 240 kHz.

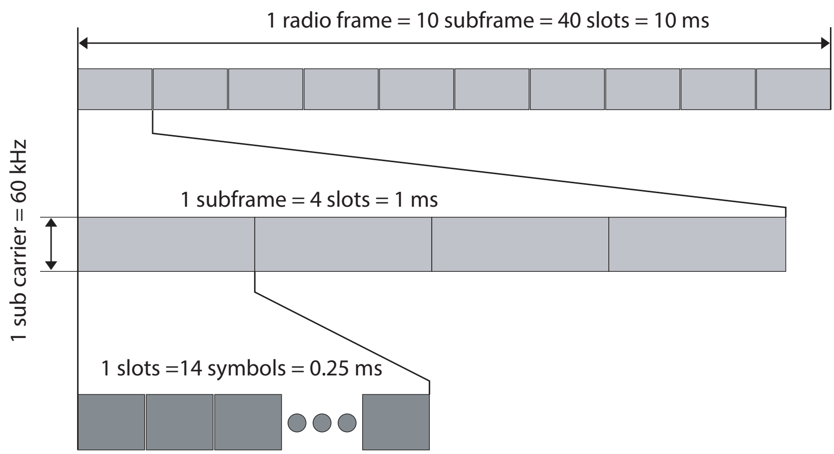
As discussed, in 5G NR multiple numerologies (waveform configuration like subframe spacing) are supported and the radio frame structure gets different depending on the type of the numerology. However, regardless of numerology the length of one radio frame and the length of one subframe is same. The length of a Radio Frame is always 10 ms and the length of a subframe is always 1 ms. Moreover, the number of symbols within a slot is variable in 5G NR. However, the number of symbols within a slot does not change with the OFDM numerology. It only changes with slot configuration type. For slot configuration 0, the number of symbols for a slot is always 14 and for slot configuration 1, the number of symbols for a slot is always 7. Figure 4.12 depicts the frame organization for all supported numerologies, for slot configuration 0. The same logic is applied for slot configuration 1.



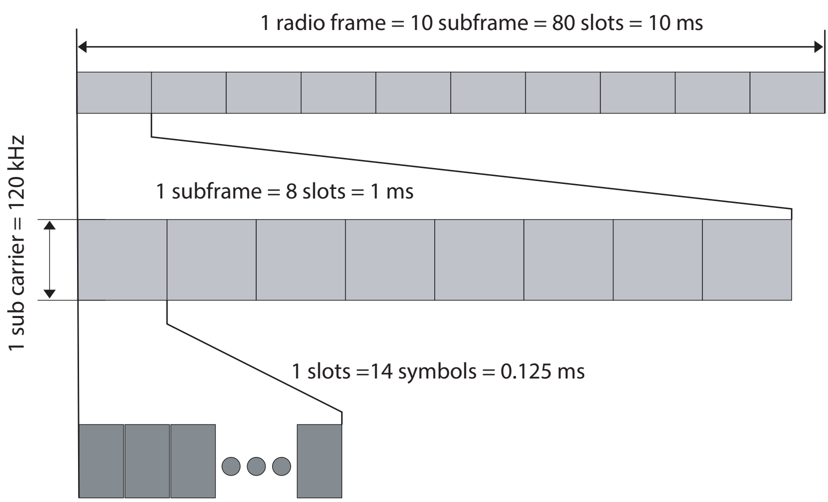

a)


1 radio frame = 10 subframe = 20 slots = 10 ms
1 subframe = 2 slots = 1 ms
1 slots =14 symbols = 0.5 ms
1 sub carrier = 30 kHz

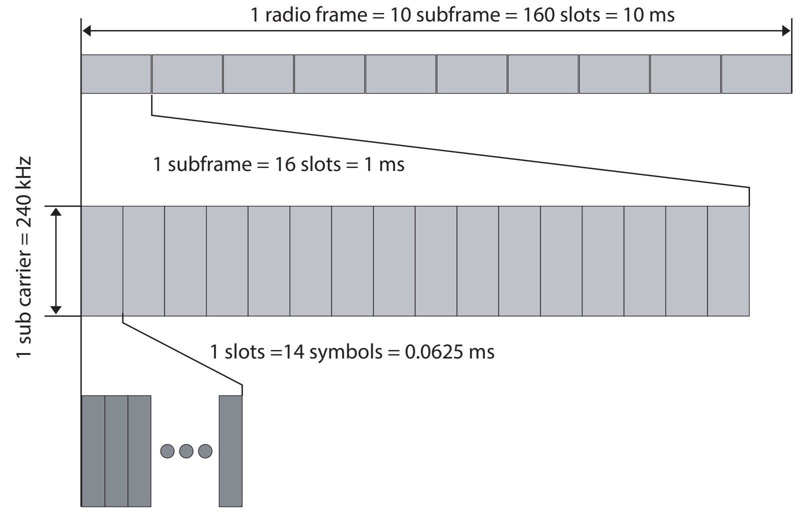
b)


1 radio frame = 10 subframe = 40 slots = 10 ms
1 subframe = 4 slots = 1 ms
1 slots =14 symbols = 0.25 ms
1 sub carrier = 60 kHz

c)


1 radio frame = 10 subframe = 80 slots = 10 ms
1 subframe = 8 slots = 1 ms
1 slots =14 symbols = 0.125 ms
1 sub carrier = 120 kHz

d)




e)

Figure 4.12: 5G NR radio frame format:
a) 15 kHz b) 30 kHz c) 60 kHz d) 120 kHz e) 240 kHz sub-carrier spacing (3GPP TS 38.211 2020)

Because of the OFDM-based communication 5G NR also applies the concept of resource blocks. However, compared to LTE/4G the resource block organization is significantly modified and more complex. In 5G NR the resource block organization depends on the numerology in use, Figure 4.13. As seen from the figure, a 5G NR resource block is consisted of 12 consecutive sub-carriers and a varying number of slots, depending on the used numerology. For numerology 0, 5G NR has the same resource block organization as LTE/4G.

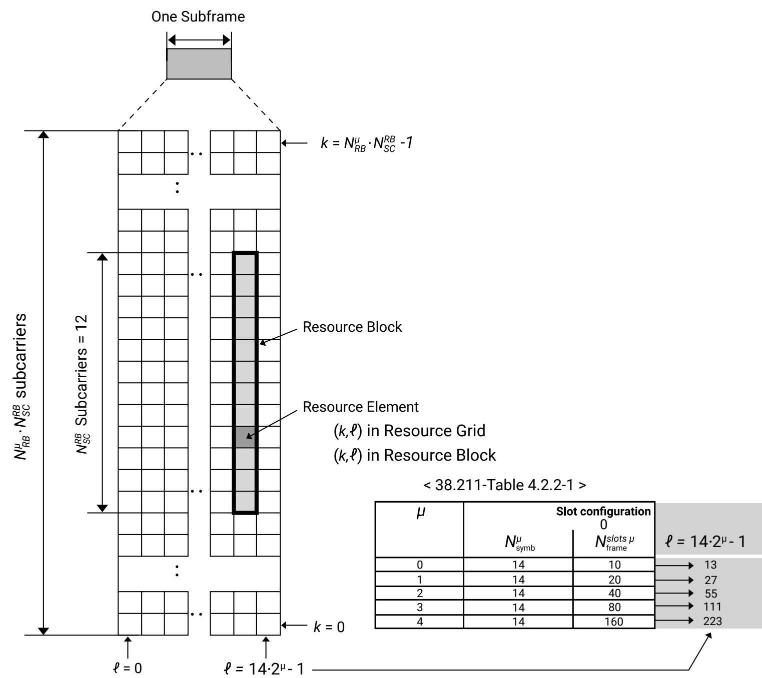



Figure 4.13: 5G NR resource block organization (3GPP TS 38.211 2020)

The 5G NR physical layer that is used as the primary facilitator of the wireless transmissions is based on several 3GPP Technical Specifications. As discussed, 5G NR utilizes a multi-carrier transmission based on OFDM. Specifically, 5G NR utilizes BPSK, QPSK, 16QAM and 64QAM and 256QAM as the core modulation for the radio transmissions, Moreover, the multiple antenna design in 5G NR is design and standardized to support maximum of 2 codewords mapped to maximum of 8 layers in downlink and to a maximum of 4 in uplink. However, 5G NR stipulates the utilization of massive MIMO, where the number of antenna elements are significantly larger compared to legacy standards, such as 3G and 4G. Currently the wide used notion of massive MIMO incorporates an antenna array with dimensions 64x64. Hence the number of spatial layers is the same as in LTE-A. However, the higher number of antennas can be used for beamforming and better spatial resolution, as well as improved MU-MIMO operation.

5G NR is the first standard and technology that incorporates two significantly distinct frequency regions, FR1 - frequency range 1 (3GPP TS 38.101-1 2020) and FR2 - frequency range 2 (3GPP TS 38.101-2 2020). The bands in frequency range 1, FR1 are envisaged to carry much of the traditional cellular mobile communications traffic. The higher frequency bands in range FR2 are aimed at providing short range very high data rate capability for the 5G radio. With 5G wireless technology anticipated to carry much higher speed data, the additional bandwidth of these higher frequency bands will be needed. Originally the FR1 band was intended to define bands below 6 GHz, but with anticipated additional spectrum allocations, the FR1 range has now been extended to 7.125 GHz. The RF facet of 5G's physical layer is organized in several distinct spectrum bands, Table 4.8, Table 4.9, Table 4.10.

| 5G NR frequency band | Uplink band [MHz] | Downlink band [MHz] | Duplex mode |
|---|---|---|---|
| n1 | 1920 – 1980 | 2110 – 2170 | FDD |
| n2 | 1850 – 1910 | 1930 – 1990 | FDD |
| n3 | 1710 – 1785 | 1805 – 1880 | FDD |
| n5 | 824 – 849 | 869 – 894 | FDD |
| n7 | 2500 – 2570 | 2620 – 2690 | FDD |
| n8 | 880 – 915 | 925 – 960 | FDD |
| n12 | 699 – 716 | 729 – 746 | FDD |
| n20 | 832 – 862 | 791 – 821 | FDD |
| n25 | 1850 – 1915 | 1930 – 1995 | FDD |
| n28 | 703 – 748 | 758 – 803 | FDD |
| n34 | 2010 – 20225 | | TDD |
| n38 | 2570 – 2620 | | TDD |
| n39 | 1880 – 1920 | | TDD |
| n40 | 2300 – 2400 | | TDD |
| n41 | 2496 – 2690 | | TDD |
| n50 | 1432 – 1517 | | TDD |
| n51 | 1427 – 1432 | | TDD |
| n66 | 1710 – 1780 | | TDD |
| n70 | 1695 – 1710 | | TDD |
| n71 | 663 – 698 | | TDD |
| n74 | 1427 – 1470 | | TDD |

| | | | |
|---|---|---|---|
| n75 | – | 1432 – 1517 | SDL |
| n76 | – | 1427 – 1432 | SDL |
| n77 | 3300 – 4200 | | TDD |
| n78 | 3300 – 3800 | | TDD |
| n79 | 4400 – 5000 | | TDD |
| n80 | 1710 – 1785 | – | SUL |
| n81 | 8800 – 915 | – | SUL |
| n82 | 832 – 862 | – | SUL |
| n83 | 703 – 748 | – | SUL |
| n84 | 1920 – 1980 | – | SUL |
| n86 | 1710 – 1780 | – | SUL |

Table 4.8: 5G FR1 generic spectrum allocation

| 5G NR frequency band | Uplink band [MHz] | Downlink band [MHz] | Duplex mode |
|---|---|---|---|
| n257 | 26 500 – 29500 | 26500 – 29500 | TDD |
| n258 | 24 250 – 27 500 | 24 250 – 27 500 | TDD |
| n260 | 37 000 – 40 000 | 37 000 – 40 000 | TDD |
| n261 | 27 500 – 28 350 | 27 500 – 28 350 | TDD |

Table 4.9: 5G FR2 generic spectrum allocation

In N. Macedonia there are several allocated bands that can be used for 5G and are specific to the deployment type of the system (Agency for Electronic Communications 2021). Specifically in N. Macedonia 5G can be deployed in multiple bands for both FDD and TDD based on the syntax from Table 4.8 and Table 4.9.

| Band | Operation |
|---|---|
| 694 – 790 MHz | Mobile Broadband |
| 790 – 862 MHz | Mobile Broadband |
| 880 – 960 MHz | Mobile Broadband |
| 1710 – 1785 MHz / 1805 – 1880 MHz | Mobile Broadband |
| 1900 – 2690 MHz | Mobile Broadband |
| 3400 – 3800 MHz | Fixed Wireless Access |
| 24.25 – 27.5 GHz | Mobile Broadband |

Table 4.10: 5G spectrum allocation in N. Macedonia

## 4.5 Radiation aspects and energy analysis

The level of exposure of biological systems to RF EMF is a function of the energy carried by the EMF, the frequency, and the distance of the object from the source. The transmission of part of the field's electromagnetic energy into the tissues of biological systems is the physical mechanism of influence during their exposure to the RF EMF.

The base stations of the mobile operators radiate electromagnetic energy on radio frequencies in the so-called radiation mode and sleep mode. Although in the general case, 75% -90% of the time the base stations remain unused, still in those intervals there is a significant consumption of energy or significant radiated energy. This phenomenon is because each of the standards for mobile communications includes sending mandatory control signals even in standby mode, such as synchronization signals, reference signals, and system information. For example, in previous generations of mobile networks (3G, 4G) in sleep mode control signals are sent at intervals of less than 1ms. With 3G technology this is a serious drawback because the base stations send signals in all directions, but with 4G technology that uses directional antennas it is not possible to reduce the radiated energy by more than 20 % due to the need to regularly send the mentioned signals. part of the radio interface. On the other hand, 5G technology has particular improvements in this regard due to the fact that the standard provides for the transmission of a drastically smaller number of control signals for the radio interface. The time interval of the mandatory signalization can be adjusted at an interval of 5 ms to 100 ms. This allows components to be disconnected from the base station when there is little or no communication and enters one of the standby modes. As a result, the total consumption of base stations in 5G technology, and thus the radiated energy is like that of 4G technology, but with a significantly higher information flow (Giordani et al. 2018; Shurdi et al. 2021).

The protocols of the active radiation mode at the base stations of 5G technology, as in the previous generation (4G) are based on the technique of beam formation. This technique is a data traffic signaling system to identify the most efficient paths through which data flow to users should be performed. The basic properties of antennas that work by forming beams are to reduce interference, increase the signal-to-interference and noise ratio, and establish better communication with the user (Giordani et al. 2018). For the very high frequencies at which 5G technology operates, it is of particular interest to deal with signal transmission - signals can easily be blocked by objects or attenuated over long distances. The new bundled protocols incorporated in 5G technology enable dynamic, directional shaping of base station antenna radiation that is necessary in environments where there are large numbers of users and densely spaced base stations. Innovations in bundle-forming techniques in this technology result in additional focusing of the signal in a concentrated bundle directly aimed at the device, preventing it from scattering in all directions at once. This significantly improves the radiation efficiency of the antennas, i.e., the radiated power is reduced to the minimum level necessary to ensure the flow to the users (Hamdy 2020).

## 4.6 Summary

This section provided an overview of the existing mobile technologies' designs. The section specifically focused on the radio interface of each technology, as the primary source of EMF. As described in the section, all the mobile generations have distinctly designed radio interfaces. As seen from the presented data, the major distinction in mobile systems generation is in the way they foster wireless transmission. Specifically, the major difference can be observed in the waveform design and the applied signal processing techniques that improve the signal reception and spectral efficiency of the systems. As such, these aspects have no effect in terms of the EMF exposure, as the radiated EMF is not changed. Moreover, all of the technologies primarily operate in the sub 6 GHz frequencies, except 5G, which can also operate in the so-called mmWave band, i.e., 20 GHz – 30 GHz band. However, all of these bands are classified in the non-ionizing frequency band, which is not harmful to living tissues and it is highly regulated.

## 4.7 Bibliography

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# Chapter 5

## 5 How to deploy mobile networks

This section discusses the potential guidelines for deploying mobile systems. The chapter specifically focuses on the deployment aspects related from 2G to 5G systems, taking into consideration the standardization specifics defined in 3GPP as well as the ITU radio regulations with respect to spectrum band allocation and allowed transmission power levels, from safety point of view. Moreover, the section focuses on the mmWave deployments and its effect upon human health regarding maximum allowed transmission power levels, beamforming aspects and received signal strength levels.

## 5.1 Maximum power output

This part of the section elaborates on the maximum allowed power levels per mobile generation standard. The maximum allowed power output is the most crucial metric for deploying mobile systems, with respect to the EMF exposure levels.

### 5.1.1 2G maximum power output

The maximum transmitted power levels for GSM/2G are strictly defined and regulated. They are dependent on the type of equipment, Base Station or Mobile Station, Power class, as well as the operating band. For the specific bands of interest, the power levels for the Mobile Stations are given in Figure 5.1.

| Power class | GSM 900<br>MAximum outputpower | DCS 1800<br>Maximum output power |
|---|---|---|
| 1<br>2<br>3<br>4<br>5 | -- ----<br>8 W (39 dBm)<br>5 W (37 dBm)<br>2 W (33 dBm)<br>0.8 W (29 dBm) | 1 W (30 dBm)<br>0.25 W (24 dBm)<br>4 W (36 dBm) |

Figure 5.1: GSM Mobile Station maximum output power (ETSI GSM 05.05 1996)

The power levels for the GSM base stations are given in Figure 5.2 for both bands of interest.

| TRX power class | Maximum output power |
|---|---|
| 1<br>2<br>3<br>4<br>5<br>6<br>7<br>8 | 320 - (<640) W<br>160 - (<320) W<br>80 - (<160) W<br>40 - (<80) W<br>20 - (<40) W<br>10 - (<20) W<br>5 - (<10) W<br>2.5 - (<5) W |

a)

| TRX power class | Maximum output power |
|---|---|
| 1 | 20 - (<40) W |
| 2 | 10 - (<20) W |
| 3 | 5 - (<10) W |
| 4 | 2.5 - (<5) W |

b)

Figure 5.2: GSM Base Station maximum output power:
a) 900 MHz b) 1800 MHz (ETSI GSM 05.05 1996)

From both Figure 5.1 and Figure 5.2 it can be concluded that the maximum allowed output power is highly depended on the frequency band in use. Specifically, higher bands stipulate lower transmission power levels, in order preserve the required protection and minimize the EMF exposure.

### 5.1.2 3G maximum power output

The maximum transmitted power levels for UMTS / 3G are strictly defined and regulated. They are dependent on the type of equipment, NodeB or UE, Power class, as well as the type of nodeB deployment and antenna array size. For the specific bands of interest, the power levels for the UE are given in Figure 5.3.

| TRX power class | Maximum output power |
|---|---|
| 1 | +33 dBm |
| 2 | +27 dBm |
| 3 | +24 dBm |
| 4 | +21 dBm |

Figure 5.3: UMTS UE maximum output power (3GPP TS 25.102 2001)

The power levels for the UMTS base stations, NodeBs, are given in Figure 5.4, for all system configuration of interest. Based on ETSI normative, Prated,c of the base station is the mean power level per carrier that the manufacturer has declared to be available at the antenna connector.

| BS class | Prated,c |
|---|---|
| Wide Area BS | -(note) |
| Medium Range BS | ≤ + 38 dBm |
| Local Area BS | ≤ + 24 dBm |
| Home BS | ≤ + 20 dBm (without transmit diversity or any MIMO mode)<br>≤ + 17 dBm (without transmit diversity or MIMO mode)<br>≤ + 14 dBm (with MIMO mode with four transmit antennas) |
| NOTE: There is no upper limit required for the rated output power of the Wide Area Base Station like for the base station for General Purpose applications in Release 99, 4, and 5. | |

Figure 5.4: UMTS NodeB maximum output power (3GPP TS 25.104 2018)

From both Figure 5.3 and Figure 5.4 it is evident that UMTS has a lower output power on average compared to 2G. Moreover, the maximum allowed output power at the NodeB is highly depended on the cell size and antenna configuration. Specifically smaller cells are limited to lower output power levels and the incorporation of MIMO in the NodeBs, induces further limitation to the power levels in order preserve the required protection and minimize the RF EMF exposure.

### 5.1.3 4G maximum power output

The maximum transmitted power levels for LTE / 4G are strictly defined and regulated. They are dependent on the type of equipment, eNodeB or UE, Power class, as well as the type of enodeB deployment and antenna array size. For the specific bands of interest, the power levels for the UE are given in Figure 5.5.

| EUTRA band | Class 1 (dBm) | Tolerance (dB) | Class 2 (dBm) | Tolerance (dB) | Class 3 (dBm) | Tolerance (dB) | Class 4 (dBm) | Tolerance (dB) |
|---|---|---|---|---|---|---|---|---|
| 1 | | | | | 23 | ±2 | | |
| 2 | | | | | 23 | ±2[2] | | |
| 3 | | | | | 23 | ±2[2] | | |
| 4 | | | | | 23 | ±2 | | |
| 5 | | | | | 23 | ±2 | | |
| 6 | | | | | 23 | ±2 | | |
| 7 | | | | | 23 | ±2[2] | | |
| 8 | | | | | 23 | ±2[2] | | |
| 9 | | | | | 23 | ±2 | | |
| 10 | | | | | 23 | ±2 | | |
| 11 | | | | | 23 | ±2 | | |
| 12 | | | | | 23 | ±2[2] | | |
| 13 | | | | | 23 | ±2 | | |
| 14 | | | | | 23 | ±2 | | |
| | | | | | | | | |
| 17 | | | | | 23 | ±2 | | |
| 18 | | | | | 23 | ±2 | | |
| 19 | | | | | 23 | ±2 | | |
| 20 | | | | | 23 | ±2[2] | | |
| 21 | | | | | 23 | ±2 | | |
| ... | | | | | | | | |
| 23 | | | | | 23 | ±2 | | |
| 24 | | | | | 23 | ±2 | | |
| 25 | | | | | 23 | ±2[2] | | |
| ... | | | | | | | | |
| 33 | | | | | 23 | ±2 | | |
| 34 | | | | | 23 | ±2 | | |
| 35 | | | | | 23 | ±2 | | |
| 36 | | | | | 23 | ±2 | | |
| 37 | | | | | 23 | ±2 | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 38 | | | | | 23 | ±2 | | |
| 39 | | | | | 23 | ±2 | | |
| 40 | | | | | 23 | ±2 | | |
| 41 | | | | | 23 | ±2 | | |
| 42 | | | | | 23 | ±2 | | |
| 43 | | | | | 23 | ±2 | | |
| Note 1: The above tolerance are applicable for UE(s) that support up to 4 E-UTRA operating bands. For UE(s) that support 5 or more E-UTRA bands the maximum output power is expected to decrease with each additional band and is FFS<br>Note 2: For transmission bandwiths (Figure 5.6-1) confined within $F_{UL\_low}$ and $F_{UL\_low}$ + 4 MHz or $F_{UL\_low}$ - 4 MHz and $F_{UL\_high}$, the maximum output power requirement is relaxed by reducing the lower tolerance limit by 1.5 dB<br>Note 3: For the UE which supports both Band 11 and Band 21 operating frequencies, the tolerance is FFS.<br>Note 4: $P_{PowerClass}$ is the Maximum UE power specified without taking into account the tolerance | | | | | | | | |

Figure 5.5: LTE UE maximum output power (3GPP TS 36.101 2011)

The power levels for the LTE base stations, eNodeBs, are given in Figure 5.6, for all system configuration of interest. Based on ETSI normative, Prated,c of the base station is the mean power level per carrier that the manufacturer has declared to be available at the antenna connector during the transmitter ON period.

| BS class | $P_{rated,c}$ |
|---|---|
| Wide Area BS | -(note) |
| Medium Range BS | ≤ + 38 dBm |
| Local Area BS | ≤ + 24 dBm |
| Home BS | ≤ + 20 dBm (for one transmit antenna port)<br>≤ + 17 dBm (for two transmit antenna port)<br>≤ + 14 dBm (for four transmit antenna port)<br>< + 11 dBm (for eight transmit antenna port) |
| NOTE: There is no upper limit required for the rated output power of the Wide Area Base Station. | |

Figure 5.6: LTE and LTE-A eNodeB maximum output power (3GPP TS 36.104 2017)

From both Figure 5.5 and Figure 5.6 it is evident that LTE/LTE-A has the same output power on average compared to 3G and lower power output than 2G. Moreover, the maximum allowed output power at the eNodeB is highly depended on the cell size and antenna configuration. Specifically, smaller cells are limited to lower output power levels, and the incorporation of MIMO in the eNodeBs, induces further limitation to the power levels, in order preserve the required protection and minimize the EMF exposure. Specifically, for doubling the antenna array size, the transmit power of the eNodeB should be decreased for 3 dB.

### 5.1.4 5G maximum power output

The maximum transmitted power levels for 5G NR are strictly defined and regulated. They are dependent on the type of equipment, gNodeB or UE, Power class, as well as the frequency region for deployment. For the specific bands of interest, the power levels for the UE are given in Figure 5.7.

| EUTRA band | Class 1 (dBm) | Tolerance (dB) | Class 2 (dBm) | Tolerance (dB) | Class 3 (dBm) | Tolerance (dB) |
|---|---|---|---|---|---|---|
| n1 | | | | | 23 | ±2 |
| n2 | | | | | 23 | ±2[3] |
| n3 | | | | | 23 | ±2[3] |
| n5 | | | | | 23 | ±2 |
| n7 | | | | | 23 | ±2[3] |
| n8 | | | | | 23 | ±2[3] |
| n12 | | | | | 23 | ±2[3] |
| n14 | 31 | +2/-3 | | | 23 | ±2[3] |
| n18 | | | | | 23 | ±2 |
| n20 | | | | | 23 | ±2[3] |
| n25 | | | | | 23 | ±2[3] |
| n26 | | | | | 23 | ±2[3] |
| n28 | | | | | 23 | +2/-2.5 |
| n30 | | | | | 23 | ±2 |
| n34 | | | | | 23 | ±2 |
| n38 | | | | | 23 | ±2 |
| n39 | | | | | 23 | ±2 |
| n40 | | | | | 23 | ±2 |
| n41 | | | 26 | +2/-3[3] | 23 | ±2[3] |
| n47 | | | | | 23 | ±2 |
| n48 | | | | | 23 | +2/-3 |
| n50 | | | | | 23 | ±2 |
| n51 | | | | | 23 | ±2 |
| n53 | | | | | 23 | ±2 |
| n65 | | | | | 23 | ±2 |
| n66 | | | | | 23 | ±2 |
| n70 | | | | | 23 | ±2 |
| n71 | | | | | 23 | +2/-2.5 |
| n74 | | | | | 23 | ±2 |
| n77 | | | 26 | +2/-3 | 23 | +2/-3 |
| n78 | | | 26 | +2/-3 | 23 | +2/-3 |
| n79 | | | 26 | +2/-3 | 23 | +2/-3 |
| n80 | | | | | 23 | ±2 |
| n81 | | | | | 23 | ±2 |
| n82 | | | | | 23 | ±2 |
| n83 | | | | | 23 | +2/-2.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| n84 | | | | | 23 | ±2 |
| n86 | | | | | 23 | ±2 |
| n89 | | | | | 23 | ±2 |
| n91 | | | | | 23 | ±2[3,4] |
| n92 | | | | | 23 | ±2[3,4] |
| n93 | | | | | 23 | ±2[3,4] |
| n94 | | | | | 23 | ±2[3,4] |
| n95 | | | | | 23 | ±2 |

NOTE 1: $P_{PowerClass}$ is the maximum UE power specified without taking into account the tolerance
NOTE 2: Power class 3 is default power class unless otherwise stated
NOTE 3: Refers to the transmission bandwidths confined within FUL_low and FUL_low +4 MHz or FUL_high - 4 MHz and FUL_high, the maximum output power requirement is relaxed by reducing the lower tolerance limit by 1.5 dB.
NOTE 4: The maximum output power requirement is relaxed by reducing the lower tolerance limit by 0.3 dB

a)

| Operating band | Max TRP (dBm) | Max EIRP (dBm) |
|---|---|---|
| n257 | 35 | 55 |
| n258 | 35 | 55 |
| n260 | 35 | 55 |
| n261 | 35 | 55 |

b)

| Operating band | Max TRP (dBm) | Max EIRP (dBm) |
|---|---|---|
| n257 | 23 | 43 |
| n258 | 23 | 43 |
| n260 | | |
| n261 | 23 | 43 |

c)

| Operating band | Max TRP (dBm) | Max EIRP (dBm) |
|---|---|---|
| n257 | 23 | 43 |
| n258 | 23 | 43 |
| n260 | 23 | 43 |
| n261 | 23 | 43 |

d)

| Operating band | Max TRP (dBm) | Max EIRP (dBm) |
|---|---|---|
| n257 | 23 | 43 |
| n258 | 23 | 43 |
| n260 | 23 | 43 |
| n261 | 23 | 43 |

e)

Figure 5.7: 5G NR UE maximum output power: a) FR1 b) FR2 power class 1 c) FR2 power class 2 d) FR2 power class 3 e) FR2 power class 4 (3GPP TS 38.101-1 2020, 3GPP TS 38.101-2 2020)

The power levels for the 5G NR base stations, gNodeBs, are given in Figure 5.8 for all system configuration of interest. Based on ETSI normative Prated,c of the base station is the mean power level per carrier that the manufacturer has declared to be available at the antenna connector (AC), TAB Connector (TABC) or Radiated Interface Boundary, during the transmitter ON period.

| BS class | $P_{rated,c,AC}$ |
|---|---|
| Wide Area BS | (Note) |
| Medium Range BS | $\leq$ 38 dBm |
| Local Area BS | $\leq$ 24 dBm |
| NOTE: There is no upper limit required for the $P_{rated,c,AC}$ rated output power of the Wide Area Base Station. | |

a)

| BS class | $P_{rated,c,SYS}$ | $P_{rated,c,TABC}$ |
|---|---|---|
| Wide Area BS | (Note) | (Note) |
| Medium Range BS | $\leq$ 38 dBm +10log($N_{TXU, counted}$) | $\leq$ 38 dBm |
| Local Area BS | $\leq$ 24 dBm +10log($N_{TXU, counted}$) | $\leq$ 24 dBm |
| NOTE: There is no upper limit for the $P_{rated,c,sys}$ od $P_{rated,c,TABC}$ of the Wide Area Base Station. | | |

b)

| BS class | $P_{rated,c,TRP}$ |
|---|---|
| Wide Area BS | (Note) |
| Medium Range BS | $\leq$ + 47 dBm |
| Local Area BS | $\leq$ + 33 dBm |
| NOTE: There is no upper limit required for the $P_{rated,c,TRP}$ of the Wide Area Base Station. | |

c)

Figure 5.8: 5G NR gNodeB maximum output power:
a) BS type 1-C b) BS type 1-H c) BS type 1-O/2-O (FR2) (3GPP TS 38.104 2020)

From both Figure 5.7 and Figure 5.8 it is evident that 5G NR has the same output power on average compared to 4G and 3G and lower power output than 2G, for FR1. Moreover, the maximum allowed output power for FR2 is higher, due to the higher propagation loss, exhibited on the mmWave frequencies. Moreover, the gNodeB power output is highly depended on the cell size and antenna configuration. Specifically, smaller cells are limited to lower output power levels, and the incorporation of MIMO in the gNodeBs, induces further limitation to the power levels, in order preserve the required protection and minimize the EMF exposure.

## 5.2 EMF compliance and system deployment

In multi-band wireless networks, such as legacy systems, we need to calculate the compliance distance when transmit antennas for multiple bands are collocated and all networks transmitting at different spectrum bands are active. This is usually the case when a network supports multiple technologies: 2G, 3G, 4G and 5G NR. To perform this, there is a need for a more generic metric that calculates the ratio of measured or calculated power density at a distance d at frequency f, denoted as S(f), versus exposure limit Sinc at frequency f (Jevremovic 2020):

Equation 5.1: $$R = \frac{S(f)}{S_{inc}(f)}$$

The parameter R is calculated separately at each active frequency in the network. For example, if the network has 5 different bands, for example 700, 850, 1900 MHz and 3.5 and 28 GHz, there will be five *R* values to compute. The goal is to find EMF exposure compliance distance *d* at which the summation of all five *R* values is equal to 1:

Equation 5.2: $$\sum_{i=1}^{5} R_i = 1$$

This is an iterative process that can have multiple results, depending on the focus of the mobile network operator. For example, one can favorize a specific band/technology at the price of another one.

EMF compliance distance is a function of input power, antenna gain, reflections from surfaces and power density. According to ICNIRP (ICNIRP 2020), incident power density S must be averaged over time, and thus all parameters that contribute to S must be averaged as well. This must be done if:

- The duplexing is time-based (TDD)
- Input power fluctuates due to variation in cell load at the Base station in real time (applicable to 3G, 4G and 5G)
- Antenna pattern fluctuates in real time (5G massive MIMO)

### 5.2.1 TDD-based systems

When uplink and downlink share spectrum, input power must be averaged over time to account for the time when downlink does not transmit. The DL transmission duration as a fraction of the overall transmission duration needs to be known. Then, the average power, Pavg, as a function of the nominal power P0 is defined as:

Equation 5.3: $$P_{avg} = P_o \frac{T_{DL}}{T_F}$$

where P0 is the nominal power output, TDL is the downlink transmission duration within a frame, whereas TF is the duration of the whole frame.

### 5.2.2 Cell load

A base station transmit power fluctuates with the number of mobile stations transmitting/receiving the signal and/or the traffic volume. With respect to the number of mobile stations, the ratio of the number of the active ones vs. the theoretical maximum is called "cell load”. Operators usually design their networks to support average cell load in the 50 – 80 % range during busy hour. Another important parameter is overhead, which is a fraction of the transmit power reserved for signaling. For example, in LTE, it is in the 10 – 30 % range, while for 5G NR it is in the 14 – 18 % range. The average power $P_{avg}$ as a function of the nominal power $P_0$ is:

Equation 5.4:
$$P_{avg} = P_o \left[ OH + \left(1 - OH\right) CL \right]$$
$$0 \le OH \le 1$$
$$0 \le CL \le 1$$

where $P_O$ is the nominal power output, OH is the cell overhead and CL is the cell load.

### 5.2.3 Massive MIMO

Massive MIMO is one of the prevalent concepts in 5G that significantly improves signal reception and spectrum efficiency. However, its large antenna array size, improved beam focus, and stochastic behavior makes the calculation of exclusion zones more complex compared to legacy technologies such as 4G.

Massive MIMO antenna arrays in 5G NR are two-dimensional beamforming antenna arrays that form a high gain narrow beam antenna pattern in direction of a user. The Massive MIMO antennas can either be static, which means that each generated beam covers a fixed area of a 120º sector, or dynamic, which means that a beam is tracking a user in real time as it moves around within a sector. Conventional Massive MIMO designs incorporate a 64-antenna array, however larger antenna arrays can be expected in future deployments, especially ones focusing on 5G NR deployments in the FR2 band.

As the antenna array focuses the beam, the signal strength at a specific distance is no longer calculated by the conventional propagation models. As such, the Massive MIMO gain per beam $G_{mMIMO}$ can be calculated based on the discussion presented in Figure 5.8 b):

Equation 5.5: $$G_{mMIMO} = G_{antenna} + 10\log(N_{TX})$$

where $G_{antenna}$ is the antenna gain at the connector and NTX is the antenna array size. For an antenna array size of 64, and antenna gain per individual antenna of 0 dBi, the total system gain would be 18 dBi.

Moreover, the Equivalent Isotropic Radiated Power (EIRP) is a product of input power P0 and antenna gain $G_{mMIMO}$. In the context of Massive MIMO and based on the upper limits specified by 3GPP for a medium range BS of type 1-H, the maximum allowed EIRP would be 56 dBm. However, the calculated EIRP is not constant in time, because it is not prudent to have all Massive MIMO beams transmit at the same time, as this would degrade SINR and reduce throughput at mobile stations. Only a few Massive MIMO beams are active at any given time, and the decision which beams to activate and which to turn off is made in real time, with a goal to reduce the multi-user interference. Thus, Massive MIMO radiation pattern changes in real time, and the constant switching of beams on and off means that EIRP per beam must be averaged out. According to scientific studies and field trials (Jevremovic 2020), average EIRP power in Watts per Massive MIMO beam is only 25 % of the instantaneous EIRP. As discussed in the work the 25 % value is a conservative estimate and considers a typical DL/UL split in a TDD network. In the above example for an instantaneous EIRP of 56 dBm the reduction of EIRP transmission in Watts from 100 % to 25 % corresponds to 6 dB reduction in power in logarithmic scale, so the average EIRP would be 56 – 6 = 50 dBm.

## 5.3 Exclusion zones

The exclusion zones of mobile systems heavily depend on the underlying regulation for maximal EMF power density limit (W/m2), as well as the system type and deployment scenario as discussed above. This subsection presents an example model for calculated exclusion zones for different deployment scenarios (Jevremovic 2020; Pires 2016; Sebastião 2007).

### 5.3.1 Indoor deployment

Table 5.1 depicts the RF EMF power density limits for three distinct scenarios based on the ICNIRP guidelines for the bands of interest where legacy mobile systems are being deployed. Moreover, the table presents the proposed ICNIRP values as a reference point.

| | 900 MHz | 1800 MHz | 2100 MHz | 3500 MHZ | 28 Gz |
|---|---|---|---|---|---|
| ICNIRP | 4.5 | 9 | 10 | 10 | 10 |
| Legislation 1 | 6 | 10 | 10 | 10 | 10 |
| Legislation 2 | 0.45 | 0.9 | 1 | 1 | 1 |
| Legislation 3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

Table 5.1: EMF exposure limits [W/m2]

It can be noticed that Legislation 1 allows EMF exposures that are above the ICNIRP recommendations for lower frequency bands, whereas it complies with the ICNIRP recommendations for higher frequencies. Countries such as **Japan and USA** utilize these limits.

Legislation 2 is also denoted as the 1/10 ICNIRP, as all values are limited conservatively at the 10 % of the recommendation limit by ICNIRP. Countries such as **Slovenia and Lithuania** utilize these limits. This is a very conservative approach, leading to significantly higher protection levels that the required ones.

Legislation 3 is the most conservative approach where the exposure limit is fixed at 0.1 W/m2. It is an extremely conservative approach that facilitates protection levels, which are several orders of magnitude higher than the international regulation. Countries such as **Russia and Italy** utilize these limits.

The system configuration of interest is as follows: GSM is a SISO system. HSPA+, LTE and 5G NR (FR1) are 2x2 MIMO systems. 5G NR at 28 GHz (FR2) is a cross polarized massive MIMO (128 elements). The output power is 20 dBm for the GSM system, 23 dBm for the 3G, 4G and 5G NR (FR1) systems, because they utilized 2-chain transmitter design, resulting in double the power gain in W, i.e., 3 dB in the log scale. Moreover, the 5G NR (FR2) system has the transmit gain of 35 dBm, based on Equation 5.5 and the average EIRP discussion in the previous section.

| Exclusion Zone (Front) [cm] | Legislation 1 | Legislation 2 | Legislation 3 |
|---|---|---|---|
| Legacy system deployment (2G + 3G + 4G) | 7.8 | 22.6 | 63.1 |
| Full system deployment (2G +3G +4G +5G (FR1) | 8.8 | 25.9 | 74.6 |
| Full system deployment (2G +3G +4G +5G (FR2) | 18.15 | 56.5 | 175.5 |

Table 5.2: Exclusion zone calculations (Indoor)

Table 5.2 depicts the exclusion zones for the three legislation scenarios and for three different deployment cases. It must be noted that the proposed three deployment cases reflect all real-world situations. The first deployment case focuses on only the legacy technologies, i.e., situations where 5G is not deployed. The second deployment case analyzes the situation where 5G is also being deployed with the legacy technologies. In this case the 5G deployment is in the FR1 band and incorporates conventional MIMO. The third deployment case focuses on the deployment of all wireless systems where 5G NR is deployed in the FR2 band and utilizes Massive MIMO. By careful analysis of the EMF exposure limits in the ICNIRP guidelines or Table 5.1 it can be concluded that the exposure limits are the same for mmWave bands and the lower regions. Hence, the third deployment case reflects the application of Massive MIMO in the systems, as the higher frequencies have no impact on the exclusion zones. The rules for exclusion zones in home scenarios are presented in Figure 5.9, which is based on the rules developed in ITU-T K.100 2019 and IEC 62232 2017.

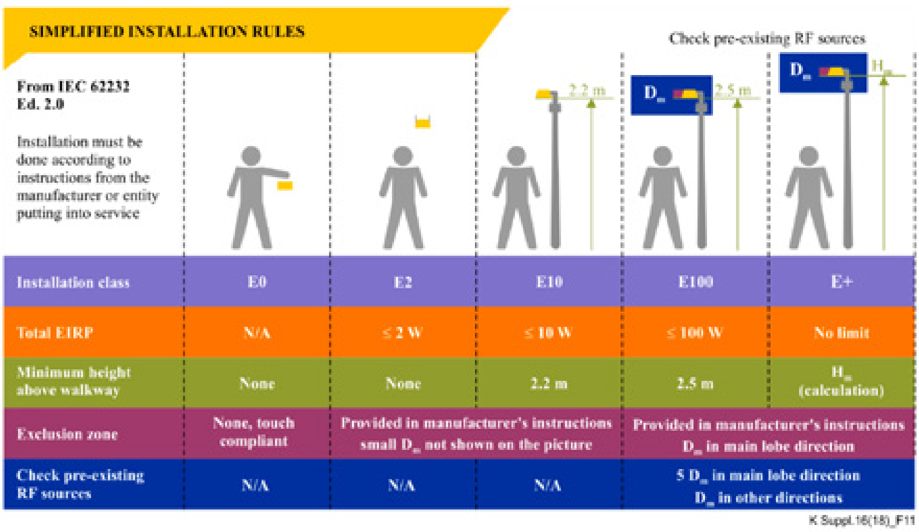


Figure 5.9: 5G NR gNodeB installation rules and exclusion criteria for home and indoor environments (ITU-T K.16 2018)

### 5.3.2 Outdoor deployment

Outdoor deployments are very similar to the indoor ones, with two distinct features:

- the power output of the BSs is significantly higher, compared to the indoor case,
- BSs utilize directional antennas,

- users are located further from the BSs. Due to these features, the exclusion zones for outdoor scenarios will be different from the ones presented in the previous chapter.

Table 5.3 and Table 5.4 depict the exclusion zone of a typical BS deployment with site collocation of all legacy technologies 2G, 3G and 4G based on the ICNIRP guidelines.

| Exclusion Zone [m] | 4G (800 MHz) | 2G (900 MHz) | 2G (1800 MHz) | 3G (2100 MHz) | 4G (2600 MHz) |
|---|---|---|---|---|---|
| Front | 2.5 | 2.5 | 2.3 | 2.3 | 2.5 |
| Side | 0.9 | 0.9 | 0.9 | 1.0 | 1.1 |
| Back | < 0.1 | < 0.1 | 0.1 | 0.1 | 0.2 |
| Top | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |
| Bottom | < 0.1 | < 0.1 | < 0.1 | < 0.1 | < 0.1 |

Table 5.3. Exclusion zone calculations (Outdoor, Output power: 37 dBm)

| Exclusion Zone [m] | 4G (800 MHz) | 2G (900 MHz) | 2G (1800 MHz) | 3G (2100 MHz) | 4G (2600 MHz) |
|---|---|---|---|---|---|
| Front | 14.3 | 14 | 10.1 | 9.7 | 9.9 |
| Side | 4.8 | 4.8 | 3.9 | 3.9 | 4.2 |
| Back | 0.4 | 0.4 | 0.5 | 0.5 | 0.6 |
| Top | < 0.1 | < 0.1 | 0.2 | 0.2 | 0.2 |
| Bottom | < 0.1 | < 0.1 | 0.2 | 0.2 | 0.2 |

Table 5.4. Exclusion zone calculations (Outdoor, Output power: 47 dBm)

It can be noticed from Table 5.3 and Table 5.4 that the exclusion zones will vary greatly with respect to the BS output power. Specifically, a 10 dB increase in the power output significantly proliferates the exclusion zone. Hence, operators must perform safety evaluations when updating the radio link-budget, cell coverage or installing new antennas on outdoor BS installations to ensure the safety of the public due to RF EMF exposure.

#### 5.3.2.1 Massive MIMO effects

As seen from the results in Table 5.2 deploying 5G results in an increase of the exclusion zone size. However, this increment is not very significant. It is approximately 12% for Legislation 1 and Legislation 2, and approximately 20 % for Legislation 3. The most noticeable difference in the exclusion zones can be noticed in the third deployment case, i.e., when deploying 5G NR with Massive MIMO. In this case, the exclusion zone is significantly larger. The main reason for the high discrepancy in zone size is the large number of antennas used in the system. Increasing the antenna array size will induce higher gains per beam, resulting in higher exclusion zones. Moreover, depicts the exclusion zone for a 5G NR FR2 gNodeB with 512 antenna elements and transmit power of 30 dBm. Massive MIMO is being deployed for the first time with 5G and should be analyzed separately from the other deployment types, related to legacy systems.

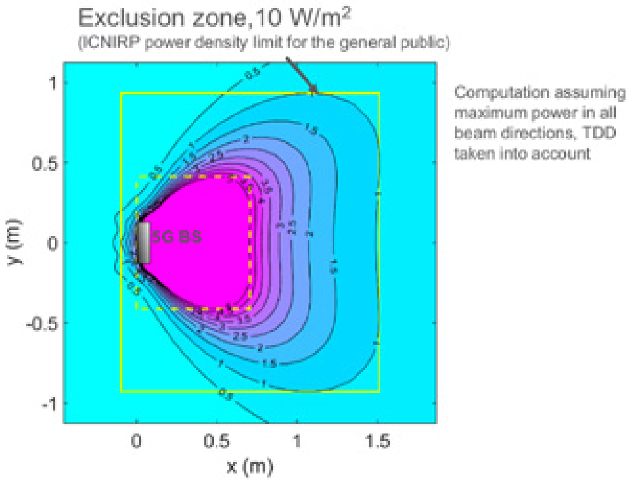


Figure 5.10. 5G NR gNodeB FR2 exclusion zone diagram (Törnevik 2017)

For low transmit powers, i.e., conventional deployment cases, the exclusion zones are very small, even for 5G NR with Massive MIMO, as seen in Table 5.2 and Figure 5.10. However, using the upper limits specified by 3GPP for deployments and exclusion zone calculation can prove to be a more complex task. For example, the exclusion zone for a gNodeB with Massive MIMO (64 elements) and ~72 dBm EIRP is depicted in Figure 5.11. In this example the exclusion zone is calculated with the assumption that the gNodeB constantly transmits with the maximal power level. However, 5G like current 2G, 3G and 4G networks, will not be designed to operate at maximum power except for very short times to handle traffic variations. This means that the transmitted power averaged over time periods of relevance for RF EMF exposure assessments, e.g., several minutes, is significantly lower than the rated maximum transmitted power for the equipment.

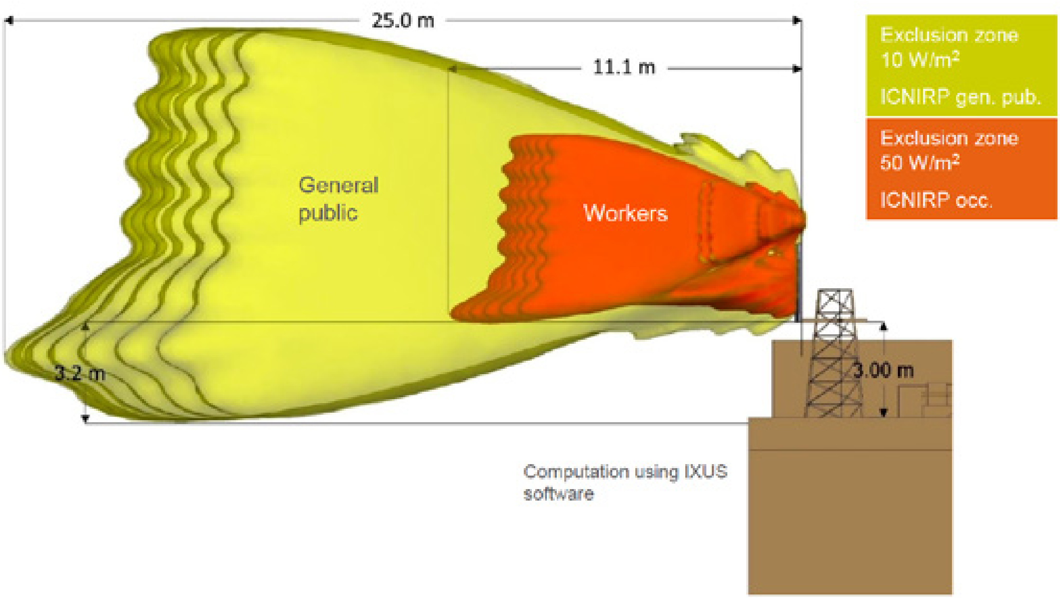


Figure 5.11. 5G NR gNodeB exclusion zone with Massive MIMO: Fixed maximal power (Törnevik 2017)

Moreover, using the maximum power will lead to overly conservative RF EMF exposure assessment and compliance boundaries, especially in the case of several different technologies and antennas at the site. To address this issue, both key documents (ITU 2019, IEC 2017) 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. For example, the **actual maximum power** can be taken as the 95th percentile value of the obtained power distribution (IEC 2019, ITU 2018). For RF EMF exposure assessments of 5G sites using Massive MIMO, it is important to accurately determine the actual maximum transmitted power. Massive MIMO base stations transmit several 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. The work in (IEC 2019) provides detailed guidance on how to determine the actual maximum power for Massive MIMO antennas. This must be taken into consideration by regulative bodies as well as mobile network operators when deploying such systems.

Table 5.5 depicts the gNodeB system configurations used for a specific case study calculation with respect to the real-world exclusion zones for 5G.

| | |
|---|---|
| Product name | 5G NR gNodeB (TDD) |
| Operating frequency band | 3400 MHz to 3600 MHz |
| Antenna array configuration | (8 x 8) array of cross-polarized antennas (128 antenna elements)<br>64 (2 x 1) sub-arrays (32 per polarization) |
| Tx/Rx configuration | 64T / 64R |
| Maximum gain | 23.7 dBi |
| Maximum scan range in the horizontal plane | ±60° |
| Maximum scan range in the vertical plane | ±20° |
| Downtilt | 3° |
| TDD duty cycle | 75 % |
| Total rated maximum power | 200 W |
| Maximum EIRP | 73.7 dBm |

Table 5.5. gNodeB configuration

The actual maximum transmitted power of the array antenna can be determined using the methodology described in IEC TR 62669 2019 and ITU-T K.16 2018 or the discussions provided in this section. Consequently, an actual maximum power of 50 W (25% of 200 W) was used for the 5G site exposure assessment.

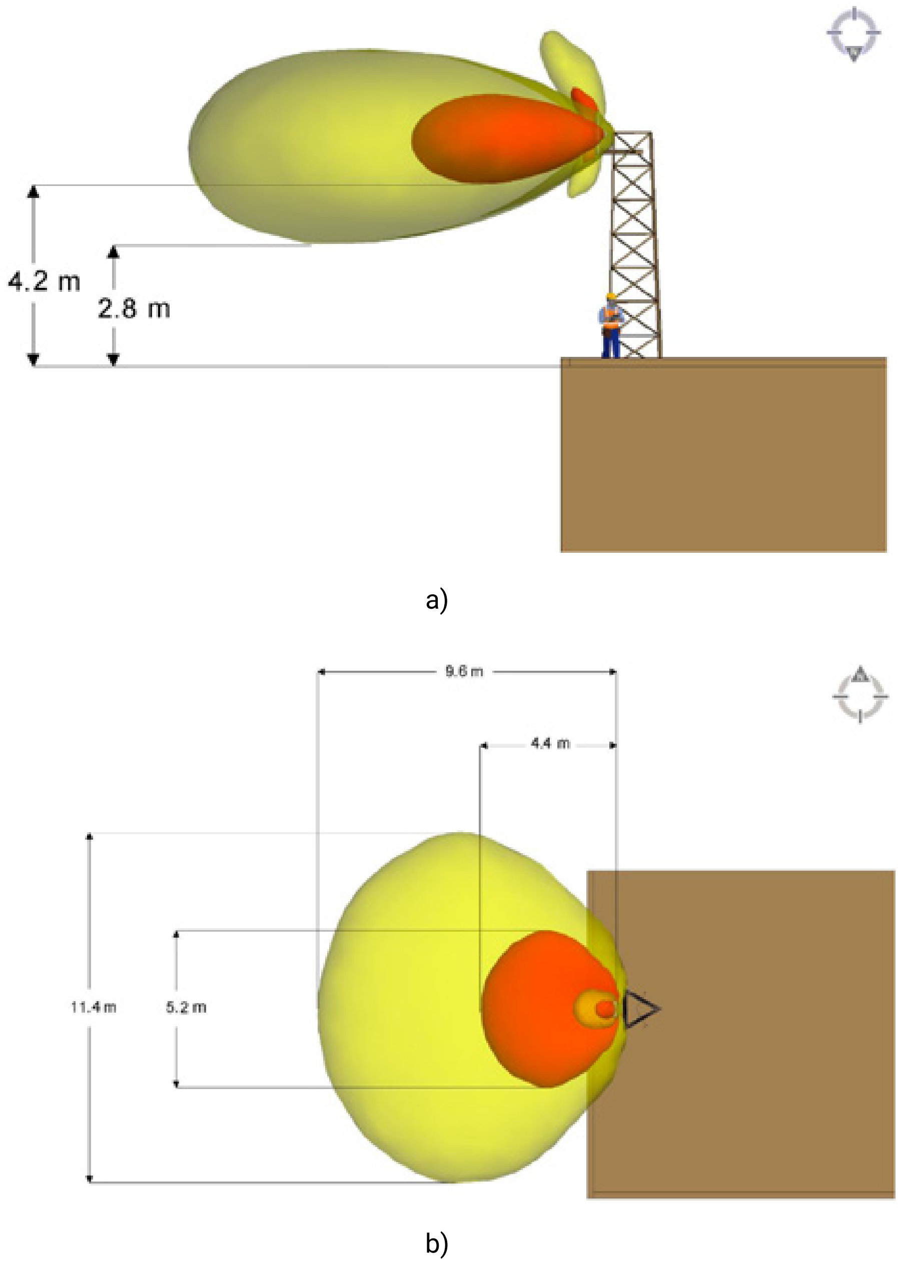


Figure 5.12. 5G NR gNodeB computed exclusion zones for the general public (yellow) and workers (red): a) vertical b) horizontal (ITU-T K.16 2018)

Figure 5.12 shows the resulting compliance boundaries (exclusion zones) for the public and workers at the evaluated 5G Massive MIMO rooftop site and for the actual maximum power of 50 W. The minimum vertical distance from the rooftop to the lower edge of the compliance boundary is 2.8 meter for the public and 4.2 meter for workers. In front of the base station antenna, the public RF EMF compliance distance is 9.6 meter. Assuming that the distance to adjacent buildings and areas accessible for the public is larger than this, the 5G site is compliant with the relevant limits.

## 5.4 Summary

This section provided an overview on the specific aspects related to mobile systems deployment with respect to the RF EMF exposure limits. As discussed in the section 5G in general does introduce some additional complexity in the deployment, because of the introduction of Massive MIMO. As such there are several takeaways that can be summarize:

- existing international exposure guidelines are not technology specific and apply to all new applications.
- some adaptations are required when calculating the exclusion zones for 5G Massive MIMO systems due to the large antenna array size and stochastic behavior.
- 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.

Without any spectrum or technology reframing strategy, the 5G technology could increase localized exposure resulting from wireless technologies during the transition period. However, in North Macedonia, spectrum reframing is heavily relied on, see section 3 (spectrum band allocation). However, for the mmWave band it is important to include the Agency for Electronic Communication (AEC) from North Macedonia at an early stage in establishing how 5G can be deployed and activated and compliance with national assessed limits.

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# Chapter 6

## 6 Analysis of the situation in North Macedonia – existing mobile communication networks, construction of 4G and 5G networks and the role of AEC

The entry of other mobile operators in North Macedonia brings quality and competition, and the users could choose for certain funds what types of services they want to use, thus giving the operator an incentive to develop its mobile communication network and develop competition.

Thus, with the gradual development of technologies, we come to the technologies 4G, 5G and 6G, in the part of mobile telecommunication networks, technologies that besides broadband high internet have other excellent features in the part of providing appropriate communication services to the users. Theoretical review of the differences between 4G and 5G is given. The advantages of 5G are emphasized and with appropriate examples and tests will show the goals of the entire Scientific study on the benefits of 5G technology and opportunities for further development in 6G technology, etc., and on the other hand whether there are or are some dangerous effects of this type of technology on ecology, the environment that surrounds us and most importantly on human life itself. Appropriate pre-measurements from the tests with sophisticated measuring equipment are presented by reading parameters that will help in better display the impacts of the telecommunication devices themselves used in 5G.

Quality telecommunication infrastructure and network nowadays must be owned and upgraded by every Operator of electronic communication network because the technical-technological development requires fast and always included connections and communications through mobile networks, thus the progress and development or transition from development technologies to 4G in 5G and from 5G to 6G etc. in the future it is extremely important.

### 6.1 The beginnings of mobile telephony and the current situation in North Macedonia

The first base stations and construction of the first mobile operator, Mobimak AD Skopje, as part of the company Makedonski Telekom AD Skopje, were built in the mid-1990s, and later this operator was renamed T-Mobile MK. In fact, the beginnings of mobile technologies and construction of mobile networks in North Macedonia begin with the mobile operator Mobimak AD Skopje with the beginning of the development of the technologies themselves, starting from 2G, 3G and the current 4G existing technologies for the functioning of electronic mobile communications.

The entry of other mobile operators in North Macedonia brings quality and competition, and the users could choose for certain funds what types of services they want to use, thus giving the operator an incentive to develop its mobile communication network and develop competition. Later, between 2002 and 2007, the following appeared in North Macedonia: Cosmofon Skopje and a little later VIP DOOEL Skopje, which started building their own network based on 3G technology. Today in North Macedonia there are two mobile operators that provide public electronic communication services to users after the merger of mobile operators ONE DOO Skopje (formerly Cosmofon Skopje) and VIP DOOEL Skopje and Makedonski Telekom AD Skopje, after Mobimak AD Skopje was renamed or rebranded into T-Mobile Macedonia AD Skopje and later merged with the fixed operator of electronic public communication services Makedonski Telekom AD Skopje, which means the two mobile operators are A1 Operator DOOEL Skopje (after the merger of One Operator and VIP Operator) and Makedonski Telekom AD Skopje. Besides them, in North Macedonia there are so-called virtual operators such as Laika Mobile DOOEL Skopje, Telekabel DOOEL Skopje and Green Telekom Prilep, which are actually mobile operators that use another leased network to provide mobile electronic communication services to their customers.

## 6.2 Broadband internet access and its importance

Digital data transmission has an increasing role in the lives of citizens and in the operation of public institutions and enterprises. The vast availability and speed of the Internet, which enables broadband Internet access, are key to helping companies in Europe maintain their competitiveness in a global society. For example:

- Increasing the number of broadband connections in certain countries by 10% would lead to an increase in GDP per capita of 1 % per year.
- Increasing the number of broadband connections by 10% could lead to a 1.5% increase in labor productivity over the next five years.
- Investments in broadband internet access will contribute to providing quality education, improving the social inclusion of people, and will also benefit rural and remote regions.
- Some experts believe that broadband internet access is so important that it could be placed in the category of basic utilities, along with communal hygiene, electricity, heat.

Otherwise, “Broadband” in the context of Internet access has no special technical significance but is used to describe any infrastructure for high-speed Internet access that is always available and fast compared to traditional telephone line access. There are three categories of data download speeds defined:

- “Basic access” with speeds from 144 Kbps to 30 Mbps.
- “Fast access” with speeds from 30 Mbps to 100 Mbps.
- “Ultrafast access” with speeds greater than 100 Mbps.

Broadband access network generally consists of three parts: network base or skeleton, aggregate network, and access network.

When estimating internet speed, it is important to distinguish between data download speeds and data loading speeds. Data download speed and data upload speed. Data download speed refers to the speed of receiving data from a remote level, examples when searching the Internet or transferring video content, while data loading speed refers to the speed of sending data at a remote level, for example when maintaining video conferencing. Some other technical features are increasingly important for the provision of certain services (such as video conferencing, complex cloud computing operations, networked driving, and e-health).

The current use of infrastructure networks determines the upper limit of the speed of Internet use. There are five types of broadband access infrastructure: fiber optics, coaxial cables, copper telephone lines, terrestrial wireless equipment (antenna stations/poles), and satellites. Rapid technological development makes available a growing number of other technologies that can be used to provide high-speed broadband Internet services.

In any case, the actual speed in practice, which would be available to users, depends on the service provider and the technical upgrades and capacities of the network itself and its components.

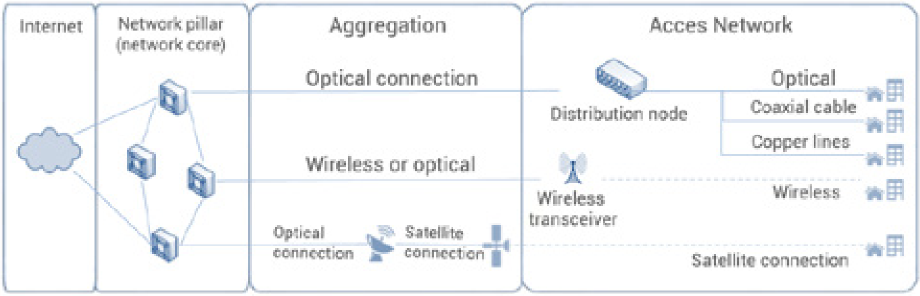


Figure 6.1: Broadband View

Hybrid broadband internet solutions are a network of copper telephone lines combined with a 4G mobile network to provide users with access speeds, so that a special access (modem type) is used for them. Such solutions are mostly used in Belgium and the Netherlands, and thanks to them speeds of up to 50 Mbps are achieved in areas that were not previously sufficiently covered by the Internet.

The satellite industry currently provides satellite broadband access to the next generations. There are two new innovations in satellites, and that is their high permeability and their non-geostationary position. The use of this type of satellites provides access to Internet speeds greater than 30 Mbps, so that in the future they could be available to a larger number of users in rural or remote areas.

The fifth generation 5G mobile networks make up the next generation of standard wireless telecommunications. When planning a 5G network, the goal is to increase the capacity compared to the existing 4G network, which should provide greater density of users of mobile broadband Internet access and support device-to-device communication, as well as mass and secure communication between devices. 5G mobile networks have three elements:

- Improved mobile broadband access (on-the-go access).
- Mass use of the Internet.
- Mission critical services, eg self-driving cars).

For the 5G network, the aggregation network must be based on fiber optic infrastructure, which makes the 5G network a complement to the high-speed broadband networks, which would be available near the end users, but certainly cannot replace them.

## 6.3 Objectives for the introduction of 5G

It is very important to note that in North Macedonia because in 2020 the testing of 5G network placement was started by the operators of public mobile electronic networks in North Macedonia, such as A1 Operator and Makedonski Telekom, and in that context the activities of mobile network operators were reduced to testing 5G to 14.07.2020 at 3.7-3.8 GHz (by the A1 Operator) and to 31.10.2020 to 3.6-3.7 GHz (by Makedonski Telekom).

In April 2019, the Ministry of Information Society and Administration in cooperation with the Agency for Electronic Communications prepared a National Broadband Strategy which sets out the following objectives:

- By the end of 2023, at least one major city to be covered by 5G signal.
- By the end of 2025, the highways and highways/main corridors of the basic and comprehensive road network in the country determined by the Agency to be covered with uninterrupted 5G signal.
- By the end of 2027, all cities in the country to be covered with uninterrupted 5G signal.
- By the end of 2029, everyone should be able to access the Internet via 5G with a minimum internet access speed of at least 100 Mbps.
- By the end of 2029, at least 50% of the total number of subscriber agreements of households in the entire country, to have Internet access of at least 100 Mbps.
- By the end of 2029, all households at an affordable price to have access to a network that provides download speeds of at least 100 Mbps with the ability to upgrade to gigabit speed.
- By the end of 2029, all public institutions (schools, universities, research centers and other educational institutions, health institutions, ministries, courts, local governments and other state bodies and bodies), to have symmetrical Internet access at a speed of at least 1 Gbps.

## 6.4 Benefits of 5G implementation

The main benefits of 5G networks are usually expressed through the technical parameters of:

- increased speed up to 10 Gbps,
- delay less than 1 ms,
- 1000 times increased bandwidth,
- 100 times more connected devices,
- 99.99 % availability,
- 100 % coverage.

However, despite significant improvements in the speed and reliability of relationships, the main benefits that go beyond traditional electronic communications lie in the evolution of new business models and different types of clients and partnerships.

With the implementation of the 5G architecture, operators can directly support the vertical industries and contribute to their mobilization. The partnerships that can be established are multi-layered, starting from simple sharing of infrastructure, by opening specific network features in the form of available service, to integrating the partners in a system with the help of software-oriented architecture. The values that are created include transparent and comprehensive availability, delivery of consistent quality of service, different types of interaction, personalization of services, highly promising communication.

The range of services that can be radically innovated and offered through this architecture is the main motivator for the development of every industrial sector. The mobile connected society and the fully digital infrastructure offered by 5G are a prerequisite for the development of modern industry, and thus the growth of the economy. Therefore, the implementation of this technology is an investment in the potential for opening new markets and opportunities to encourage development in several different fields from smart farming to smart factories.

It is considered that the implementation of 5G technology will be managed by the vertical industry, an ecosystem of technical and business integrated network solutions in a programmable and unified infrastructure. 5G technology is expected to be applied in the automotive industry, public safety, healthcare, financial sector, utilities, high-tech manufacturing, internet/digital homes, healthcare, media/games, etc.

## 6.5 Defined 5G pilot examples for use

One of the reasons that the definition of 5G standard and network architecture is still incomplete is because unlike other wireless network upgrades, the architecture and implementation of 5G depends on how and what the network will be used for. For example, the analysis shows that video traffic is expected to grow significantly in the next period, which means that there will be a need to provide higher speeds for applications such as support for streaming video, video conferencing and high-resolution virtual reality. To achieve this level of performance, the network will need to be built from several small cells that will achieve not only coverage but also higher utilization of the available bandwidth. At the same time, a few 5G pilot implementations are based on the use of the network as a basis for building IoT. To provide support for a huge number of devices, many of which require longer battery life, the 5G network must operate extremely efficiently in low-bandwidth transmission, where speeds are not important but good coverage and reliability are.

According to the ITU, IMT-2020, three main scenarios of using 5G technology have been identified, according to which the development of specific services with specific requirements depending on the industry (sector) in which they will be identified is underway:

- mMTC–Massive Machine Type Communications. Many connected devices with different service quality requirements. The aim is to provide a response when the density of connected devices increases exponentially.
- eMBB – Enhanced Mobile Broadband connections mobile broadband internet with ultra-high speeds (indoors and outdoors) with uniform quality of service.
- URLLC – Ultra-reliable and Low Latency Communications. This scenario has special requirements such as latency to ensure increased response speed.

Within the definitions of 5G networks are defined groups of families of examples of typical use of 5G:

- broadband access in dense environments, examples: Ubiquitous video, smart offices, cloud services, high resolution video sharing.
- broadband everywhere, examples: more than 50 Mbps everywhere, ultra-cheap networks.
- high user mobility, examples: high speed trains, remote calculations, mobile hot spots, 3D drone connectivity.
- extreme real-time communications, examples: tactile internet.
- emergency communications, examples: natural disasters.
- ultra-hopeful communications, examples: automated traffic and driving control, collaborative robots, e-health, remote operations, drone control, public safety.
- broadcasting services, examples: real-time news and information, local cell-level

services, regional services, national services.

## 6.6 AEC's role as a regulatory body in the field of electronic communications in the mobile telephony market

AEC's role as a regulatory body is the most important in the part of giving directions to the operators, in the part of the construction of networks themselves, as well as in the part of construction and functioning of 5G networks and their impact on the environment.

Certain types of documents are needed for network construction and the role of AEC in the entire administrative procedure according to the legislation is described in detail below in the text, to clarify certain dilemmas that appear in practice as unclear and create certain confusions and misunderstandings.

## 6.7 The only point of information application for submitting data for newly built Electronic Communication Networks (ECN) with new functionalities

The only point of information allows operators who want to build a public communication network to easily access information about the current situation with infrastructure facilities of other owners in the planned construction area, namely: data on the type, basic technical characteristics and horizontal and vertical layout of underground and aboveground infrastructure facilities and associated installation, as well as data on the entities that manage them. The single information point also provides information on the manner and conditions for obtaining a building permit, in accordance with the Law on Construction, the Law on Spatial and Urban Planning and other bylaws.

The only point of information, fulfills the obligations arising from the Law on Electronic Communications (LEC), which relate to:

- giving consent to the basic project for construction of a public electronic communication network and associated means (Article 8, paragraph 22).
- giving opinions during the procedure of preparation and adoption of documents for spatial planning (Article 8, paragraph 23).
- giving consent for the fulfillment of the special conditions for performance of works in the zone of the electronic communication network and the accompanying means; (Article 8, paragraph 24, Article 65).
- enabling the municipalities, the municipalities in the City of Skopje and the City of Skopje through ETI to submit information regarding the planned construction of a public electronic communication network and means (Article 67, paragraph 3).
- Improved coordination of construction works financed with public funds (Article 68, paragraph 5, Article 75, paragraph 5).

WEB GIS application for submission of data for the newly built ECN fulfills the obligations arising from the Law on Electronic Communications, which refer to:

- providing information on access to physical infrastructure in a high-speed building (Article 69, paragraph 5).
- upgrades the additional functionalities of the Single Information Point and the WEB GIS application for submission of data for the newly built ECN, in full, in accordance with the requirements specified in the tender documentation.

## 6.8 Giving opinions and consents by AEC

The Telecommunications Department of the Agency for Electronic Communications in its scope of work has an obligation in accordance with the LEC, and thus in accordance with the work obligations and tasks, with the help of functionalities of the Single Information Point and the WEB GIS application for submitting data for newly built ECN. The applications issue opinions and consents at the request of the user for:

- giving consent to the basic project for construction of a public electronic communication network and associated means.
- giving opinions during the procedure of preparation and adoption of documents for spatial planning.
- giving consent for the fulfillment of the special conditions for performance of works in the zone of the electronic communication network and the accompanying means.

For Consent of the basic project for construction of public ECN the applications enable electronic submission of the basic project for construction of public electronic communication network and associated means by the user / operator of ECN. When submitting the basic design electronically, the user must submit information on the spatial location of the construction project. Spatial placement can be provided in one of the following ways by:

- manually drawing a point, line or polygon, depending on the ECN topology.
- drawing the geography and / or scope of the ECN based on coordinates loaded from the shp file.
- attaching a pdf or dwg file that contains information on the spatial layout of the ECN or the construction scope.

The electronically submitted request should automatically create an entry in the electronic archive and in the document management system of AEC. The applications enable the preparation of a response to the submitted request, which consists of a text part and a graphic attachment. In the preparation of the textual part of the answer, the employee of the Telecommunications Department of AEC, who prepares the answer, could choose between several standard templates, where in each template there is an opportunity to insert free text. When preparing the graphic report, the data from the GIS database of AEC are used, where the employee who prepares the answer should have the opportunity to choose which thematic layers to include in the report. The applications enable electronic submission of documentation for spatial planning to provide an opinion from the AEC during the procedure of preparation and adoption of the documentation. When submitting the spatial planning documentation, the user must submit information on the spatial location of the scope of the spatial planning documentation. Spatial placement can be provided in one of the following ways:

- with manual drawing of a polygon.
- draw the scope of based on coordinates loaded from the shp file.
- by attaching a pdf or dwg file that contains information about the spatial layout of the spatial planning documentation.

The electronically submitted documentation automatically creates an entry in the electronic archive and in the document management system of AEC, which enables the preparation of an opinion based on the submitted documentation. The opinion should consist of a textual part and a graphic attachment. In the preparation of the textual part of the opinion, the employee who prepares the opinion should have the opportunity to choose between several standard templates, where each template should have the opportunity to insert free text. During the preparation of the graphic report, the data from the GIS database of AEC are used, where the employee in the Telecommunications Sector of AEC, who prepares the opinion, can choose which thematic layers to include in the report.

Consent for fulfillment of special conditions for performance of works in the area of ECN, the applications enable electronic submission of a request for issuance of consent by the AEC for the fulfillment of special conditions for performance of works in the zone of the electronic communication network and associated means.

## 6.9 Challenges in the implementation of 5G in North Macedonia

To support the 5G implementation in the test phase, but also the commercial phase that should follow, the current situation in North Macedonia indicates a number of challenges that need to be addressed or regulated. Operators are expected to invest in two key areas:

- Infrastructure investments. Mainly to build a dense optical network infrastructure to ensure the connection of 5G base stations, as well as to finance their installation. The next generation of 5G wireless networks will support applications that require high speeds. One of the solutions in that case is to enable higher density of base stations by placing small cells.
- Investments in service innovation. To stimulate the emergence of new 5G services. This includes funding for pilot projects that will demonstrate and test potential 5G features and enable the development of new services.

The implementation of the 5G architecture mainly depends on the small cell installation capabilities and the level of connectivity to the kernel system using a high-bandwidth network infrastructure based on optical technology. This process is currently laborious due to various complications that occur when finding a location for a new base station and obtaining permission to set it up, as well as due to the procedures to be followed when installing the cable network infrastructure.

From this point of view, it is necessary to provide legal and economic relief to mobile operators so that:

- when finding locations for new base stations it is necessary to facilitate the conditions for installing the appropriate equipment.
- the need for locations should be considered when planning the construction of new facilities i.e. the possibility of setting up base stations on the facilities should be provided.
- the cost of setting up network infrastructure will be reduced.
- to respect the obligation from article 63 and article 69 in the LEC to build new facilities with obligatorily installed optical infrastructure.

To make the most of the opportunities offered by the 5G architecture and to attract the widest possible range of end users, which means a wide range of different service quality requirements, the implications for network neutrality should be set at the level of the network layer that will enable the definition of a set of layers with different levels of service quality that will be intended for different applications. In addition, the defined rules for network neutrality should be in accordance with the norms prescribed by the EU.

The use of 5G services largely depends on the end users and the benefits they receive. However, to provide a truly connected society such as the goal of 5G, it is necessary to work on providing skills to citizens as end users so that they can enjoy the benefits offered by this ecosystem. In other words, projects are needed that will be aimed at raising the level of digital skills of the citizens. Such an investment will also mean supporting economic development as a society with a higher level of digital skills will create a new market through new service demands from providers.

The development of 5G networks and services requires support from the institutions relevant for the regulation of electronic communications and the construction of electronic communications networks, as follows:

- to prepare procedures and administrative procedures that will enable quick and easy obtaining approvals for the construction of the new 5G network,
- much of the benefits of 5G technology will be based on the density of base stations in the network itself, primarily due to the use of higher frequencies in populated areas.

Due to this, there will be a need to set up base stations in places for which the current legislation does not allow it (e.g.: along roads, installation of equipment on existing lighting poles, bus stops, poles of power lines, etc.).

Due to this, it is necessary to adjust the relevant laws to enable the installation of 5G equipment and such facilities, as well as the installation of optics next to them:

- regulation of installation of equipment for mobile network with small size and output power, should be in accordance with legal conditions for installation of urban equipment (without approval / solution), and with a very simple and fast procedure,
- when building the new 5G networks to consider the possibility of shared use and to avoid building parallel networks by business users in the so-called. "Campus networks" in large industrial complexes, hospitals, and other institutions, in accordance with Article 75 of the LEC, Coordination of radio frequencies for 5G.

The Agency for Electronic Communications (abbreviated AEC) conducted a procedure for Public Call for submission of Opinions for obtaining Authorizations for use of 5G radio frequencies (Posts). Specifically, on April 20, 2020, the deadline for submitting Opinions ended. This deadline was scheduled to end on March 6, 2020, but due to the new situation in the country with the Corona virus COVID - 19 and at the request of the two network operators in North Macedonia, Makedonski Telekom and A1 Operator, to extend the deadline, the deadline was extended. As of April 20, 2020, AEC (Agency for Electronic Communications) received Opinions from several interested parties, such as: operators in North Macedonia, citizens of North Macedonia and other interested foreign companies. Until this moment, all steps are implemented in accordance with the dynamics provided in the NOBP (National Operational Broadband Plan) which was adopted by the Government of North Macedonia on 02.04.2019. All received Opinions in the coming period are reviewed by the expert service of the Agency and will be properly implemented in the legal procedure provided in accordance with the LEC - Law on Electronic Communications for the allocation of these frequencies. It should be noted that according to the National Liberation War, the tender procedure for allocation of radio frequencies intended for 5G is expected to begin in late 2020. After summarizing the received Opinions and in accordance with the existing regulations in North Macedonia, which is in line with the European one, the conditions will be prescribed which will be listed as a kind of Requirements that the operators that will receive the Authorizations for use of radio frequencies will need and must to meet.

According to the LEC, one of the competencies of the AEC is to measure, as I mentioned above in my presentation, the non-ionizing radiation from all transmitters that emit electromagnetic waves. This means that even with the introduction of 5G, it remains the responsibility of AEc. Measurements are performed continuously, at the request of the user or in accordance with a pre-defined location measurement plan. So far, AEC has conducted measurement of non-ionizing radiation at several locations of the 5G test network of Makedonski Telekom, for which a Temporary Test Approval has been issued until 31.10.2020 for the band from 3.6 GHz to 3.7 GHz on the territory of Skopje. The results show that the maximum allowable level, according to the International Commission for Protection against Non-ionizing Radiation Protection (ICNIRP), the cumulative radiation is 14.9% (of the maximum allowable value of the electric field). All the results shown are far from the critical limit that would be harmful to human health. It must be noted that the radiation decreases with increasing distance.

The A1 Operator on the territory of Skopje has also received temporary approval for testing the 5G test network, valid until 01.07.2020.

## 6.10 Optical Infrastructure for 5G operation

From the generic concepts of 5G itself, it is clearly emphasized that in any scenario, 5G will require significant capacity in the background network infrastructure, which will result in a huge number of connections in the domain of optical networks.

Although it is possible to use fixed wireless connections for background network infrastructures in more remote areas, the need for higher data rates will require access to fiber optic networks to be a vital element in the introduction of 5G, especially in scenarios and locations where small cells with high capacity.

Although most of the investment, which is needed for the introduction of new optical network resources and 5G, should be provided by the private sector, the public sector, i.e.. The government will encourage a range of initiatives and activities to increase access to optical infrastructure. An example of such a thing is the determination of so-called white zones (zones in which there is no commercial interest in building an electronic communications network) which are obtained through an appropriate mapping procedure.

### 6.10.1 Infrastructure sharing

Infrastructure sharing, in accordance with concisely defined competition rules, can be an effective and economically efficient way of introducing and implementing 5G telecommunications infrastructure, especially in areas where it is unprofitable to introduce more competitive network infrastructures. However, in parallel, the need to protect and guarantee the investment interests of operators should be considered. In general, infrastructure sharing can be divided into two categories, passive, or active sharing.

Passive sharing is generally defined as the sharing of space or physical infrastructure that does not require active operational coordination between network operators. For example, sharing a location for a base station or antenna tower is a form of passive sharing.

Active sharing is an approach when operators share an active telecommunications infrastructure. For example, shared network sharing or national roaming are specific realizations of active sharing.

The competent state bodies and bodies in cooperation with the AEC identify the unnecessary obstacles for sharing the existing telecommunication infrastructure. Additionally, this cooperation would result in the development of a more stable and robust sharing framework, which would significantly speed up and facilitate the process of 5G implementation in North Macedonia.

## 6.11 4G vs. 5G: The key differences between the cellular network generations

Every decade the cellular industry performs a major upgrade to its wireless infrastructure. The 2000s were dominated by 3G, while mobile phones in the last decade ran on 4G. Here is a breakdown of the major differences between the two networking technologies.

### 6.11.1.1 Speed

In most conversations about 5G, speed is often the spec that is used to differentiate it from 4G. And that makes sense since each cellular generation has been significantly faster than the one before. 4G can currently reach top speeds of up to 100 Mbps, though real-world performance is generally no more than 35 Mbps.

5G has the potential to be 100 times faster than 4G, with a top theoretical speed around 20 Gbps and current, real-world speeds from 50 Mbps to 3 Gbps.

There are three main flavors of 5G, and each one has its own speed. The so-called low band 5G is somewhat faster than 4G with performance around 50-250 Mbps. The fastest version of 5G, called high band 5G, is the version that reaches 3 Gbps. For details, read our article on the three ranges of 5G frequency.

### 6.11.1.2 Latency

Latency is a measure of the time it takes a packet of information to travel between two points. It can be thought of as the delay that taxes any data transfer, no matter how fast the connection otherwise is. Latency in 4G networks is currently about 50ms, while 5G networks are expected to shrink that to an impressive 1ms.

Reducing latency will be critical for many applications where 5G will allow connected devices to rely on the cloud for processing of data — such as self-driving cars that might use 5G to let a cloud-based AI make real-time navigational decisions.

### 6.11.1.3 Bandwidth

5G is expected to have significantly more bandwidth, or capacity, than 4G as well. In part, this is because 5G will make much more efficient use of available spectrum. 4G uses a narrow slice of the available spectrum from 600 MHz to 2.5 GHz, but 5G is divided into three different bands. Each band has its own frequency range and speed and will have different applications and use cases for consumers, businesses, and industries.

## 6.12 Draft Internal Report on the EU 5G Cyber Security Strategy

5G networks will play a central role in achieving the digital transformation of the EU's economy and society. Indeed, 5G networks have the potential to enable and support a wide range of applications and functions, extending far beyond the provision of mobile communication services between end- users. With worldwide 5G revenues to reach an estimated €225 billion in 2025, 5G technologies and services are a key asset for Europe to be able to compete in the global market.

The cybersecurity of 5G networks is therefore essential to protect our economies and societies and to enable the full potential of the important opportunities they will bring. It is also crucial for ensuring the technological sovereignty of the Union.

Following the support expressed by the European Council on 22 March 2019 for a concerted approach to the security of 5G networks, the European Commission adopted its Recommendation on the cybersecurity of 5G networks (hereafter 'The Recommendation') on 26 March 2019. The Recommendation called on Member States to complete national risk assessments and review national measures, to work together at EU level on a coordinated risk assessment and to prepare a toolbox of possible mitigating measures.

Each Member State completed its own national risk assessment of its 5G network infrastructures and transmitted the results to the Commission and ENISA - the European Union Agency for Cybersecurity.

Based on these national risk assessments, on 9 October 2019 Member States - with the support of ENISA and the Commission - published a report on the EU Coordinated Risk Assessment on Cybersecurity in 5G Networks2. This report identifies the main threats and threat actors, the most sensitive assets, the main vulnerabilities (including technical ones and other types of vulnerabilities, such as the legal and policy framework to which suppliers of information and communications technologies equipment may be subject to in third countries), and the main associated risks. To complement this report and as a further input for the toolbox, ENISA carried out a dedicated threat landscape mapping, consisting of a detailed analysis of certain technical aspects, in particular the identification of network assets and of threats affecting these.

The EU coordinated risk assessment report highlights several important security challenges which are likely to appear or become more prominent in 5G networks. These security challenges are mainly linked to:

- increasing security concerns related to the availability and integrity of the networks, in addition to the confidentiality and privacy concerns.
- key innovations in the 5G technology (which will also bring a few specific security improvements), in particular the increased important role of software and the wide range of services and applications enabled by 5G networks; and
- the role of suppliers in building and operating 5G networks, the complexity of the interlinkages between suppliers and operators, and the degree of dependency on individual suppliers.

The report further concludes that these challenges create a new security paradigm, making it necessary to reassess the current policy and security framework applicable to the sector and its ecosystem, and making it essential for Member States to take the necessary mitigating measures.

The EU coordinated risk assessment report provides the basis to identify mitigation measures that can be applied at national and European level.

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Following the support expressed by the European Council on 22 March to a concerted approach to the security of 5G networks, the European Commission adopted the Commission Recommendation Cyber security of 5G network2 (hereafter 'The Recommendation'). The Recommendation identifies a few concrete actions, which will support the development of a Union approach to ensuring the cyber security of 5G networks. In particular, it requests each Member State to carry out a national risk assessment of the 5G network infrastructure.

In July 2019, Member States submitted the results of their national risk assessments to the Commission and ENISA, based notably on a questionnaire. The information provided by Member States allowed the collection of information on main assets, threats and vulnerabilities related to 5G infrastructure and main risk scenarios, describing potential ways in which threat actors could exploit a certain vulnerability of an asset to impact government objectives.

Member States were asked to answer the questionnaire based on the results of their national 5G cybersecurity risk assessments, from the perspective of the governments (i.e., legislators/regulators), supported, where necessary, by other stakeholders' views (including network operators or suppliers). The work to develop national risk assessments involved a range of responsible actors in the Member States, such as, in particular, cybersecurity and telecommunication authorities, security, and intelligence services.

According to the Recommendation, these national risk assessments should form the basis for a coordinated Union risk assessment. For this purpose, EU Member States agreed this high-level report, which was prepared with the support of the Commission and together with ENISA.

To complement this report, ENISA is finalizing a dedicated threat landscape mapping, which consists of a detailed analysis of certain technical aspects, in particular the identification of network assets and of threats affecting them specifically.

This high-level report sets out the key common findings emerging from the national risk assessments of 5G networks carried out by each Member State. It highlights the elements that are of particular strategic relevance for the EU. As such, it does not aim at presenting an exhaustive analysis of all relevant aspects or types of individual cybersecurity risks related to 5G networks.

This report represents a first step in a process aimed at ensuring the solid and long- term security of 5G networks. As the 5G technology and the connected applications evolve, and in view of the fast-moving threat environment, this report may be reviewed annually or when necessary, within the NIS Cooperation Group. Any future reviews should consider relevant developments at national level.

The coordinated Union risk assessment will serve as a basis for the preparation of a toolbox of possible risk mitigation measures. This is in line with the Recommendation, which calls on Member States to agree on a toolbox by 31 December 2019. This will be carried out within the NIS Cooperation Group.

### 6.13 Key technological novelties of 5G networks

From a technological perspective, 5G networks will make use of several new technical features, compared to the current situation in existing networks:

- A move to software and virtualization through Software Defined Networks (SDN) and Network Functions Virtualization (NFV) technologies. This will represent a major shift from traditional network architecture as functions will no longer be built on specialized hardware and software. Instead, functionality and differentiation will take place in the software. From a security perspective, this may bring certain benefits by allowing for facilitated updating and patching of vulnerabilities. At the same time, such increased reliance on software, and the frequent updates they require, will significantly increase the exposure to the role of third-party suppliers and the importance of robust patch management procedures.
- ‘Network slicing' will make it possible to support to a high degree the separation of different service layers on the same physical network, thus increasing the possibilities to offer differentiated services over the whole network. Network slicing features will require the roll-out of a new core network, i.e., replacing the 4G core network with a 5G core network, following the so- called "Stand-Alone" network architecture.
- Enhanced functionality at the edge of the network and a less centralized architecture than in previous generations of mobile network: this is reflected both in enhanced connectivity options within the radio access network, and in support for ‘Mobile Edge Computing', which allows the network to steer traffic to computing resources and third-party services close to the end-user, thus ensuring low response times.

These new features will bring numerous new security challenges. In particular, they will give additional prominence to the complexity of the telecoms supply chain in the security analysis, with various existing or new players, such as integrators, service providers or software vendors, becoming even more involved in the configuration and management of key parts of the network. This is likely to intensify further the reliance of mobile network operators on these third-party suppliers. In addition, the distribution of responsibilities will also become more complex, with the specific challenge that some new players lack familiarity with the mission-critical aspects of telecom networks. This source of risk will become even more important with the advent of network slicing, the differing security requirements per slice and the subsequent increase in attack surface.

Moreover, some sensitive functions currently performed in the physically and logically separated core are likely to be moved closer to the edge of the network, requiring relevant security controls to be moved too, in order to encompass critical parts of the whole network, including the radio access part. If not managed properly, these new features are expected to increase the overall attack surface and the number of potential entry points for attackers, as well as increase chances of malicious impersonation of network parts and functions.

At the same time, 5G technologies and standards could improve security compared to previous generations of mobile networks, due to several new security functions, such as stricter authentication processes in the radio interface. These new security features will however not all be activated by default in the network equipment, and therefore their implementation will greatly depend upon how the operators deploy and manage their networks.

## 6.14 Current AEC Activities about the implementation of 5G technology in North Macedonia

On its own initiative and based on a request received from an operator in North Macedonia, on 01.06.2021 the Agency for Electronic Communications announced a public intention to conduct a public tender procedure with public bidding for the issuance of a limited number of approvals for use of radio frequencies to enable public debate on the published number of approvals for use of radio frequencies.

According to the Plan for allocation and using of the radio frequencies in North Macedonia (Official Gazette of RSM, no. 60 from 17.03.2021), the bands 694 – 790 MHz, 3400 – 3800 MHz and 24.25 – 27.5 GHz are intended for public mobile / fixed communication MFCN networks, including IMT-2020 / 5G networks. The conditions of use are determined by the provisions of Decisions ECC / DEC / (15) 01, ECC / DEC / (11) 06, ECC / DEC / (18) 06, Recommendations ECC / REC (15) 01, ECC / REC / (15) 01, ECC / REC (20) 01, ECC / REC / (19) 01 and standard MKS EN 301 908.

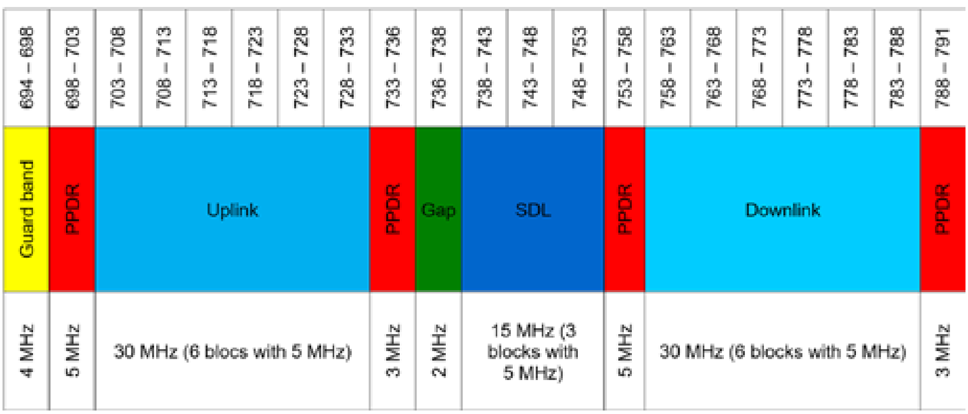


Figure 6.2: Frequency allocation in 700 MHz band

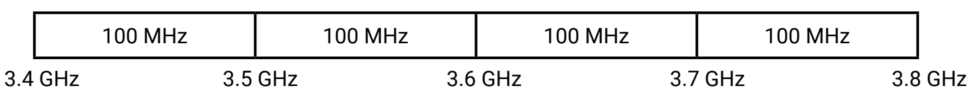


Figure 6.3: Frequency allocation in 3.5 GHz band

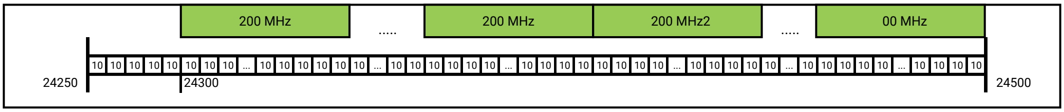


Figure 6.4: Frequency allocation in 26 GHz band

Subject of the public tender are:

- 2×30 MHz in the frequency range 694 – 790 MHz,
- 328.5 MHz in the frequency range 3400 – 3800 MHz and
- 800 MHz in the frequency range 24.25 – 27.5 GHz.

### 6.14.1 Number of radio frequency approvals that will be issued

The Agency plans to grant three approvals for the using of the radio frequencies in the band 700 MHz, seven approvals for the using of radio frequencies in the band 3.x GHz and four approvals for the using of radio frequencies in the band 26 GHz as shown in Table 6.1.

| 700 MHz | | |
|---|---|---|
| Approval | Frequency band | Radio communication service |
| A1 | 703 – 713/758 – 768 MHz | Land mobile |
| A2 | 713 – 723/768 – 778 MHz | Land mobile |
| A3 | 723 – 733/778 – 788 MHz | Land mobile |
| 3.x GHz | | |
| Approval | Frequency band | Radio communication service |
| B1 | 3.5 – 3.6 GHz | Land mobile |
| B2 | 3.6 – 3.7 GHz | Land mobile |
| B3 | 3.7 – 3.8 GHz | Land mobile |
| B41 | 3.4315 – 3.460 GHz | Fixed Service Region 1 |
| B44 | 3.4315 – 3.460 GHz | Fixed Service Region 4 |
| B45 | 3.4315 – 3.460 GHz | Fixed Service Region 5 |
| B46 | 3.4315 – 3.460 GHz | Fixed Service Region 6 |
| 26 GHz | | |
| Approval | Frequency band | Radio communication service |
| C1 | 24.3 – 24.5 GHz | Land mobile |

| | | |
|---|---|---|
| C2 | 24.5 – 24.7 GHz | Land mobile |
| C3 | 24.7 – 24.9 GHz | Land mobile |
| C4 | 24.9 – 25.1 GHz | Land mobile |

Table 6.1: Plan of grants for radio frequencies

Explanation of the reasons for the announced limited number of approvals for using of the radio frequencies.

The frequency bands 700 MHz, 3.x GHz, and 26 GHz, according to their propagation characteristics are an important resource for providing electronic communication services to the users through 5G network. Due to the limited of the free frequency resource of only 2×30 MHz, 368.5 MHz and 2.7 GHz, respectively for the above bands, it is necessary to limit the number of approvals. In accordance with the regulatory policy and regarding the use of radio frequencies for provision of public mobile electronic communication networks/services, for providing conditions for the market presence of more than two network operators of public mobile electronic communication networks/services, the Agency plans for approvals A1 and B1, and to reserve them for assigning to a new network operator.

### 6.14.2 Terms and conditions for using the radio frequencies

The validity period of the approvals for using of the radio frequencies A1, A2, A3, B1, B2, B3, C1, C2, C3 and C4, following the example of other regulatory bodies from European countries and in accordance with the EEC, will be 15 years with the possibility for extension for another 5 years. The validity period of the approvals for using of the radio frequencies B41, B44, B45 and B46, will be harmonized with the previously issued approvals, i.e., until 20.09.2027.

Conditions under which the radio frequencies will be used, and which conditions will be specified in the approval are:

- Location and coverage area:

o The approvals A1, A2, A3, B1, B2, B3, C1, C2, C3, C4 will be for national coverage, i.e., for the entire territory of North Macedonia.

o The approvals B41, C44, C45 and C46 will be for regional coverage, i.e. for Region 1 (City of Skopje, Ilinden, Petrovec, Zelenikovo, Studenicani, Sopiste, Cucer Sandevo and Aracinovo), Region 4 (Bitola, Prilep, Demir Hisar, Krushevo , Dolneni, Krivogashtani, Mogila, Novaci and Resen), Region 5 (Ohrid, Struga, Debarca, Vevcani, Kicevo, M. Brod, Drugovo, Zajas, Oslomej, Vranestica, Plasnica, Debar and Centar Zupa) and Region 6 (Tetovo, Gostivar, Tearce, Jegunovce, Zelino, Brvenica, Bogovinje, Vrapciste, Mavrovo and Rostuse), respectively.

- Coverage obligations

o The operators that will receive approval for national coverage are obliged to the newly issued and existing approvals for using of the radio frequencies to provide the following coverage (according to the National Operational Broadband Plan):

- At least one city to be covered by 5G signal, until the end of 2023.
- The main corridors in accordance with the Agreement for establishing a transport community on the basic and comprehensive road network in the country, to be covered with uninterrupted 5G signal, until the end of 2025,

- All cities in the country will be covered with uninterrupted 5G signal until the end of 2027, and
- Every citizen should have the opportunity for access the Internet via 5G with a minimum internet access speed of at least 100 Mbps, until the end of 2029.
- Sync:

o Operators that will receive the national coverage approval in the 3400 – 3800 MHz band are required to use the preferred synchronization scheme - Framework A (»DDDSU«) of ECCREC (20) 03 (approval holders may propose another harmonized scheme). If the operator does not adapt to a harmonized synchronization scheme, it is obliged to provide protection bandwidth within the assigned frequency block.

o Operators are required to use a preferred common reference clock: GNSS in accordance with the ECC Reports 216 and 296 (another reference clock may be aligned). In the event of harmful interference, it is preferred common reference clock to be used in accordance with ECC Reports 216 and 296.

- Quality of public electronic communication services

o The quality of services of the public electronic communications services that will be provided, should be in accordance with the “Rulebook on the quality parameters of the public electronic communications services that are realized through a public radio communication network”.

- Network construction

o The holder of the approval must start of using the assigned radio frequencies, no later than 1 year from the date of commencement of validity of the approval.

o In the areas where there is little or no coverage, if the permit holder plans to build a new site, he will have to consult with the other joint venture operators. The operator will also have to provide access to passive infrastructure, based on the reasonable request from the other operators.

- Neutrality of the Technologies

o The approval will be neutral in the terms of the technology and services, i.e. all types of technologies can be used, in accordance to the Plan for purpose of the radio frequency bands and the Plan for the allocation and the using of the radio frequencies.

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# Chapter 7

## 7 Importance of spatial management in the context of EMF

The rapidly growing number of electromagnetic fields (EMF) sources (e. g. mobile base stations, broadcasting stations, public WiFi networks, professional communication networks) in the environment and increasing public concerns of the impact of EMF on living environment, call for a sustainable deployment of EMF sources. The deployment in environment is always a question of finding the best compromise solution. In general, there are at least three key elements to be considered: capacity, coverage, and cost of deployments (OS 2018), but impact on environment is also becoming a very important considerable element (Figure 7.1) as well as public acceptability.

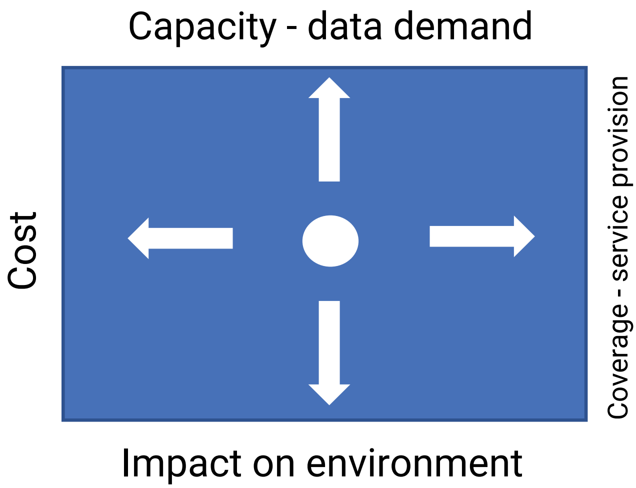



Figure 7.1: The most important key elements to consider when designing wireless networks.

In the case of EMF sources, it is about maximising the capacity and coverage of users with wireless services, while minimising the costs and impact on human health, animals, and nature. Spatial management, which refers to the entire process of spatial planning, designing, construction and spatial data infrastructure, plays a crucial role in sustainable deployment in environment. Determining the so called "sweet point" is a matter of balancing all four key elements and is a process specific to a single use case.

Quality spatial data infrastructure is required to find optimal solutions and take the right decision in all spatial management processes. In the first place spatial data are required to determine the wireless service demand. The European Commission has set out a strategic goal for 2025 in the Towards a European Gigabit Society strategy document »All urban areas and all major terrestrial transport paths to have uninterrupted 5G coverage« (EC 2016). To identify areas of greatest demand for wireless networks is possible to use spatial data on population (including residence address), settlements and towns, building locations, actual land and building use, and transport infrastructure routes (roads, railways, ports, airports, etc.). Quality spatial data from these areas are crucial for determining the areas of potential demand for wireless network services.

The so-called "cost reduction" directive 2014/61/EU identifies the shared use of physical infrastructure, the joint construction of new infrastructure and the optimization of permit granting procedures as key measures to reduce costs and accelerating the construction of communication networks. Shared use of infrastructure and joint construction has also a positive impact on sustainable deployment of EMF sources in environment. The existence, transparency, and availability of data on existing infrastructure (telecommunication, electricity, etc.) are essential to identify the colocation candidates. Unlike fixed networks, the existence of spatial data on existing EMF radiation is also extremely important when locating wireless networks in space by sharing existing infrastructure. Locations that are already heavily exposed to EMF are not suitable for collocation.

The deployment of new wireless networks needs to take into account also the information on natural (vegetation, terrain, etc.) and built-up environment (buildings and other built-up objects) as these objects have a major impact on EMF propagation, especially on new technologies in near future like 5G. A detailed digital terrain model and 3D model of buildings, vegetation and infrastructure objects are the key data for the assessment of EMF propagation and creating impact maps and make the optimization of network deployment easier.

An important step forward in the field of spatial data infrastructure in electronic communications processes has been set by the EC with the adoption of the European Electronic Communication Code (Directive (EU) 2018/1972). This requires, inter alia, national electronic communications regulators to carry out spatial analyses of the existing range of wireless and fixed network services and planned investments in telecommunication networks. The Body of European Regulators for Electronic Communications (hereinafter: BEREC) has developed guidelines to assist national electronic communications regulators in setting up a spatial data infrastructure to monitor the existing services coverage and investments in new networks.

In general, the main benefits of introduction of spatial data infrastructure in the field of wireless network deployment are:

- better utilization of existing physical infrastructure through easier identification of candidates for colocation of sources.
- optimization of new network deployment through easier identification of existing EMF sources and exposure, assessment of service demand in specific area, existing service, modelling and assessment of EMF propagation, identification of existing physical infrastructure, etc.
- faster identification of suitable locations.
- more rational land use through minimization of construction outside of infrastructure corridors, and reduction of pressures on green fields according to the sustainable development concept.
- the acceleration of network roll-out and lowering the investment costs.
- reduction of the environmental footprint.
- open data about EMF levels on specific locations (EMF maps) decrease misinformation and could improve public acceptance and mitigate social resistance to the deployment of wireless transmitters, especially of new technologies such as 5G.

The objective of this chapter is to present an overview of the spatial management aspect in the context of wireless networks deployment. First, an overview of relevant recommendation and guidelines is given. Basic principles and techniques of spatial planning and deployment of EMF sources are given and spatial data relevant for wireless network deployment is presented. Finally, an overview of existing spatial data and registers of electronic communication network in North Macedonia and results of RF EMF assessment in Skopje area are given.

## 7.1 Overview of relevant recommendations and guidelines

The International Telecommunication Union (ITU), the United Nations agency specialized for information and communication technologies, The European Commission (EC) and Body of European Regulators for Electronic Communication (BEREC) developed several guidelines and recommendations also covering the aspect of spatial management. An overview of most important guidelines is given below.

### 7.1.1 Connectivity Union Toolbox

Connectivity Union Toolbox was prepared pursuant to Commission Recommendation (EC) 2020/1307 on a common Union toolbox for reducing the cost of deploying very high-capacity networks and ensuring timely and investment-friendly access to 5G radio spectrum, to foster connectivity in support of economic recovery from the COVID-19 crisis in the Union. The Connectivity Toolbox Recommendation contains best practises for fostering investments, where the key elements are spatial data on existing infrastructure and planned civil works on infrastructure. Spatial data are essential for better utilization of existing physical infrastructure and for more joint constructions agreement, which lead to the acceleration of network roll-out and more rational land use. The recommendations also provide the following best practise examples related to EMF and public health:

- EMF measurements results should be publicly available.
- continuous scientific research on EMF, carried out by credible and independent institutions is crucial for mitigating social resistance to the deployment of 5G networks.
- coordinated and targeted communication for informing and educating on 5G implementation.

### 7.1.2 BEREC Guidelines on Geographical surveys

BEREC has prepared Guidelines on Geographical Survey to assist national regulators on the consistent application of Geographical surveys of broadband service coverage (fixed and mobile). For mobile broadband, data should be collected at a level of a 100 m x 100 m or smaller grid. BEREC considers that a first approach to characterize the reach of the mobile network is to determine the availability of a broadband service depending on the technology served at a specific location. 3G, 4G and 5G generations offer distinct services and performances and may be mapped accordingly.

### 7.1.3 The ITU recommendations

Two ITU recommendations, ITU-T K.83 Monitoring of EMF levels and ITU-T K.113 Generation of RF EMF level maps cover long term RF EMF monitoring and RF EMF maps. Details of these two recommendations are available in chapter 3.6 EMF Recommendations and standards published by International Telecommunication Union (ITU).

## 7.2 The role of spatial management

### 7.2.1 Overview

**Spatial management** is a conscious human activity aimed at directing processes in space, including the design, construction, use, maintenance, and renovation of all components of space (https://ipop.si/urejanje-prostora/izrazje/). Spatial planning consists of three types of activities:

- spatial planning,
- spatial management measures/land policy measures and
- spatial Information System.

**Spatial planning** is an interdisciplinary activity within which spatial development is planned at the strategic level, while on the implementation level activities are planned or placed in space and provides for implementing regulation for spatial interventions. Spatial planning is carried out through a process in which the interests of different users of space are confronted. They shall be coordinated with each other in the spatial planning process. The placement of objects in space is a phase in the spatial planning process in which it is searched, optimized, and finally determined by the detailed location of the spatial arrangement and its basic characteristics. The final result of spatial planning is spatial planning act. Strategic spatial planning acts are a mandatory basis for implementation spatial acts, and this are the basis for obtaining building permits or for carrying out other spatial interventions. The spatial planning document shall be deemed to determine the public interest in the spatial development and land use.

**Land policy measures are** measures for the implementation of spatial planning documents. With land policy measures, the institutions responsible for the realization of the public interest in a given area (state, regions or municipalities) carry out activities that enable the realization of spatial development objectives and the realization of the arrangements provided in implementing spatial planning documents. Land policy measures include, for example:

- construction of municipal infrastructure with public funds,
- land consolidation,
- the acquisition of land for public ownership through purchase or expropriation,
- sale of land for investments which are also in the public interest,
- the introduction of forced easement for the use of immovable property for the public benefit,
- regulation of the field of transport in immovable property (day parcel control, pre-emption, prohibition of real estate traffic),
- financial measures through the setting of duties on immovable property (e.g.: Contribution to the connection of the building to municipal infrastructure, property tax or special charges on unused or underutilized real estate,
- the implementation of spatial arrangements with public funds and the renovation of certain parts of settlements.

The spatial information system is a subsystem of the State Spatial Information Infrastructure, which specializes in carrying out tasks in the field of spatial planning and implementation of land policy measures. The National Spatial Information Infrastructure consists of metadata, spatial data sets and services, arrangements for sharing, access to and use of spatial data sets and services, as well as mechanisms and procedures for coordination between the holders of individual databases and services. The spatial information system consists of those databases that are generated in the process of spatial planning and implementation of spatial planning documents (e.g., data on building permits, data on works for which building permits have been issued and similar). To effectively carry out tasks in the field of spatial planning, the spatial information infrastructure must, through a spatial information system, enable the use of diverse data for the purposes of performing status and trends demonstrations, which are the expert basis for decisions on spatial development, the distribution of activities in space and the placement of objects in space. It is therefore important that the spatial information system, or the collections that form part of the spatial information system, can be linked to data on real estate (land parcels, buildings, buildings, and networks of public infrastructure), data on spatial administrative units (areas of municipalities, settlements and regions), data on the land use, topography data and statistics.

### 7.2.2 Basic principles and techniques of spatial planning and deployment of EMF sources

The following important facts must be considered in the development planning process and during the implementation phase of the location and permit granting for 5G base stations deployment:

1. 5G networks will use existing sites at least at the start of their development and shared use of existing base stations physical infrastructure.
2. 5G will operate at higher frequencies than existing networks. As a result, they have a much smaller range and there should be no obstacles between the transmitting device and the receiving device. Topography and other spatial data can be used to identify obstacles and simulate EMF propagation.
3. The 4G network antennas operate at lower frequencies and provide coverage of a larger area. For better operation, smart 5G antennas direct the signal into beams and thus ensure coverage only where and when it is needed, i.e., where the current users are located. Smart 5G antennas increase capacity and improve efficiency and reduce the average exposure to RF EMF. However, it can be concluded that the maximum exposures in the locations between fixed users and antennas can be much higher than average. As a result, it became important to anticipate the locations of permanent larger user groups in the surrounding of base stations and to consider this when deploying 5G base stations.
4. In 5G networks, small cells located close to users in urban settings will be used to optimise signal range and provide small are coverage, e.g., on a public lighting poles, traffic signs or inside shopping centres and other commercial buildings.

In the process of spatial planning and RF EMF sources deployment, we face the technical-functional, conservation and spatial development aspects of planning.

As part of the technical-functional aspect of spatial planning, we consider or define:

1. locations where there will be a need for signal coverage for the performance of activities:
   - existing settlements and current signal coverage,
   - envisaged settlements regarding spatial development,
2. locations where the installation of new base stations is technically optimal or at least feasible:
   - existing facilities,

- o existing electricity and telecommunications networks,
- o ownership of real estate,
- o no topographic obstacles.

The purpose of the spatial development aspect of spatial planning is to:

3. ensure that the RF EMF sources deployment does not prevent the performance of other activities in the space, or that the possibility of land use for other activities will be minimized.
4. prevent or minimize visual degradation of landscape due to the installation of new RF EMF sources.
5. search for synergies between network operators or providers of telecommunications services in a way that will enable them to share locations or/and networks for transmitting signals.

The purpose of the protection aspect of planning is, however, to:

1. limit interventions to protected areas and protected animal and plant species in such a way that the construction and operation of a new network may have an excessive negative impact on the environment, nature, or cultural heritage, and in particular to
2. prevent any health effects of the RF EMF of persons located around the 5G network base stations. The maximum total exposures due to the operation of RF EMF sources is legally limited.

An integral part of the process of spatial planning and installation of 5G networks is public involvement. Spatial planning acts are adopted by state and municipal authorities, which are composed of individuals who have been elected in the elections. This means that the spatial act is also a political document expressing a social consensus on the development of space and the activities of placement. It is therefore important that we provide the public with adequate information at an early stage which enables them to develop an opinion on a particular spatial arrangement and to be involved in the process of placement.

## 7.3 Spatial data relevant for network deployment

The importance of spatial data of electronic communications and their mapping was recognised some time ago by the European Commission through the SMART 2012/0022 projects concerning the study of broadband and infrastructure mapping and SMART 2014/0016, which deals with mapping of fixed and mobile broadband services across Europe. Four types of mapping were defined (Arnold et al., 2014):

- infrastructure mapping,
- service mapping,
- demand mapping,
- investment and funding mapping.

In addition, related to EMF, mapping of RF EMF sources and exposure is highly recommended.

### 7.3.1 Registry of RF EMF sources

To avoid excessive negative impact on nature, the environment and cultural heritage during the construction or operation of the network, the data on the sensitivity of environmental and nature components and data on protected areas are needed. To protect human health and reduce the doubts about the excessive exposure of the RF EMF, we need to include data on the existing EMF exposure in the EMF impact assessment models. That is why we need register of existing RF EMF sources (Gajšek 2011). To assess the impact of the RF EMF on residential buildings, it is reasonable to link the building data to the data on the number of persons registered at the address.

In general, registry of RF EMF sources should include all non-pulsed sources. It can possibly include also pulsed sources like radars, but as the exposure of pulsed sources is evaluated separately from non-pulsed sources, inclusion of pulsed sources is not necessary. To allow further analysis, it is important to define the RF EMF source unambiguously: RF EMF source is a source which emits the RF EMF with a defined radiation pattern at known frequency and known power. Therefore, for a base station, each sector, and each transmitter unit at one frequency is one source of RF EMF. Most common RF EMF sources are:

- FM transmitters,
- DAB transmitters,
- DVB-T transmitters,
- GSM-R base stations,
- 2G, 3G, 4G and 5G base stations at 800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2600 MHz and 3500 MHz,
- public Wi-Fi hotspots at 2,4 GHz and 5 GHz.

There are also different professional networks like TETRA (Terrestrial Trunked Radio) which are also sources of RF EMF, but availability of their data is very limited. If available, they should be included in the registry of RF EMF sources. For each RF EMF source several technical data should be included in the registry to allow later calculations of RF EMF:

- source owner.
- source type (FM, DVB-T, 2G base station, 3G base station...).
- location ID.
- source ID (Cell ID).
- frequency or channel.
- location of source – coordinates in known coordinate system.
- altitude.
- height of the antenna above ground.
- radiation pattern either by:
  - o antenna type (especially for base stations: the exact antenna type provided by the manufacturer).
  - o as vertical and horizontal radiation pattern file or
  - o if no better data are available, as the vertical and horizontal beam angles.
- azimuth of antenna.
- down tilt of antenna.
- radiated power either by
  - o effective isotropic radiated power (EIRP) or
  - o power delivered to antenna together with the antenna gain.

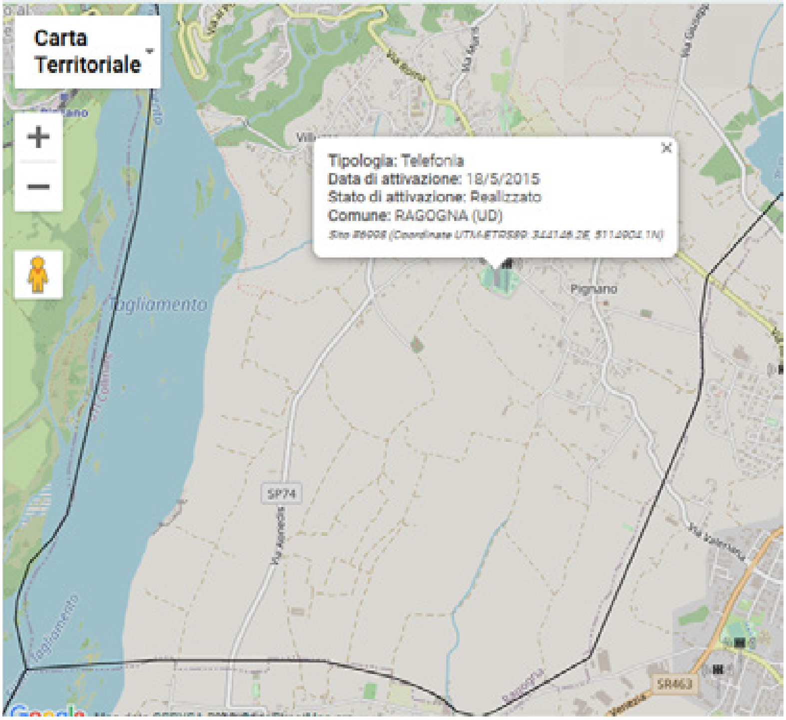



Figure 7.2: Example of a simplified publicly available registry of RF RMF sources for Friuli Venezia Giulia region in Italy. Available at: http://www.arpaweb.fvg.it/rrf/gmapsrf.asp.

Registry of RF EMF sources and physical infrastructure data may also be used for the protection of existing infrastructure and installations. After the RF EMF sources deployment, their locations need to be secured in an appropriate manner. Protection against physical damage is important here, and it is particularly important to ensure that the network is not compromised by the creation of new barriers to transmitting the signal or by locating objects to locations that would be overloaded by the EMF. To prevent such incidents, information on existing EMF sources may be publicly available so no one can claim that they did not know about the base stations. Alternatively, data are only accessible to authorised planners and for the purpose of administrative authorization procedures. The restriction of access to data may lead to conflicts in the case of facilities that do not require permits.

### 7.3.2 Mapping the RF EMF exposure in the environment

There are three different methods for mapping RF EMF exposure: monitoring, spatial measurements, and numerical modeling. Each method has its benefits and shortcomings.

Monitoring is intended for surveying the long-term exposure of the RF EMF. This gives very good insight in the time variability of the exposures, especially important to determine the average exposure and to determine the influence of implementation of new wireless technologies or new generations of current wireless technologies. Monitoring campaigns are used extensively in some countries like Serbia or Greece. They have established a network of fixed automated measurement stations which measure the RF EMF 24/7. On a predetermined intervals measurement results are transferred to a server. Through the web application everyone can access the results of the measurements in a desired time interval.

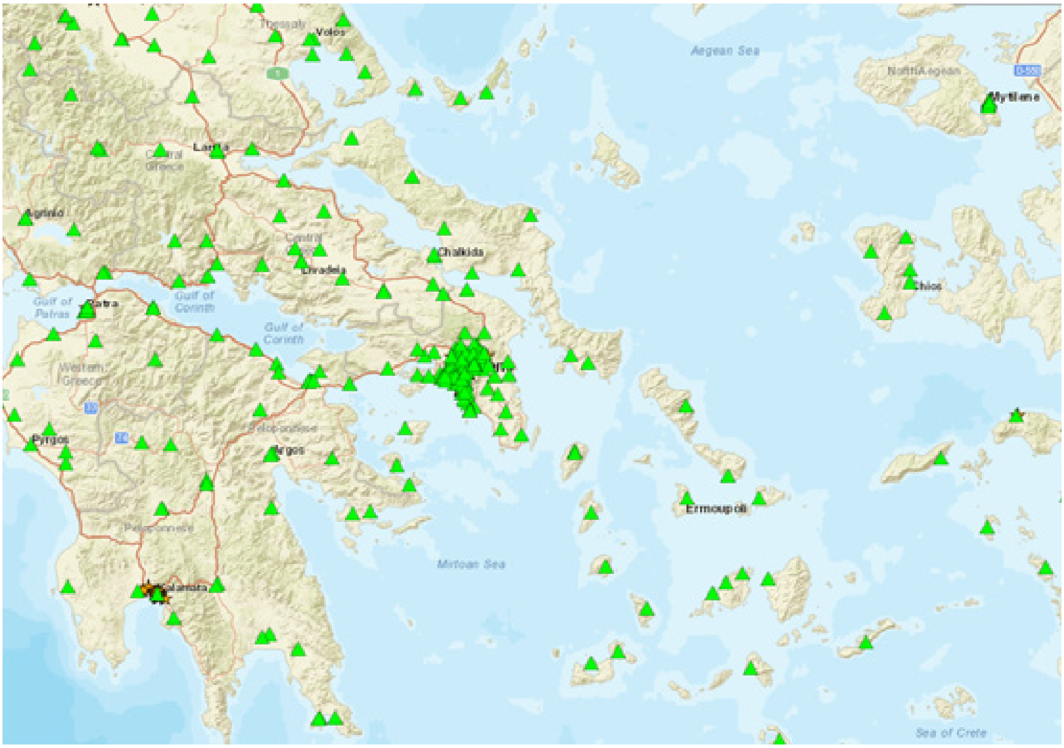



Figure 7.3: Locations of monitoring stations in Greece. Available at: https://paratiritirioemf.eeae.gr/index.php/en/measurements/map.

By selecting the location on the map additional information about the measurements and measurement results are available.

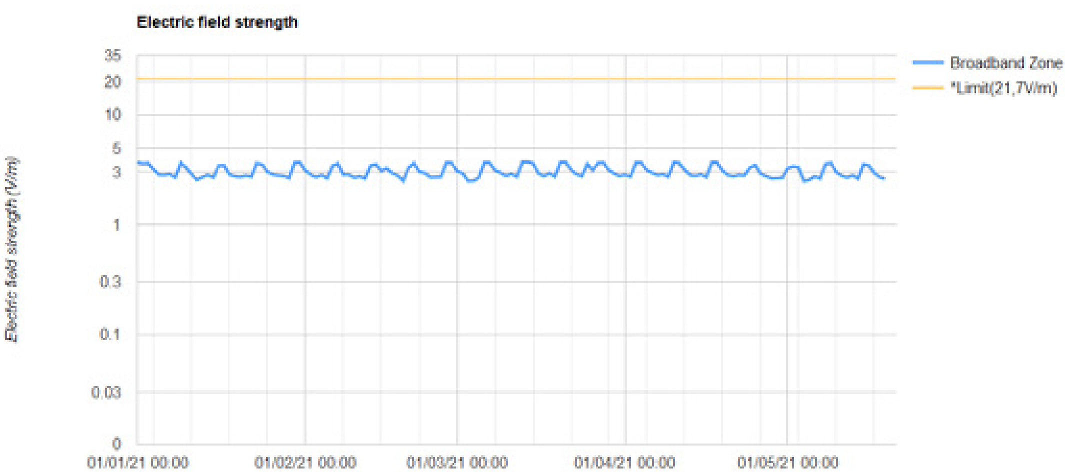



Figure 7.4: Example of one long term measurement in Greece. Available at: https://paratiritirioemf.eeae.gr/index.php/en/measurements/map.

The shortcoming of monitoring only is that the results are limited to the locations of the monitoring only. Nevertheless, that in some countries several hundred measurement stations are located, the results still cover only small portion of the total area. Big monitoring networks are also expensive to establish and maintain.

Spatial measurements are measurements made on many different locations (Trček 2018), usually from a vehicle. The benefit of such spatial measurements is that they can cover quite large areas with a good spatial resolution – for example cover all important street in a big city with the resolution of about 10 to 20 meters or cover all main roads in a whole county. The results of the measurement do present the exposure situation at the time of the measurements and therefore not necessary cover the worst-case situation nor the average situation, as the levels of the RF EMF do depend on the current network usage.

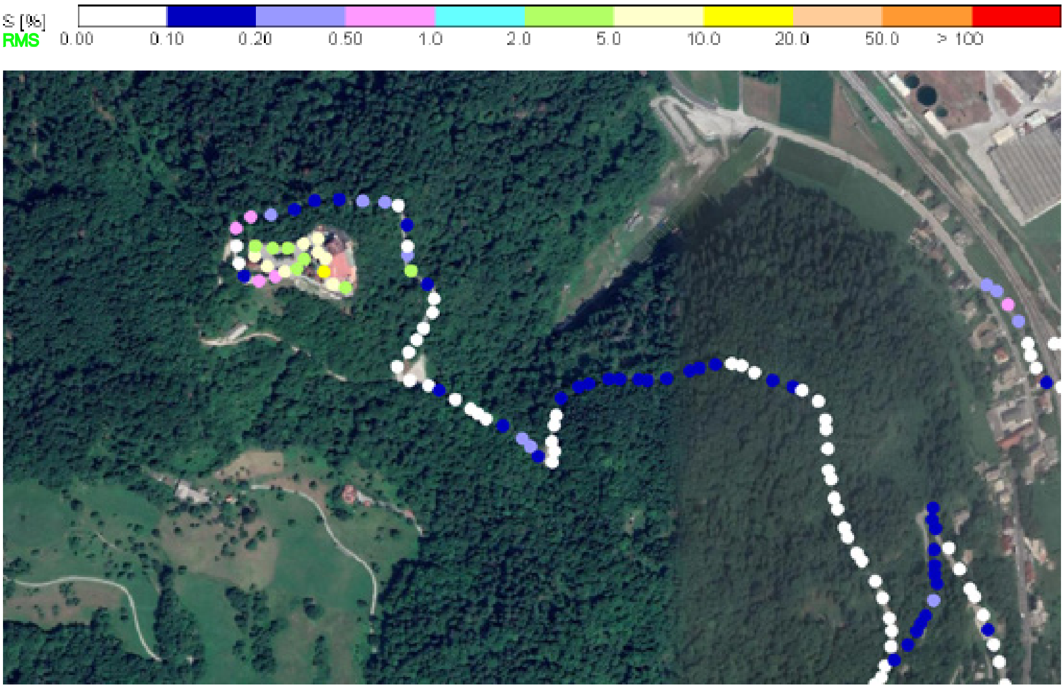
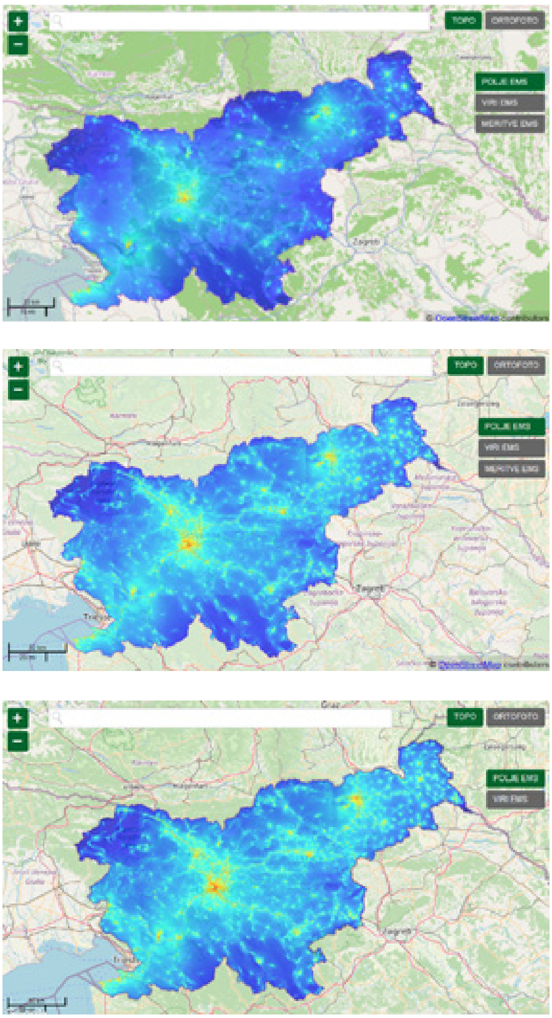



Figure 7.5: Example of spatial measurements. The color of each measurement location presents the total RF EMF exposure, normalized to Slovenian legislation, which is 10 times stricter than EU recommendation (1999).

Numerical modelling - calculations can be done on a large scale, for example whole city or even whole country with very good spatial resolution of 10 m (Gajšek 2014). The benefit of the calculations is that they can cover not only streets and roads but all the land. The calculations are usually done for the worst-case situation, when the sources are under full load, however with some statistics analysis the exposure can be calculated also for the average exposure. However, the calculations require precise input data about all sources, which can be very difficult to obtain, it also requires the digital elevation data of the calculated are and if possible, also the buildings. With the inclusion of the buildings the results of the calculations can be very precise, however for large scale calculations inclusion of buildings is very demanding because of the necessary input data and because of the increase of the resources for calculations. If buildings are not included, especially in the urban areas the exposure is slightly overestimated.

Regardless of the method how the RF EMF was determined one very important aspect of long-term EMF monitoring is the evaluation of the increase or decrease of the RF RMF exposure with time. With the development of mobile networks, placement of new base stations, introduction of new technologies and abandoning existing technologies the RF RMF exposure do vary with time. Long term monitoring allows the analysis of such changes of the RF EMF exposure as well as the influence of new technologies on the RF EMF exposures. In Slovenia, the RF EMF exposure in environment is being systematically analysed since 2013.

The results shows that the exposure is increasing over years: the average exposure in central part of Slovenia increased from 0.0200% of EU recommendation limits in 2013 (Gajšek 2014) to 0,0387 % in 2018 and 0.0465% in 2020. This means that the average exposure is still small, but due to new base stations and upgrading of existing base stations with new technologies it is increasing. The latest results are available at: http://www.inis.si/index.php?id=347.




**2013**

**2017**

**2020**

Figure 7.6: Evaluation of the total increase of RF EMF exposure in Slovenia over time.
Top: 2013, Middle: 2017, Bottom: 2020.

Publicly available 5G and RF EMF data can serve as useful risk communication tool, increase an awareness of the public that exposure levels are really low and reduce the possibility of manipulation by the activist groups. Social acceptance is of paramount importance for the successful development and operation of the 5G network. Publicly available, complete and reliable data on EMF source's locations and their total exposure are key to public confidence in health and safety.

### 7.3.3 Infrastructure and real estate data

Infrastructure mapping is a precise, spatially located, and structured collection, processing and display of data of an existing infrastructure, with a view to transparency of data to facilitate network construction by sharing existing infrastructure.

In the first phase of the development of 5G, new base stations will be located on existing 2G, 3G and 4G base stations. Information on the existing electricity and telecommunications networks is most important to identify the locations where the deployment of new base stations is technically optimal or at least feasible. To successfully plan development, it is therefore necessary to know the locations of the existing base stations and their basic characteristics (type, height, area it is becoming aware of) and the locations of connection to the existing power grid. When determining the location of the base station, it is also necessary to identify natural and artificial barriers to signal transmission. Data on these obstacles can be obtained from data on buildings (location, type of building, building height) and relief data. Data on buildings can be obtained from the cadastral or register of buildings if they are in place. It is possible that useful data may be found in topographic databases. In locating new stations, we are usually interested in ownership of real estate, which is potential for base stations. For the installation of the base station, it is necessary to obtain from the owner an appropriate right (service, building right, ownership) and it is therefore advisable to reach an agreement with the owner at the planning stage.

### 7.3.4 Investment mapping

The collection, management, and mapping of planned investments in EMF sources, other communication networks and infrastructure have several applications. The key use is coordinated infrastructure construction and an increase in the number of joint building arrangements, resulting in more efficient land use, a reduction of EMF sources location, a reduction in investment costs and, consequently, accelerating the construction of networks.

Data on planned investments can be used in the processes of spatial planning, investment planning, design, and information of relevant stakeholders. On the other hand, the management of data on planned investments also has traps such as disclosure of investments to competing companies.

### 7.3.5 Demand mapping

Demand mapping consists of collecting actual demand for electronic communications services, which may be the basis for any planning and consequent investment.

To identify current service needs, we need information on locations where activities will be carried out to ensure different levels of coverage and quality of the signal. These are locations where economic; business or information activities are carried out and where many people (markets, pedestrian zones, tourist locations) and traffic routes are collected and kept for a long time. The following types of data are needed to identify the needs:

- location in the form of a point, line, or zone
- number of users at the site
- average number of users per time interval

The locations of commercial and residential premises can be obtained from building databases (e.g., cadastre or register of buildings in which information on the location, dimensions, and type of use of the building is kept), the locations of traffic roads from the register of public infrastructure, and the location of public areas from municipal databases (e.g., municipal spatial acts or public land cadasters).

The number of users in individual time slots in buildings can be estimated based on data on permanent addresses of occupants or the number of employees in enterprises, and the number of users on roads can be estimated from traffic counting data and the number of visitors to public places based on experience. The number of users at individual locations can also be estimated based on data held by mobile service providers and apps.

To determine future needs, it is necessary to obtain and interpret data on the planned development of settlements and the future use of areas in settlements. For this we need data on development and implementing spatial planning documents.

### 7.3.6 Service mapping

Service mapping consists of collection, analysis and display of data on the provision of electronic communications services with individual service quality parameters. BEREC guidelines on mobile broadband service mapping recommend collecting data for each technology: 3G, 4G, 5G. Data to be collected to characterize the reach and performance of mobile broadband:

- operator code,
- grid code or polygon ID,
- technology availability,
- VHCN class,
- upload Maximum Speed classes (optionally),
- download Maximum Speed classes (optionally).

The main purposes of service mapping are to inform the public and provide information as a basis for planning and decision-making.

### 7.3.7 Other spatial data relevant for network deployment

The construction and operation of the network shall not prevent or significantly reduce the possibility of carrying out other activities in the space. Therefore, spatial planners need information on existing activities and land use (for example: tourist routes, recreational zones, social activities) and planned activities. Data are obtained from actual land use register and real estate cadaster (lands and buildings), the infrastructure cadaster and of course spatial acts. To reduce visual degradation, it is important to have data available in such a form that it is possible to establish and visualize a 3D model on which we display actual land use and buildings and public infrastructure. For this purpose, data from the digital relief model, data on actual land use and public infrastructure and data on buildings are used. It is important that every building has at least information on the use of the building and the height of the building above the terrain. At the same time, 3D displays of the state of the space where new objects are displayed (e.g., new base stations, EFM sources) are also an effective tool for communicating and involving the public in the process of developing a development or implementation plan.

The spatial information infrastructure must support the permit granting processes for the installation of buildings (buildings and engineering facilities) in such a way that it is possible to obtain the information in the permit granting process, while ensuring the registration of the permit and of the operation for which authorization has been granted. In this way, we ensure the up-to-date and reliability of data on the actual situation in space through the spatial information infrastructure. These data are important for both planning and monitoring of the implementation of spatial planning documents. In view of the characteristics and social acceptance of the 5G network, the ex-ante deployment of base stations and data transmission networks and the digitization of the planning and permitting process for base station locations and in some cases (higher human density) micro-cells are also of paramount importance.

## 7.4 Electronic communication networks spatial data infrastructure in North Macedonia

### 7.4.1 Infrastructure data

Electronic communications networks and other infrastructure data are available in the infrastructure cadastre, which was established in 2014 as part of the Real Estate Cadastre (Official Gazette 04/2014). The basic purpose of Infrastructure cadastre is to provide basic information on public infrastructure facilities and thus basic information on space occupancy in one place. The legal basis for Infrastructure cadastre is given by Regulation for real property survey (Official Gazette nr. 121/2013). The infrastructure cadastre include data on the following types of infrastructure:

- electronic communication infrastructure (electronic communication, telecommunication equipment and constructions),
- traffic infrastructure (roads, railways, water traffic, air traffic, terminals),
- water supply (consumption, technical water),
- sewerage (faecal infrastructure, atmospheric water),
- energy infrastructure (power lines, oil pipeline, gas pipeline, heating lines, product lines),
- other types of infrastructure.

Infrastructure data relevant for electronic communication network deployment are in the first-place data on electronic communication infrastructure, which provide the information on existing infrastructure. But also, data on other types of infrastructure make an important contribution when planning the deployment of new network objects:

- identification and location of physical infrastructure, candidates for shared use (power pillar, infrastructure buildings, abandoned objects, etc.),
- location of existing antennas and other EMF sources,
- identification and location of existing infrastructure (space occupancy and infra-

structure protection).

All electronic communication and other infrastructure are registered in the infrastructure cadastre based on construction technical documentation and legal basis (project documentation, geodetic project, building permit in accordance with the sectoral legislation of the individual infrastructure, etc.). In addition to the regular procedure of registering infrastructure in the cadastre, most of the infrastructure was registered in the cadastre based on the law on legalization of infrastructure facilities. The Real Estate Cadastre Act allows infrastructure to be registered in the infrastructure cadastre without legal status. The main objective is just to register the existing infrastructure (land occupancy) and then the owner of that infrastructure facility can carry out administrative procedures to acquire ownership. For all registered infrastructure facilities, burdens and restrictions may be imposed in accordance with legal acts and legal procedures. In addition to the legal documentation, the registration of the infrastructure is carried out by a geodetic study prepared by a certified surveyor.

All Infrastructure cadastre data are available only to professional users of distribution data system of Agency for real estate cadastre.

Below a more detailed overview of electronic communication network data in Infrastructure cadastre is given. In addition to 3D spatial data which define the spatial component of infrastructure objects, the survey collects several descriptive data:

- unique object ID number of the infrastructure object in the infrastructure cadastre and in the owner cadastre,
- type of infrastructure in the basic classification,
- CC classification,
- type of sub-classification within the basic classification,
- registration number of the manager of the infrastructure,
- accuracy definition of object position (horizontal, height),
- source and date of source from which the location information has been obtained,
- outside layout and vertical dimension of the facility,
- size (length or area),
- abandoned facilities.

Each section within the infrastructure cadaster system shall be separate. Within each section there is sub-classification which is handled in the cadaster. Electronic communication infrastructure for electronic communications sub-classification includes 23 subtypes, which can be grouped in these categories:

- physical infrastructure objects (aerial pillars, TV pillar, canals for telecommunication lines, shafts, galleries),
- wireless network objects: transmitter and radio relay stations, e-communication facility (on building, on ground)
- telecommunication lines (copper, optic, co-axial, IT cables, ground phone lines, ground telegraph lines),
- other: telecommunication box, signal amplifiers, wall connectors on buildings, signal safety and technical devices in traffic, public phone booths, alarm phones, taxi station phones, video surveillance cameras, remote control devices.

Infrastructure cadastre data are high quality data, as the data are registered in cadastre by a geodetic project prepared by a certified surveyor. Spatial data accuracy is 0.10m and

0.15m for underground objects. Currently in the infrastructure cadaster are registered:

- 225 antennas on buildings and 623 on the ground,
- 298.5km of ducts,
- 2.925km of copper cables,
- 660km of optic cables,
- 48km of co-axial cables.

The availability of electronic communications network cadastral data in North Macedonia undoubtedly has a wide range of applications. Key aspects of use include:

- planning the network deployment by shared use of existing infrastructure with available capacity (pillar, tower, buildings, ducts, abandoned infrastructure, ducts, etc.),
- protection of existing infrastructure,
- infrastructure development planning in spatial planning processes,
- analysis of existing infrastructure for the needs of regulation, development policies, co-financing programs with public funds, etc.

### 7.4.2 Planned investments in electronic communication network

Register of planned investments in electronic communication network is operated by Agency for Electronic Communications of The Republic of North Macedonia (hereinafter: AEC). Data are public and available via web GIS viewer:
https://e-agencija.aek.mk/eti/PlannedConstructionPreview.html


Figure 7.7: Planned investments in electronic communication network WEB GIS viewer (AEK, 2021).

Now, data on only 7 planned investments in optic cable deployment is available via web GIS portal. There is no data on planned investments in wireless network.

The main purpose of managing planned investments is to ensure transparency over planned construction works in North Macedonia and to promote the joint construction of electronic communications infrastructure. The web GIS viewer is intended primarily for telecommunication investors for the purpose of planning joint construction with other operators, but it will be necessary to improve the completeness of data on planned investments to use the data for these purposes.

### 7.4.3 Mobile network coverage

There are no data on mobile network coverage publicly available yet. AEC has GIS portal with several spatial data on https://e-agencija.aek.mk/AEKGISPortal, but coverage data are available only for fixed NGA networks.

### 7.4.4 Need for Registry of RF EMF sources in North Macedonia

There is no registry of RF EMF sources available in North Macedonia yet, but a test case was developed for the area of the city Skopje. The registry covers city of Skopje consists of the following technical details for each source:

- source owner.
- source type (FM, DVB-T, 2G base station, 3G base station, 4G base station).
- location ID: unique location ID used by the source owner.
- source ID (cell ID): unique ID of source used by the source owner (Cell ID).
- frequency of the source.
- x and y coordinate of the source in North Macedonia state coordinate system zone 7 (EPSG: 6316).
- altitude of the ground at the location of the source.
- antenna type: unique manufacturer antenna type (for base station antennas).
- if antenna type is missing, then either:
  - o horizontal and vertical radiation pattern file name or
  - o horizontal and vertical main beam width.
- azimuth.
- elevation.
- height of antenna above ground.
- radiated power either as EIRP or as a power delivered to antenna and antenna gain.

The registry is based on the available data from the registries of AEC and mobile operators, it includes radio and DVB-T transmitters, however due to unavailability it does include only base stations from operator Makedonski Telekom. It includes a total of 2293 outdoor sources with all relevant technical data, which were combined from multiple sources. Some of the technical data were not available, so they were determined by the best practice and technical knowledge:

- for FM and DVB-T transmitters the radiation patterns were not available. Therefore, pictures of all FM and DVB-T transmitters were analysed to determine the antenna configuration of each transmitter and prepare the radiation patterns based on the identified type and number of antennas used for each antenna system.
- for about one percent of 2G and 3G antennas information about antenna height and antenna type was missing. The antenna heights were estimated based on the Google Street View images available in Google Maps, for antenna one of the most common antenna type was used (AQU4518R24),
- for 2G and 3G antennas the transmitted power was missing, therefore the same transmitted power was used as for the 4G antennas at the same base station was used. If no 4G system was installed on location, typical transmitted power of 30 W was used.

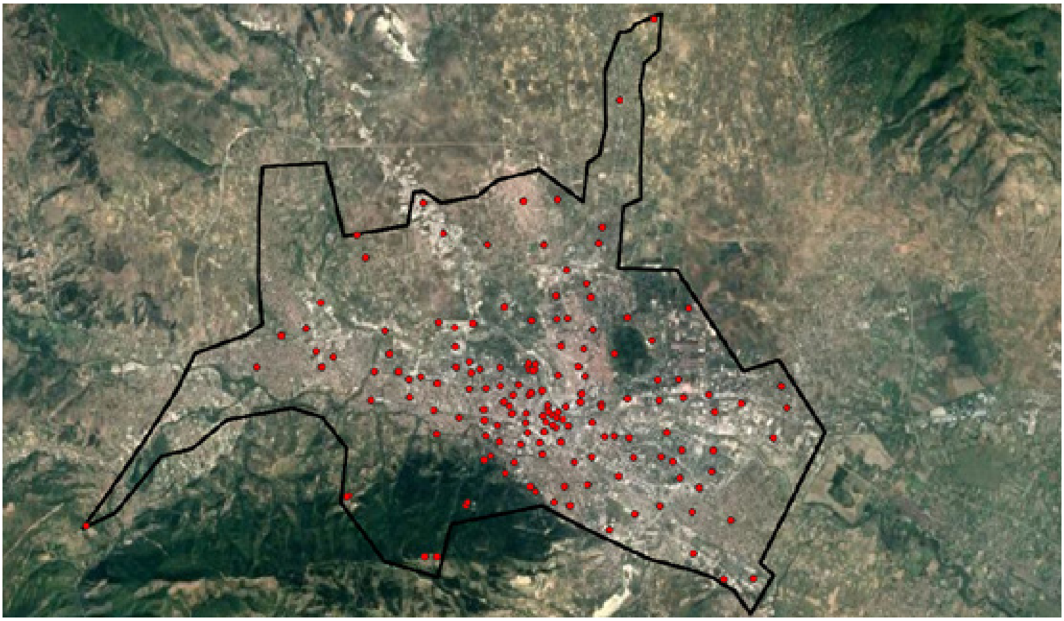


Figure 7.8: Registry of RF EMF sources in the territory of the Skopje city

## 7.5 Results of RF EMF exposure assessment in the Skopje area

Based on the data from the prepared registry of RF EMF sources the calculation of the exposure to RF EMF was calculated for the whole city of Skopje. For numerical modelling and calculations program package Narda EFC-400EP Electric and Magnetic Field Calculation was used. The calculations are done according to international standard EN 50383, which determines how the calculation is done in near and far field regions. Far field is the region, which is at least for $R = 2D^2/\lambda$ far from the source, where D is the largest dimension of the antenna and λ is the wavelength of the source. Near field is further divided in two regions, radiated near field, where the radiation is like plane wave, but the electric and magnetic component of the field are not proportional and in phase, and reactive near filed. The boundary between both near field regions is at the distance $R = \lambda /4$.

Program package Narda EFC-400EP calculates far field region using the ray tracing method based on the power flux density. Power flux density in each point of location is calculated based on the following equation:

Equation 7.1:
$$S = \sum\nolimits_{\text{all sources}}\left(S_{\text{direct}} - \sum\nolimits_{\text{all buildings}} S_{\text{attenuated}} + \sum\nolimits_{\text{all buildings}} S_{\text{diffused}} + \sum\nolimits_{\text{all walls and ground}} S_{\text{reflected}} + \sum\nolimits_{\text{all edges}} S_{\text{diffracted}}\right)$$

As it can be seen the total power flux density in one point is a contribution of power flux densities from all sources $S_{\text{direct}}$ reduced for attenuated part in buildings $S_{\text{attenuated}}$ and enlarged by diffuse emission from all buildings (due to partially diffuse $S_{\text{attenuated}}$) $S_{\text{diffused}}$, reflected emission from all walls and ground and diffracted emission on all edges $S_{\text{diffracted}}$.

In near field regions the calculations are adapted to use segmentation of the source and calculate the power flux with synthetic model.

Calculations were performed on a grid of 10 × 10 m for the whole area of the Skopje City.

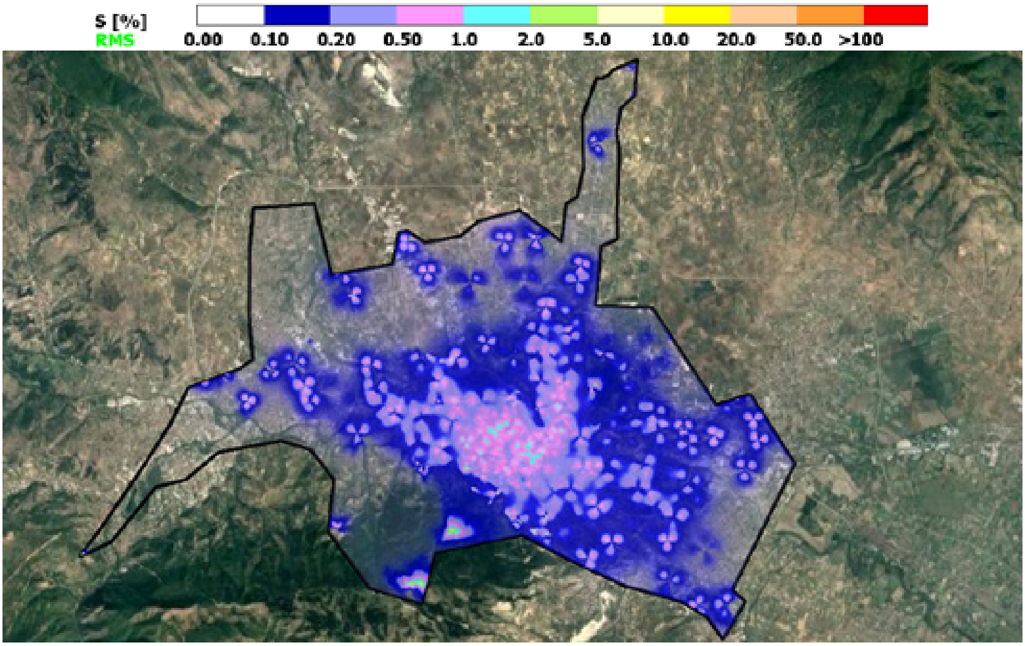



Figure 7.9: RF EMF values, normalized to the ICNIRP guidelines for general public, for the whole are of Skopje

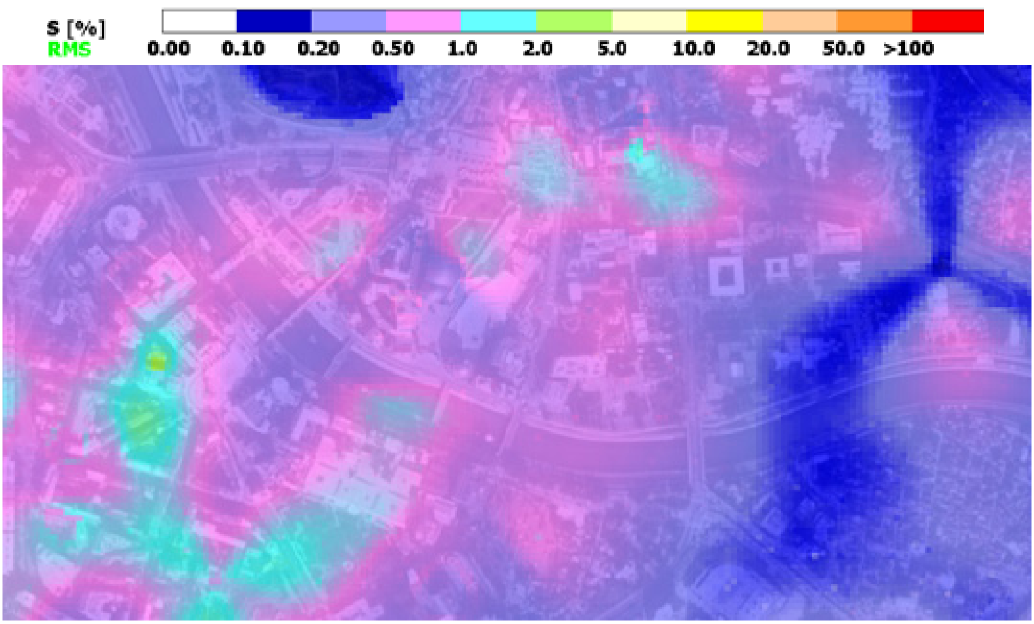



Figure 7.10: Detail of the Figure 3 covering the city centre.

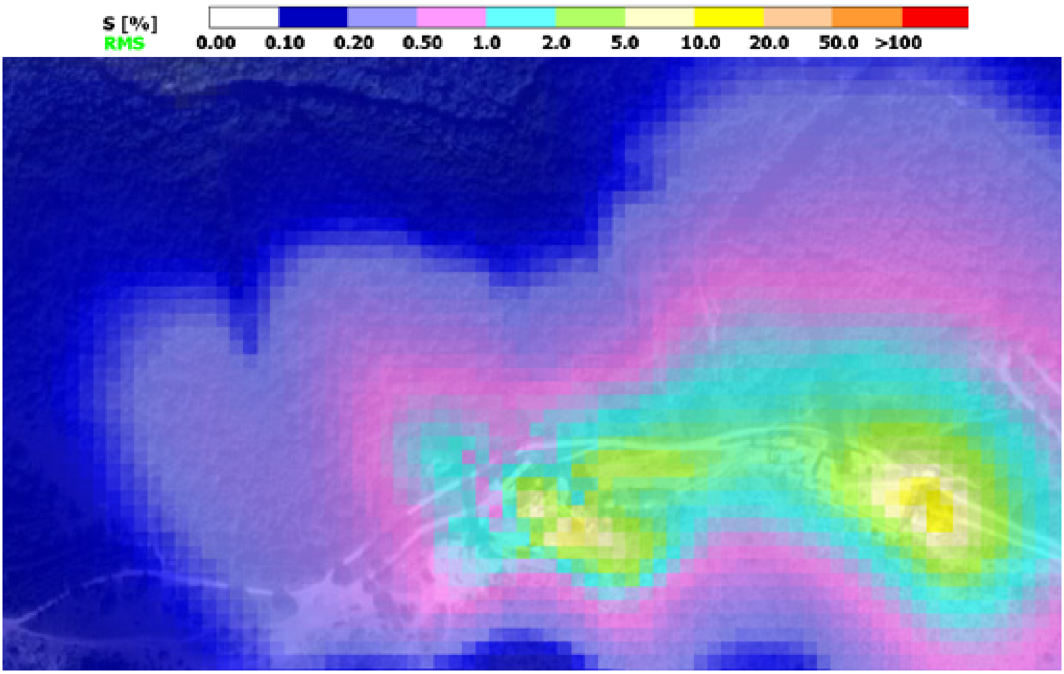



Figure 7.11: Detail of the Figure 3 covering the Vodno location.

The calculated values of RF EMF exposure for the area of city Skopje shows that the exposures are higher in the vicinity of locations with FM and DVB-T transmitters (Vodno mountain and Sredno Vodno) and in the city centre, where the density of base stations is the highest. However, the calculated exposure is well below the limit values and does not exceed 20 % of limit values. Based on the results of the calculations the measurements of the RF EMF have been planned in the city of Skopje. For measurement handheld spectrum analyser Narda SRM 3006 (Narda Safety Test Solutions, Germany) has been used with the suitable 3D measurement antenna Narda 3501. The expanded measurement uncertainty of the equipment is 2.72 dB. The measurements of the RF EMF were done in the following frequency bands:

- FM (87.5 – 108 MHz): radio transmitters,
- VHF (174-230 MHz): digital radio transmitters (DAB),
- TETRA (380-470 MHz): professional radio communication systems,
- UHF (470 – 790 MHz): DVB-T transmitters,
- 800 MHz (790 – 862 MHz): base stations,
- GSM-R (921.1 – 925.1 MHz): GSM-R (railway) base stations.
- 900 MHz (925.1 – 960 MHz): base stations,
- 1800 MHz (1805 – 1880 MHz): base stations,
- DECT (1880 – 1900 MHz): cordless DECT phones,
- 2100 MHz (2110 – 2170 MHz): base stations.
- WLAN (2400 – 2484 MHz): Wi-Fi devices and
- 2600 MHz (2570 – 2690 MHz): base stations.

The measurements on a total of 21.705 locations have been conducted either by car or by foot. When planning the measurements, different aspects were considered:

- results of the numerical calculations of RF EMF were considered, so the measurements covered the areas where the calculations have shown, that the RF EMF values are the highest.

- locations of FM and DVB-T transmitters, as they are the most powerful RF RMF sources, and it is known that especially close to FM transmitters the exposures can be high. Therefore, the measurements were done in the vicinity of all locations with FM and/or DVB-T transmitters in a city of Skopje.
- as the city of Skopje and its surroundings comprises different kind of environment, the measurements were done in the city centre, on some touristic locations, in the suburbs of the town, in some rural areas close to the city and on some recreation locations.

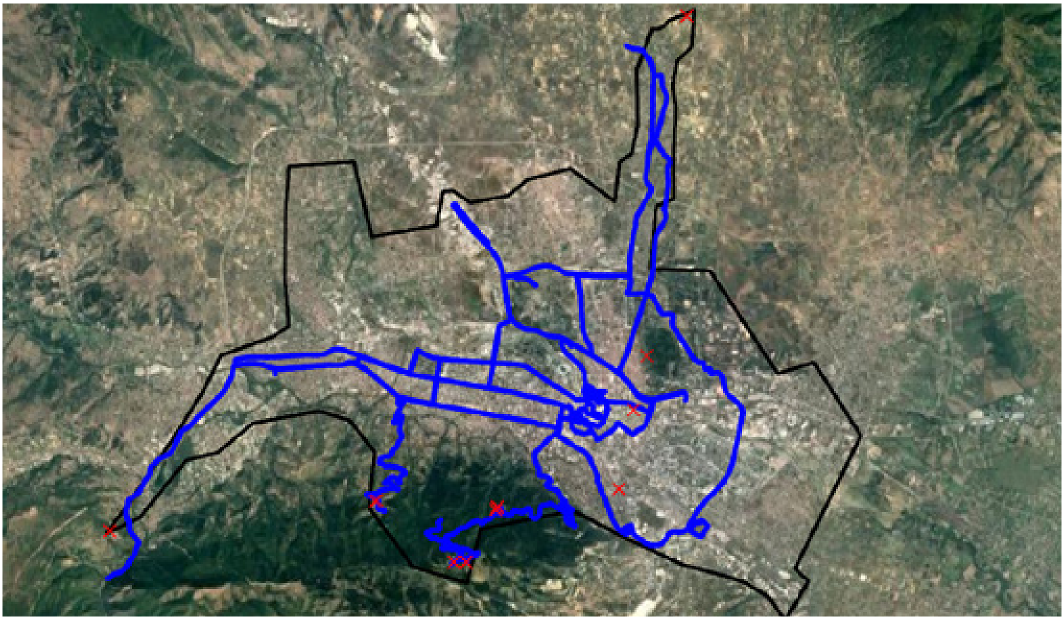


Figure 7.12: Locations of RF EMF measurements (aggregated with 10 m step).
Red crosses present FM and DVB-T transmitters.

| | FM | VHF | TET-RA | UHF | 800 | GSM-R | 900 | 1800 | DECT | 2100 | WLAN | 2600 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $EI_{max}$ | 19.33 | 0.00 | 1.36 | 2.55 | 0.71 | 0.00 | 0.62 | 0.70 | 0.00 | 0.29 | 0.01 | 0.00 | 19.44 |
| $EI_{avg}$ | 0.15 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.18 |

Table 7.1: Maximum and average exposure index (EI) in percent of ICNIRP 1998 guidelines and EU 1999 recommendations for all measured frequency bands together with the total value of EI.

As can be seen from Table 7.1 the average exposures are very low with a total value being only 0.2 % of permissible values. The most important contributor to the average values is FM frequency band. This is expected due to several reasons: FM transmitters are one of more powerful RF EMF sources, FM antennas are less directive compared to either UHF antennas or base station antennas therefore emit more energy downwards than other RF EMF sources, permissible values are the lowest for FM frequency band and they increase with the frequency, therefore the same electric field strength at, for example 1800 MHz, contributes lower *EI* than for FM frequency band.

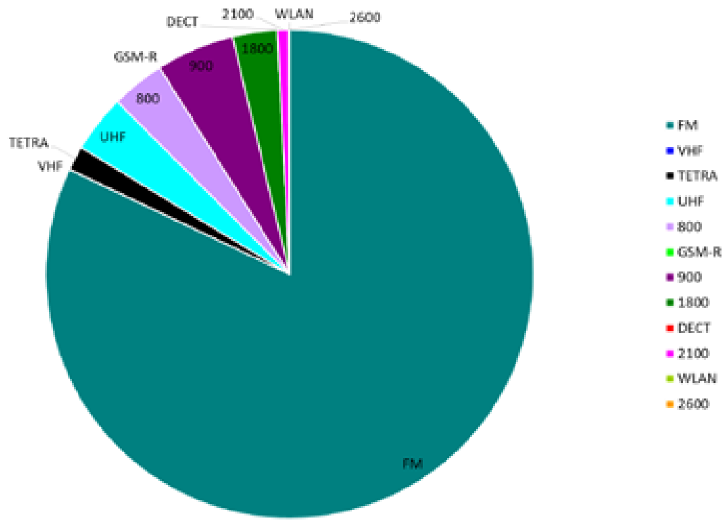



Figure 7.13: Contribution of different frequency bands to the total average exposure.

If we focus on maximum values, only three frequency bands exceeded 1% of permissible values: FM, TERA and UHF. The highest values were measured close to locations with FM transmitters. The highest exposure reached slightly less than 20% on Vodno mountain close to FM transmitters, meaning that the highest exposures are well below permissible exposures.

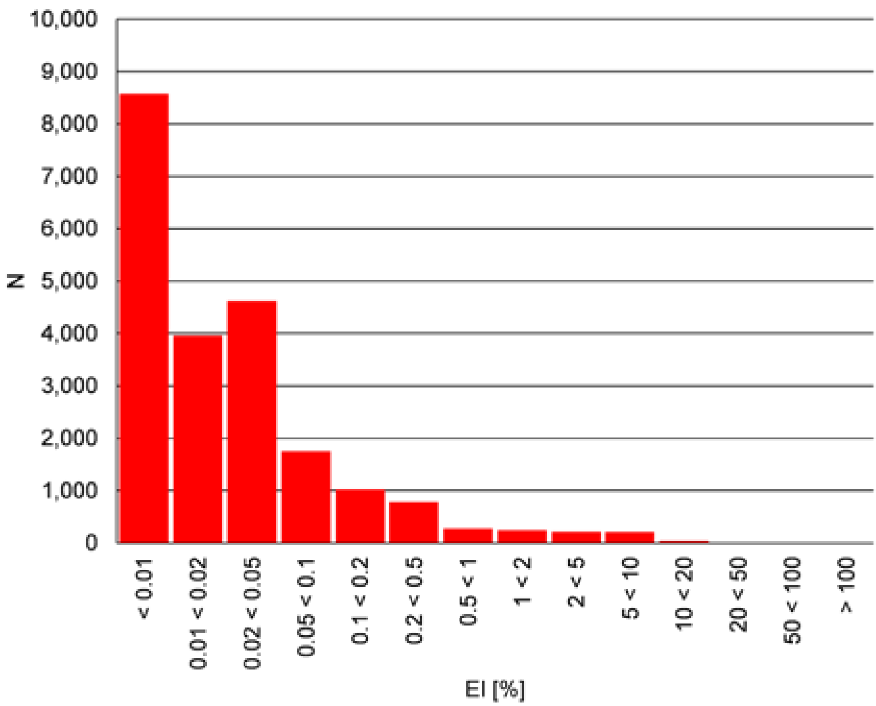



Figure 7.14: Histogram of the total exposure index (EI) for all 21.705 measurements. As can be seen on nearly half of the measurement locations the EI is below 0.01 % of permissible values and on only 228 measurement locations the EI is higher than 1 % of permissible values.

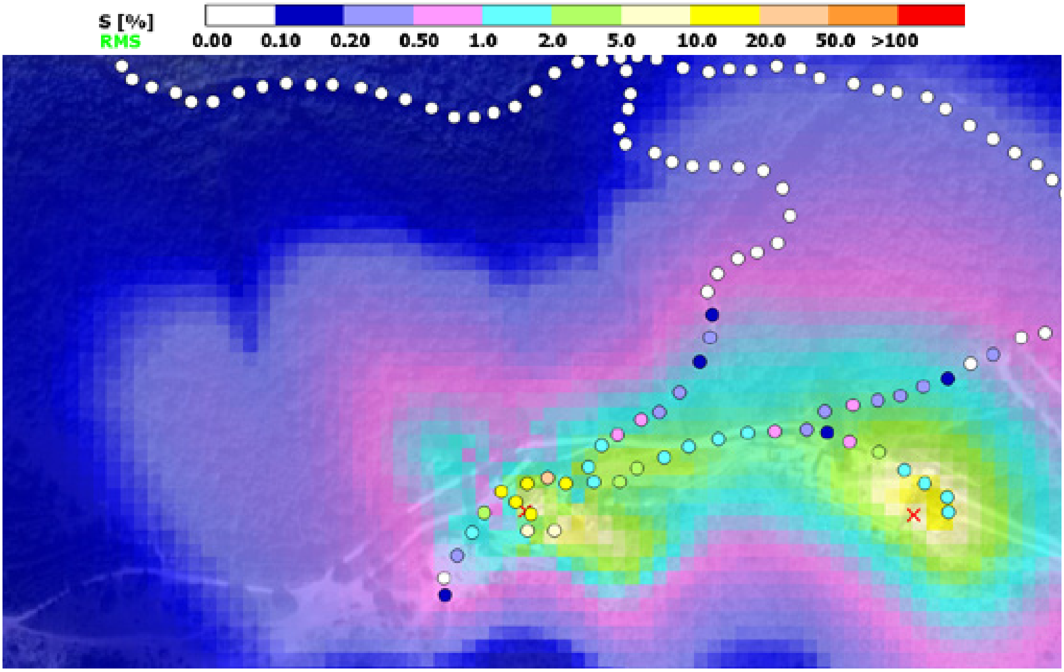



Figure 7.15: Calculated and measured RF EMF values, normalized to the ICNIRP guidelines for general public, covering the Vodno location, where FM and DVB-T transmitters are located. Measured values are presented with circles, bot calculated, and measured values use same colour scale.

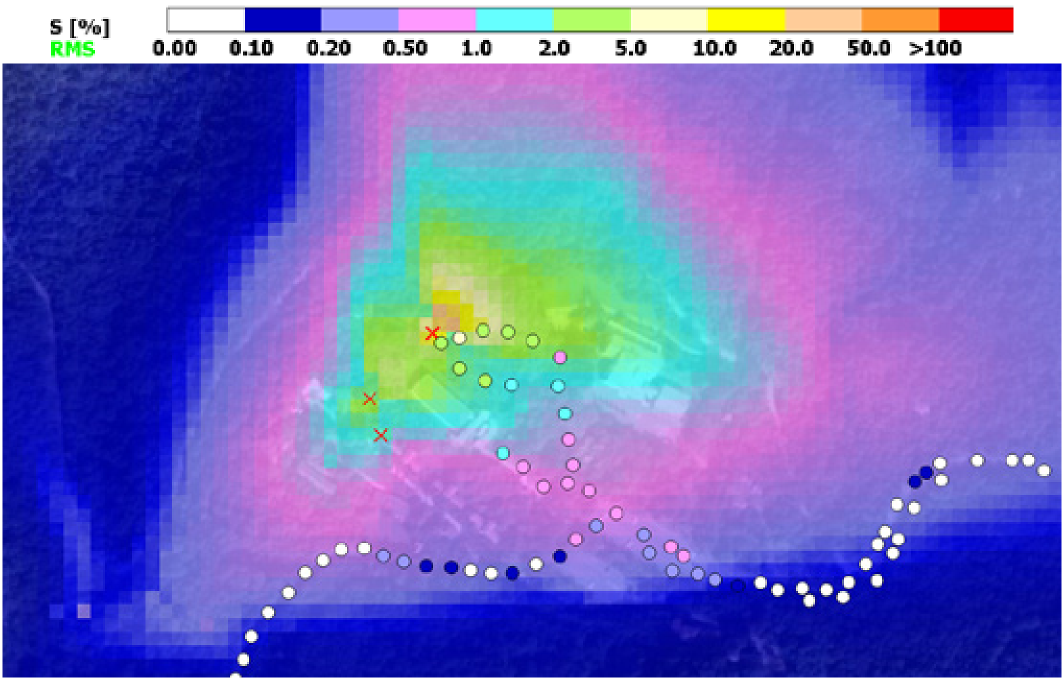



Figure 7.16: Calculated and measured RF EMF values, normalized to the ICNIRP guidelines for general public, covering the Sredno Vodno location, where FM and DVB-T transmitters are located. Measured values are presented with circles, bot calculated, and measured values use same color scale.

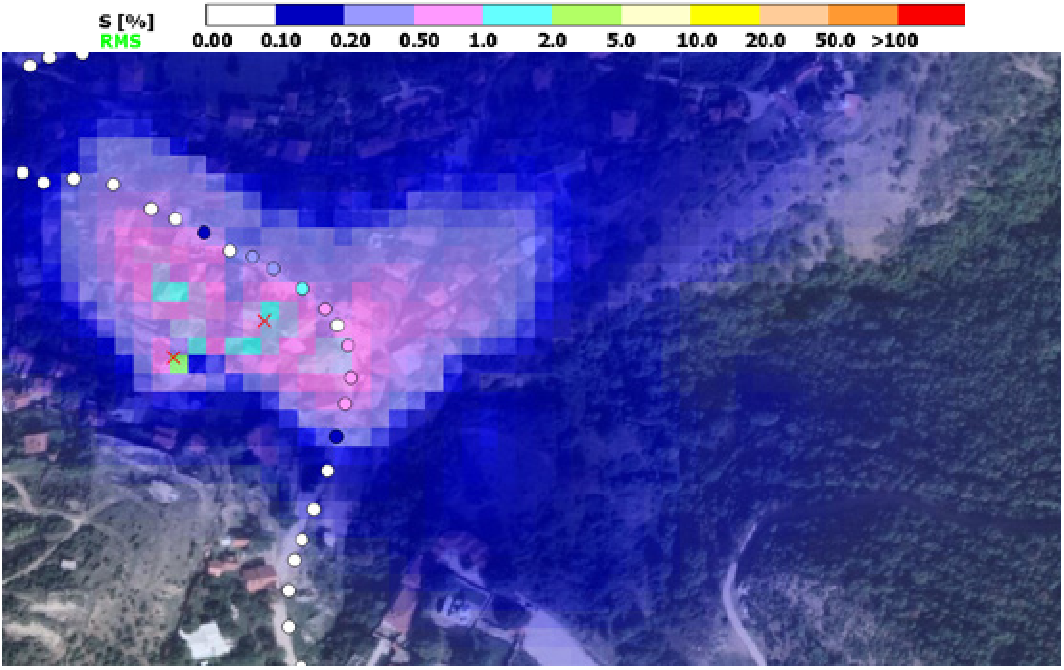



Figure 7.17: Calculated and measured RF EMF values, normalized to the ICNIRP guidelines for general public, covering the Gorno Nerezi location, where FM transmitters are located. Measured values are presented with circles, bot calculated, and measured values use same color scale.

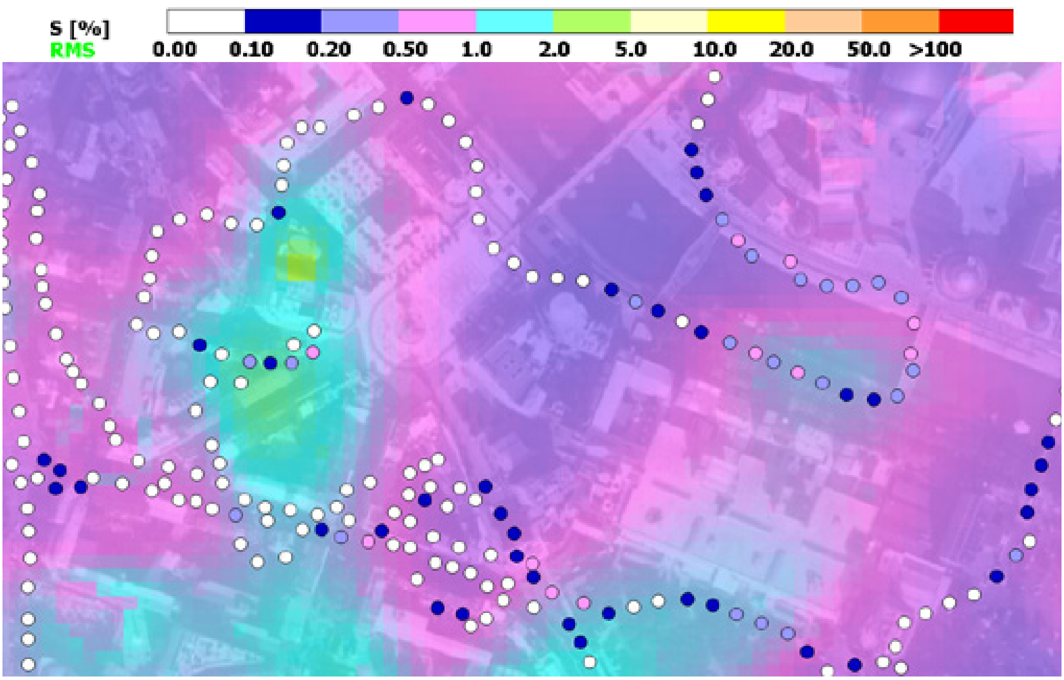



Figure 7.18: Calculated and measured RF EMF values, normalized to the ICNIRP guidelines for general public, covering the city center. Measured values are presented with circles, bot calculated, and measured values use same color scale.

Comparison of calculated and measured values show that in general calculated values are higher than measured. This is normal, as calculations were done for worst case situation, where all base stations are fully loaded and transmit at full power, however measurements represent the conditions at the measured time. However, this is irrelevant for FM and DVB-T transmitters, as they do not change transmitted power with time. The second reason for higher calculated values is the limitation of the numerical model, used for calculations, as it did not include buildings. Buildings are shielding some part of the RF EMF which was not taken into account for calculations.

## 7.6 Conclusion

To facilitate the planning and placement of 5G networks in space, the establishment of an appropriate spatial information infrastructure is of paramount importance. In the area of the 5G network, it is important to establish databases on the existing mobile network (2G, 3G and 4G) and the ESM of this network. Spatial information infrastructure must provide data on buildings (building cadaster, address register), topography data, spatial planning acts for the purposes of planning and placing 5G objects in space. It is recommended that all location data be linked to databases on residents (population registers) and enterprises (business registers). Connecting keys (e.g., address) shall be specified. Users need to be able to access and use data in a variety of ways. From digital cartographic services to the possibility of obtaining and own use of data. For uniform communication with the public, dedicated portals are established which allow easy overview of the situation and public participation in network planning. All spatial data must be properly described by metadata in such a way as to make them understandable to experts in the work as well as to the public. However, in the context of the 5G network development project, we should not forget the proper training of users of spatial information infrastructure – these are mainly spatial planners and managers.

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# Chapter 8

## 8 Risk communication related to RF EMF and recommendations for rollout of the wireless networks

Over the last few decades, there has been a controversy over possible health effects of Radio Frequency Electromagnetic Fields (RF EMF). The International Commission on Non-Ionizing Radiation Protection (ICNIRP) emphasizes that despite a substantial body of research, there is no conclusive evidence for any health effects of RF EMF within the recommended exposure limits (ICNIRP, 2020; 2009), a stance that has also been adopted by the World Health Organization (WHO). Others, e.g., the Bio Initiative Working Group (2012) and the signatories of the 5G appeal (2019), are of the opinion that prolonged exposure to low level RF-EMF results in adverse health effects. In the light of these differences, precautionary actions are recommended by many regulatory agencies and scientific organizations across the world (Stam 2017).

While most people worldwide use mobile phones, smartphones and/or wireless local access networks (WLAN) nowadays, protests against them (e.g., against the erection of mobile phone base stations) were widespread in the late 1990s and the early 2000s Nowadays, these protests are more frequent with rollout of new 5G mobile network. Nevertheless, RF EMF risk perception seems still alive due to powerful activist groups and media attention to RF EMF risk news, such as the National Toxicology Program study. Available surveys show that public concerns about RF EMF exposure from base stations and cell phones are not declining (Boehmert et al. 2020; Wiedemann et al. 2013). Having scientific controversy on the one side and public concern and misconceptions on the other side, risk communication is a difficult undertaking.

Furthermore, risk communication about RF EMF can pursue very different goals. Government agencies might predominantly have the goal to inform the public in a neutral way to empower them to make informed decisions. Other communicators (e.g., activist groups) might predominantly have the goal to raise people's risk perception and concerns. And still others, e.g., the mobile phone industry, might predominantly have the goal to decrease people's risk perception. In addition, a small group of experts and other interested individuals prepared 5G Appeal in 2019 that calls for a moratorium on the roll-out of 5th generation (5G) of the wireless mobile phone technology.

### 8.1 Understanding the risks

Over the last few decades, mobile network operators (MNO) and national authorities worldwide have been looking for ways to focus the debate on "electromagnetic tolerance" in a constructive manner in the field of potential health and environmental risks.

Along with the growth in the number of mobile telecommunication devices and the emergence of new generations of mobile communications, discussions about RF EMF exposure and related health risks remain intense and emotionally colored. Moreover, conflicts that manifest into public protests and the demolition of antenna sites are not uncommon (Gajšek et al. 2015; Eeftens et al. 2018; Gajšek et al. 2016).

According to decades of experience and several thousand published studies on possible health risks, the state of science is quite unanimous: identified health risks due to RF EMF are very small and hard to detect with existing research methodology. The World Health Organization (WHO) supports the detailed conduct of the research studies to better characterize health and environmental risks related to RF EMF exposure (WHO 2007; WHO 2011).

Are heavy concerns, intense criticism, and public engagement justified? Experts define the public concerns as justified only when it has been proven that there is a tripartite risk communication link between the three key dimensions (also called “constructive dialogue”) of the RF EMF issue:

- public risk perception,
- the way in which mobile network operators and regulators manage the risks,
- scientific findings on health risks.

Informing the public about the risks or simply about the phenomenon that contains the potential danger, is not and should not be a one-off event, but part of an ever-evolving relationship between organizations, the community, and individuals. There is a tendency to ensure that the supply of information is active rather than passive (this is limited to the availability of information, which then depends on people whether they become acquainted with it or not). Precisely because information is often not presented proactively, people at risk are informed too late or in part and inadequately. Thus, conflicts are almost unavoidable (Lundgren 2009; Renn 2010).

In trying to understand people’s perception of risk, it is important to distinguish between a health hazard and a health risk. A hazard can be an object or a set of circumstances that could potentially harm a person’s health. Risk is the likelihood, or probability, that a person will be harmed by a particular hazard. Nevertheless, every activity has an associated risk. It is possible to diminish risks by avoiding specific activities, but one cannot abolish risk entirely. In the real world, there is no such thing as “zero risk.”

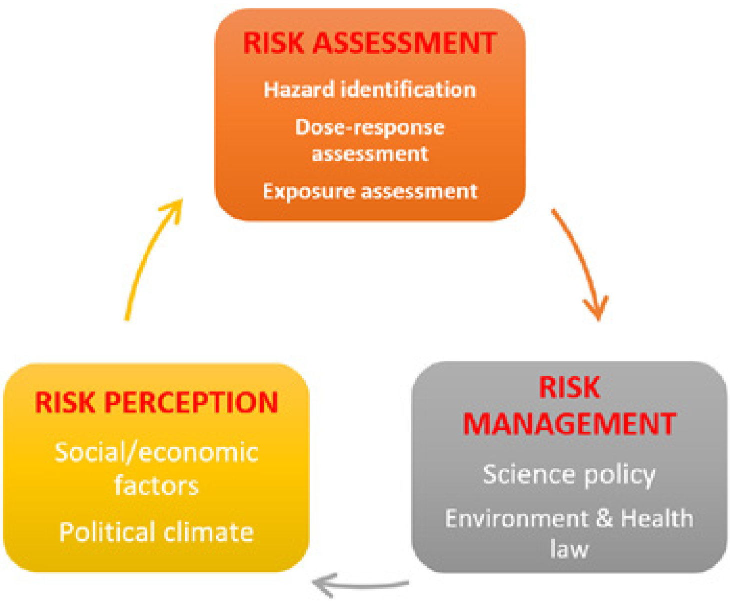



Figure 8.1: Evaluating, interpreting, and regulating risks associated with EMF.

The notifications themselves need to be simple and unambiguous, otherwise people have problems in judgment. Sometimes notifications must be designed differently for various groups of people. Emotionally charged messages need to be reduced. We need to be aware that people are most afraid of what they do not understand and cannot control (Widemann 2008).

The credibility of the source of information is important, and it depends mainly on previous experience with it as well as competence, objectivity, correctness, and consistency in the eyes of the public. Whatever the real danger, people are convinced they are at risk. Due to the aforementioned characteristics of human thinking and the emotional component of attitudes (which is not "susceptible" to opposing arguments), it will not be easy to reach a consensus. Once professional agreement has been reached, concluding that the intervention does not bring new risks (no intervention should endanger anyone if it wants to be acceptable), it is necessary to find ways to common solutions in cooperation with all those affected. It is necessary to show all sides and find a solution together.

A professional institution known as impartial and competent can play a positive role in this. People are increasingly shying away from what they find dangerous, harmful, or unnecessary. Thus, there is also opposition to power lines, various transmitters, base stations, radars, and mobile phones. The scientific contradictions still support this resistance. Even if experts do not agree on the potential health risks of specific technology, it is – people probably think – better to reject it. In addition, if the intervention is imposed from the "outside," for example by the government or a company – or if something similar has been successfully solved in another environment, it is understandable that the technology in question will not be accepted enthusiastically.  Even those who find it acceptable will oppose it due to pressure from activists.

As emotions prevail before scientifically justified arguments, a heavy atmosphere will reduce the chances of proactive dialog. No one wants to have dangers in their backyard. The **NIMBY effect** (Not In My Back Yard) consists of the opposition to the locating of something considered undesirable in one's neighborhood. In this context other acronyms are also known as **BANANA** (Build Absolutely Nothing Anywhere Near Anything/Anyone) (Gajšek et al. 2011).

## 8.2 Risk management strategies

The identification of problems and the scientific risk assessment of those problems are key steps to defining successful risk management options. To respond to that assessment, such a program should incorporate actions and strategies, e.g., finding options, making decisions, implementing those decisions, and evaluating the process. These components are not independent, nor do they occur in a predetermined order. Rather, each element is driven by the urgency of the need for a decision and the availability of information and resources.

There is a range of risk management options that could be implemented as such. The decision to take no formal action is an appropriate response in cases where the risk is considered very small, or the evidence is insufficient to support formal actions. This response is often combined with watchful waiting, i.e., monitoring the results of research and measurements along with the decisions being made by standard-setters, regulators, and others.

Communication programs can be used to help people understand the issues, become involved in the process, and make their own choices about what to do.

Research fills gaps in our knowledge, helps to identify problems, and allows for a better assessment of risk in the future.

Precautionary approaches are policies and actions taken by individuals, organizations, or governments to minimize or avoid future potential health or environmental impacts. These may include voluntary self-regulation to avoid or reduce exposure, if easily achievable.

Regulations are formal steps taken by a government to limit both the occurrence and consequences of potentially risky events. Standards with limits may be imposed with methods to show compliance, or they may state objectives to be achieved without being prescriptive.

Limiting exposure or banning the source of exposure altogether are options to be used when the degree of certainty of harm is high. The degree of certainty and the severity of harm are two important factors in deciding the type of actions to be taken.

Technical options should be used to reduce risk (or perceived risk). These may include considerations such as site sharing for mobile phone base stations, the optimization of technical parameters, and the introduction of the precautionary principle.

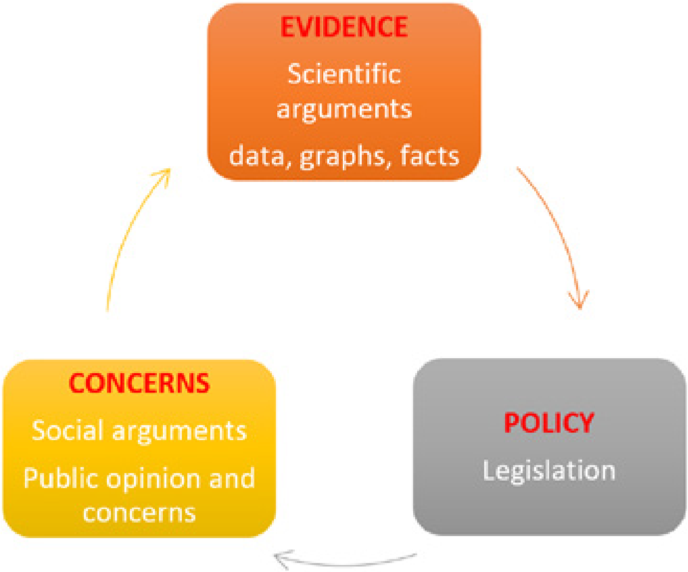
## 8.3 The need for risk communication

Today communication with the public about technological environmental risks plays an important role. Risk communication is an interactive process of the exchange of information and opinion among individuals, groups, and institutions. It involves multiple messages about the nature of the risk along with other messages, not strictly about risks, that express concerns, opinions, or reactions to risk messages or to legal and institutional arrangements for risk management.

Risk communication is, therefore, not only a presentation of the scientific calculation of risk, but also a forum for discussion on broader issues of ethical and moral concern.

Proactive and constructive cooperation and tolerant dialog among all stakeholders are crucial. Such a dialog must follow the principles of creating common goals, early information, knowledge transfer, well-intentioned adoption of different opinions, objective reporting, and the development of coordinated solutions. The answer is not unambiguous and requires a lot of effort and tolerant communication.

Environmental issues that involve uncertainty pertaining to health risks require supportable decisions. To that end, scientists must communicate scientific evidence clearly; government agencies must inform people about safety regulations and policy measures; and concerned citizens must decide to what extent they are willing to accept such risk. In this process, it is important that communication between these stakeholders be done clearly and effectively (Figure 8.2).




As the public becomes increasingly aware of environmental health issues, there has been concurrently a decreasing sense of trust in public officials, technical and scientific experts, and industrial managers, especially in large private and public businesses. Also, many sections of the public believe that the pace of scientific and technological change is too fast for governments to manage. Moreover, in politically open societies, people are ready to act and can become involved. Individuals, community-based organizations, and non-governmental organizations are willing to intervene with action to direct decisions or to disrupt activities if they are excluded from the decision process. Such a societal trend has increased the need for effective risk communication between all stakeholders.

A successful approach for planning and evaluating risk communication should consider all aspects and parties involved. These aspects could be summarized in practical recommendations that are tailored specially for deployment of existing and future wireless networks.

## 8.4 Recommendations for the deployment of wireless networks

Recommendations for the deployment of new wireless networks in the environment are geared in several directions: the optimization of technical parameters, site sharing, and the introduction of the precautionary principle.

With these measures it is possible to assure that the public RF EMF exposure in the long term is below the international exposure limits.

The complexity of the cost-benefit assessment should depend on the strength of the evidence for the occurrence of the risk. As the ***International Agency for Research on Cancer (IARC)*** has classified extremely low-frequency magnetic fields as well as RF EMF as a "possible carcinogen" (IARC 2013; WHO 2011), the analysis must be reasonably quantitative and objective, as far as data allow, like known risks with uncertainty. The IARC has recently prioritized RF EMF for review in the next four years (2020-2024).

In addition, some technical measures for RF EMF protection are possible, which enable the optimization of the rollout without higher costs and thus lower RF EMF exposure to the public and environment.

An important initiative for the introduction of these measures was also given by the European Parliament (EP) in its 2009 resolution (EP 2009), which noted that industry, regulators, and other authorities could already influence certain RF EMF burden factors by adopting provisions on: the distance between a base station and location of interest, the height of the base station antenna in relation to the surrounding buildings, and the orientation of the transmitting antenna in relation to dwellings, with the clear aim of calming and better protecting the population. Therefore, the EP calls for the optimal placement of towers and transmitters (base stations), as well as for their site-sharing among mobile network operators. The EP, therefore, calls on the European Commission and the Member States to draw up appropriate guidelines and legal solutions in this area. The following are key recommendations for the rollout of new wireless networks in the environment.

### 8.4.1 Optimization of technical parameters

A typical system for RF EMF signal transmission consists of a transmitter and a receiver. Both the transmitter and the receiver have an antenna that either transmits or receives RF EMF signals. The mobile phone and the base station are a combination of both and are, therefore, transceivers. In mobile communications every connection between the network and the user is two-way, so there is no reason for base stations with transmitting power of a few tens of W to be significantly stronger than transmitting power of mobile phones, which are up to 2 W (Gajšek et al. 2011; Valic et al. 2008a, 2008b).

Base stations are an indispensable component of a mobile telecommunications network – for example, 2G/GSM, 3G/UMTS, 4G/LTE, and the newly introduced 5G networks. These are technologically complex transceiver devices, the purpose of which is to establish a high-quality two-way radio connection between the mobile network and the user's mobile phone, while at the same time they are connected to the mobile system on the base station controller. The base station, like the mobile phone, constantly adjusts the transmitting power so that it transmits at the lowest possible power during the call to still maintain a quality radio connection.

The maximum transmit power of the base station is up to 100 W/sector (2G, 3G and 4G) whereas the transmit power of 5G networks could reach up to 200 W/sector.

A base station operates with the maximum power only when it is fully occupied – when a larger number of users are connected simultaneously and the distance between users is large enough and widespread (Gajšek, 2005). It usually operates at a power several times less than the maximum transmit power of the base station. If base stations are located at a shorter distance, their power may be lower since they must cover a smaller area. If we consider the worst possible case in terms of the highest EMF exposure of the environment due to base stations, we can say that the public exposure is only a small percent of the limit value (Valic et al. 2008a, 2008b).

In 2020 the European Commission adopted the Implementing Regulation (EC 2020) on small-area wireless access points, or small antennas, which are crucial for the timely deployment of 5G networks that are delivering high-capacity and increased coverage as well as advanced connection speeds. The Regulation specifies the physical and technical characteristics of small cells for 5G networks. It aims to help simplify and accelerate 5G network installations, which should be facilitated through a permit-exempt deployment regime, while ensuring that national authorities keep oversight.

A fully-fledged 5G rollout relies on denser and smarter wireless networks of small cells, or antennas. The Commission Implementing Regulation defines the physical and technical characteristics of those small cells, which are exempt from any individual urban planning permit or other prior individual permits. The definition of small cell in the Implementing Regulation sets tight limits in terms of size and maximum transmit power of those installations.

The Implementing Regulation ensures public health protection from exposure to EMF as well as visual integration of small cells. Small-area wireless access points should assure the protection of people's health and safety by adhering to strict EU exposure limits. For the public they are 50 times lower than what international scientific evidence suggests as having any potential effect on health. To ensure wide public acceptance for the measure, the Regulation addresses the visual appearance of small cells to avoid visual clutter. It lays out the specifications for a coherent and integrated installation, while providing national authorities with the means to oversee deployment of small cells.

Reflecting this, and to accelerate the rollout of this important new technology in the EU, small antennas should be exempted from any individual urban planning permit or other individual prior permits. Permits may still be required for deployment on buildings or sites protected in accordance with national law or where necessary for public safety reasons. The Regulation allows for broader national measures in support of straightforward small cell deployment. It also foresees future amendments to incorporate the latest technological advances.

The small new cells (antennas) will be less visible (either fully integrated and invisible to the public or, if visible, occupy a maximum space of 30 liters). Small cells will produce less RF EMF emissions. In fact, they could be compared to Wi-Fi installations. Small cells will use lower power levels and, therefore, create lower exposure levels than the existing 4G infrastructure. The overall exposure with the rollout of 5G networks will, consequently, be comparable to existing levels – it will be well below the strict EU exposure limits, which, for the public, are 50 times lower than what international scientific evidence would suggest as having any potential effect on health. Public health protection is ensured by the strict exposure limits set out in EU Recommendation 1999/519/EC (EC 1999).

The radiation beam of the 2G, 3G, and 4G base station antennas is distinctly directed. A base station emits most of the power in the major axis, that is, in the direction in which the base station radiation beam is directed. The radiation beam of the base station is only a few degrees wide in height, a few 10 degrees in width, and emits significantly less in other directions (Valič et al. 2008a, 2008b). A typical front to back ratio is 100 to 1000, which means that the antenna radiates 100 to 1000 times more in the front than back.

RF EMF exposure around the base station in an environment depends mainly on: antenna height above the ground, input power and number of active channels, mechanical/electric down tilt of the antenna, gain and radiation pattern of the antenna.

The presented procedures for calculating EMF exposure are important in the planning phase, as they can, if necessary, influence the reduction of the impact area and thus help meet the legal requirements for the placement of the source in space. With the combination of the height, the power input to the antenna, its radiation characteristics, and the mechanical inclination – the optimal operating conditions and the optimal radiation loads of a certain area can be determined to the greatest extent.

Increasing the height of the transmitting antenna by 10m indicates that the EMF exposure at the human accessible point is reduced by a factor of 10. An important role in the optimization of an individual location in terms of EMF exposure is played by the input power of the antenna. Reducing the transmit power by a factor of 10 indicates that the EMF exposure is reduced by a factor of 10. If we change the inclination of the base station's transmitting antenna (down tilt), the spatial distribution of the EMF exposure changes. In some cases, by changing the mechanical inclination by 8°, we can achieve a change in the EMF exposure of a certain area even by a factor of 100, especially at distances greater than 50 m. When the point at which the power density is calculated moves away from the main axis of the radiation pattern (exposure on the ground for the installation of the antenna on the tower), fluctuations in the resulting EMF exposure occur due to the vertical radiation pattern. Based on the performed calculations, it can be concluded that for a typical minimal 10 m height of the antenna above the ground, the EMF exposure outside the main beam is generally more than 100 times lower than for the same distance within the main beam.

Numerical calculations of the EMF exposure and analysis of different technical parameters show that with the appropriate design of base station technical parameters in the design phase of an individual wireless system, we can decisively influence whether an individual location will be more or less exposed.

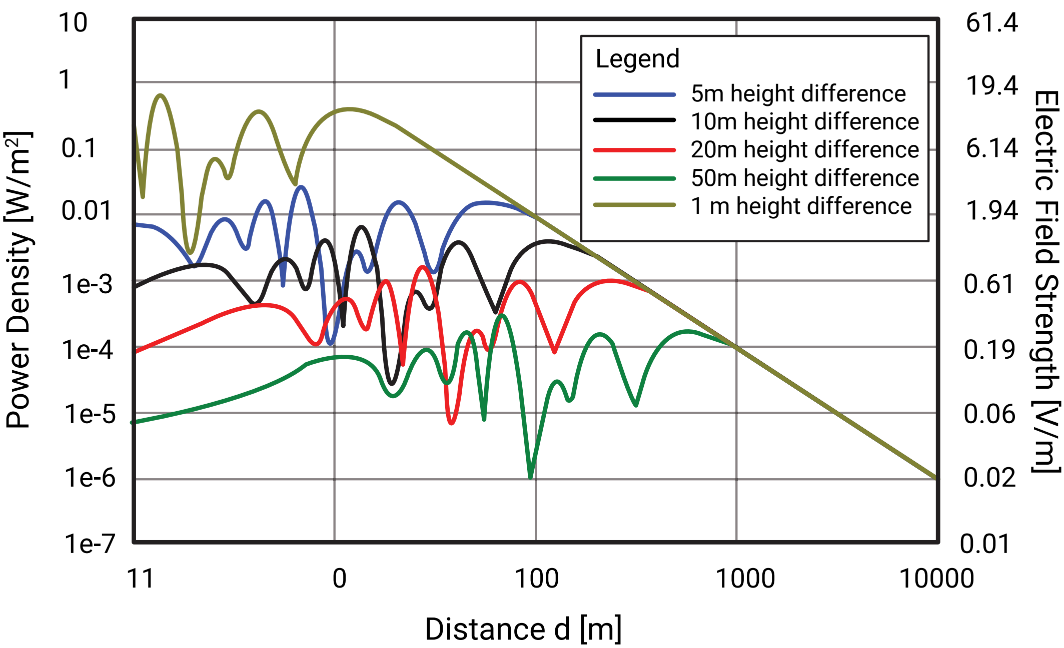



Figure 8.3: Power flux density [W/m$^2$] with respect to the horizontal distance from the base station for height ($\Delta h$) difference between the center of the antenna and the observed point.

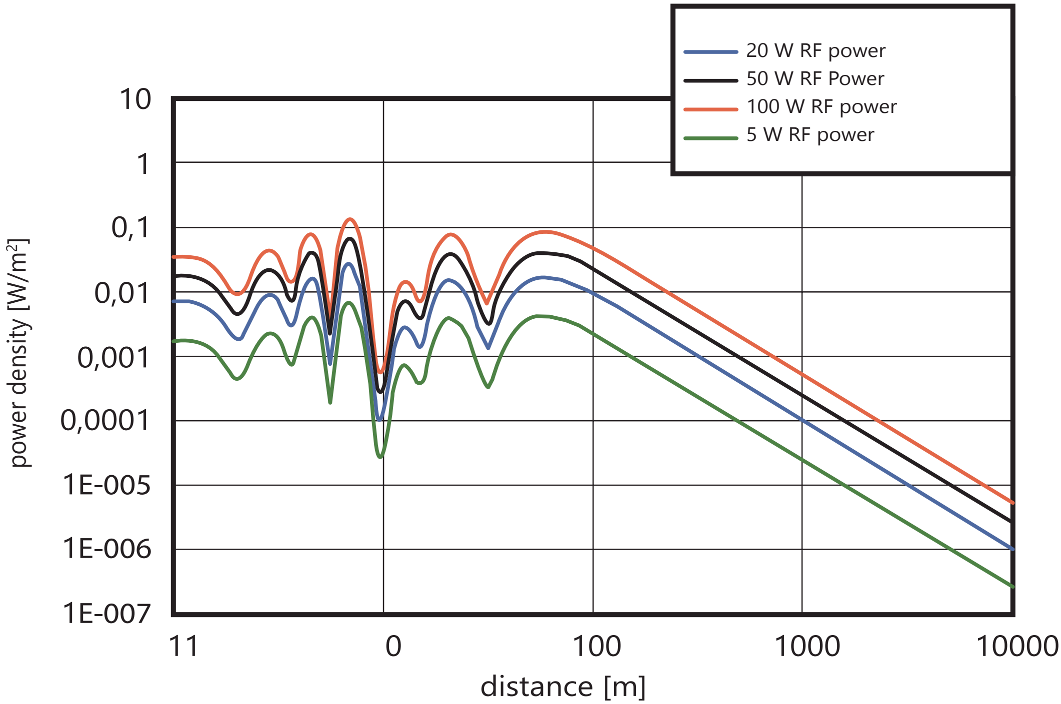



Figure 8.4: Power flux density [W/m²] with respect to the horizontal distance (m) from the base station for different input RF power delivered to antenna.

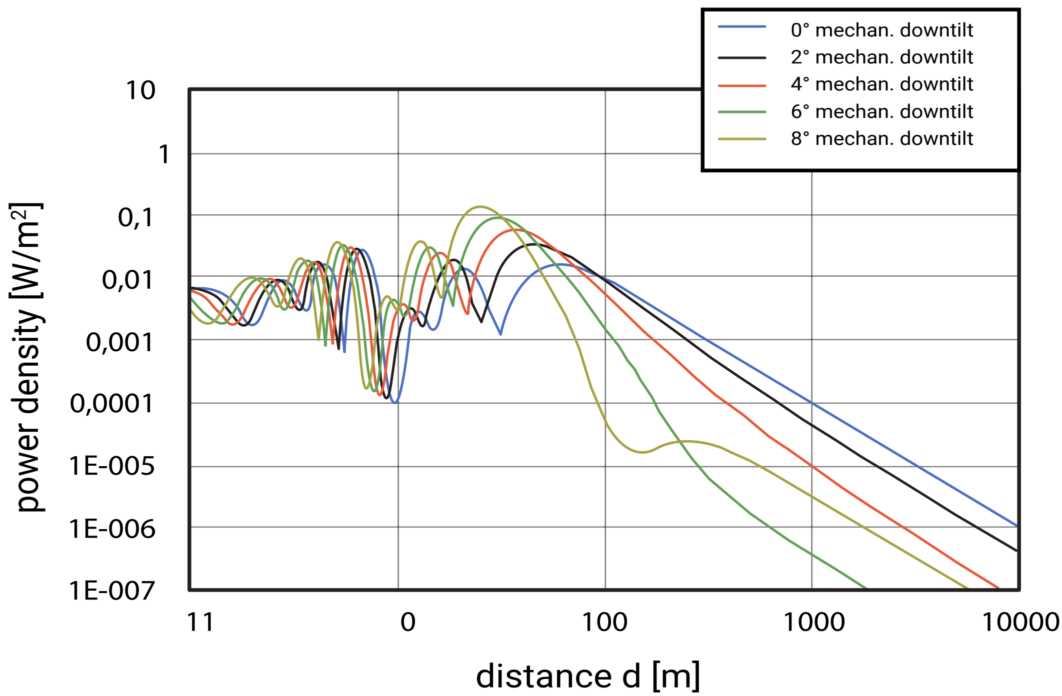



Figure 8.5: Power flux density [W/m²] with respect to the horizontal distance (m) from the base station for different mechanic down tilt of antenna.

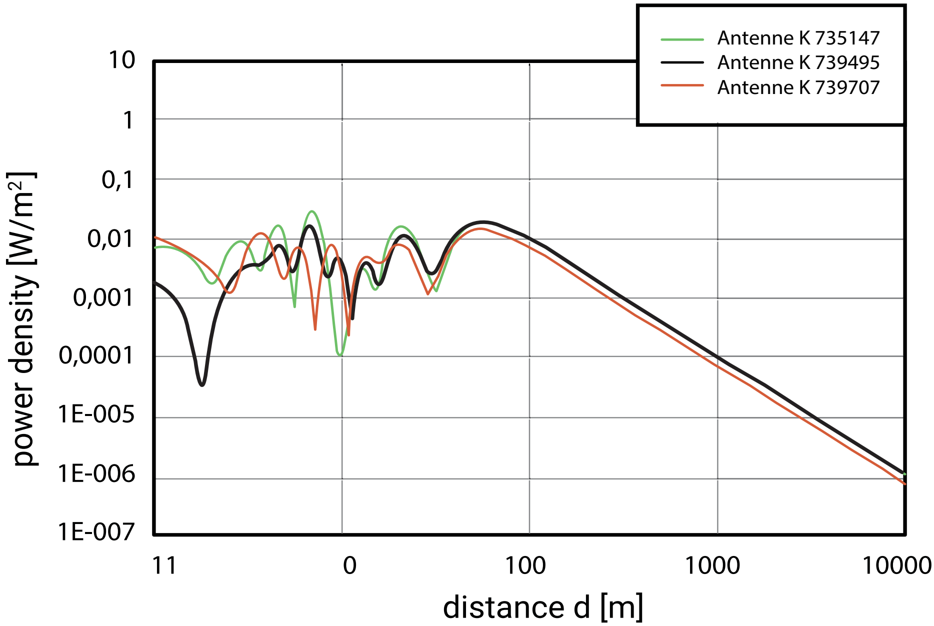


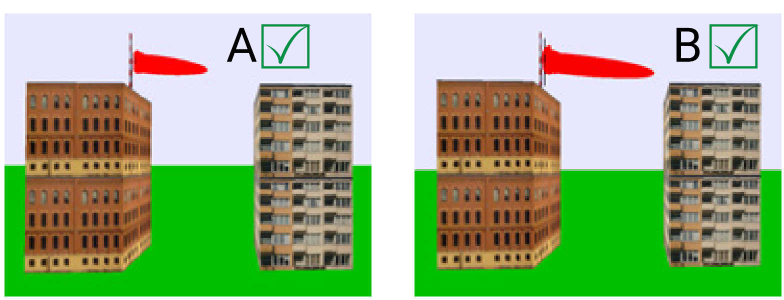

Figure 8.6: Power flux density [W/m²] with respect to the horizontal distance (m) from the base station for different type (radiation pattern) of antenna.

### 8.4.2 Site sharing

Combining devices on support antennas is one of the basic starting points of placement, and it makes sense to implement it as much as possible if technically feasible (adequate antenna load capacity is ensured) and environmentally acceptable (cumulative EMF exposure of all sources together at the location are not exceeded).

The merging of locations makes sense primarily through the implementation of the doctrine of rational use of space, the reduction of potential visible disturbances in space, and the concentration of EMF sources. Grouping locations makes sense between various operators and differing technologies.

At a given location, one operator can set up a base station without restrictions (Figure 8.7 - case A). An additional operator can be added (Figure 8.7 - case B) as well, but when a third network operator appears, the total EMF exposure can be exceeded, and the site is no longer acceptable for new installations due to the compliance zone being too large according to safety exposure limits (Figure 8.7 - cases C and D).



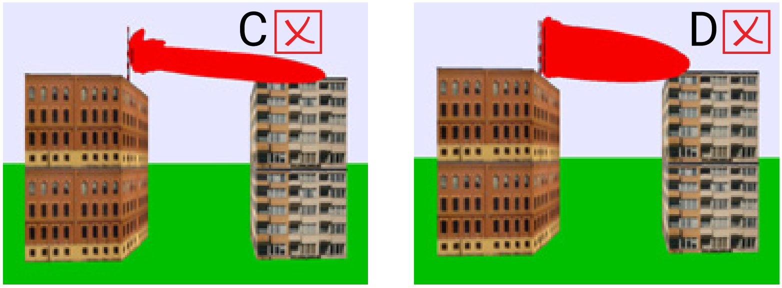



Figure 8.7: Case study of site sharing options of several wireless system operators located on an apartment building. Cases C and D are no longer acceptable due to the compliance zone being too large according to safety exposure limits.
(A) one operator - ☑
(B) two operators - ☑
(C) three operators grouping horizontally - ☒
(D) three operators grouping vertically - ☒

It is also interesting to compare the compliance zone, i.e., the area where the EMF exposure limits are exceeded in the vicinity of one base station with the transmit power 3×18 W and one base station with the transmitting power 3×2 W. The compliance zone at the height of the antennas is up to 10m in front of the antennas, and for another case up to 1m, respectively.

At first glance, placing a larger number of low-power base stations (small cell) in the environment seems to be a much more demanding intervention than installing a single, high-power base station.

This applies if the conditions and requirements for the installation of low-power base stations are the same as for installing a larger base station, but if the conditions are set differently (for example, as suggested in the European Commission's document Implementing Regulation on small-area wireless access points), this would no longer be the case. The installation of such small cells would be simplified even further if the necessary infrastructure exists on larger areas where such micro-locations are relevant. The ideal option in urban areas is provided by public lighting poles (streetlights) where electricity is already available – it would only be necessary to provide broadband access to the infrastructure.

The figure shows that the signal coverage on the right is significantly more even, which means that mobile terminal equipment will be able to operate better and faster, while the average EMF exposure of the public is lower due to smaller areas with high EMF exposures close to base stations and due to the lower required transmitting power of the mobile terminal equipment. The scale shows the EMF exposure as a fraction of the limit value (in %) according to the international guidelines.

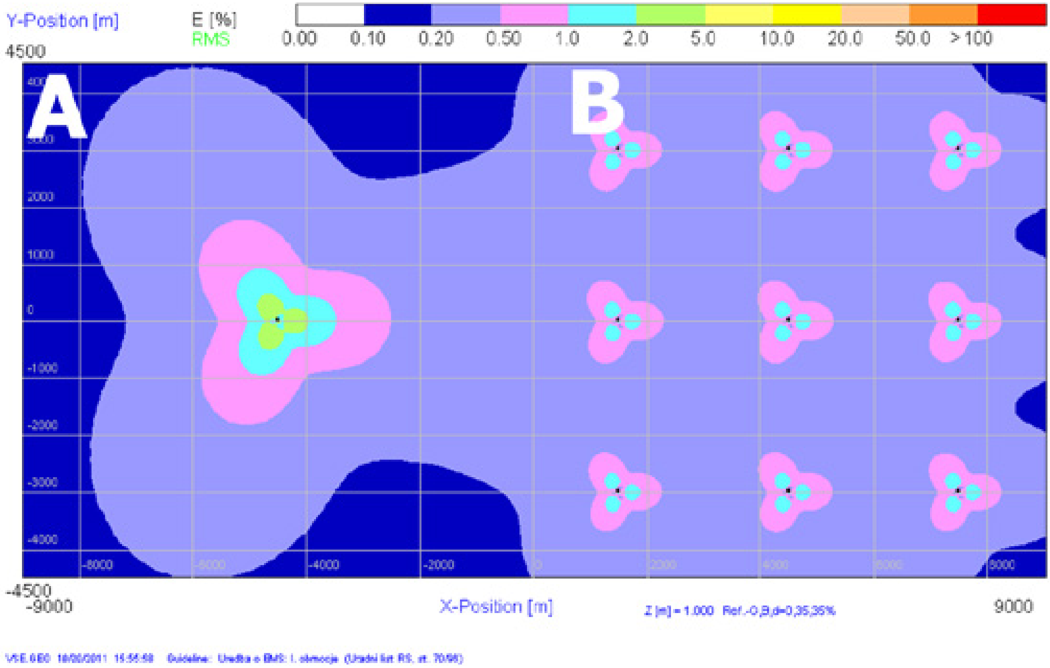



Figure 8.8: EMF exposure at a height of 1 m above the ground due to one base station of transmitting power 3 × 18 W (left) and 9 base stations of transmitting power 3 × 2 W (right). The total transmitting power of the base stations on the right and left is the same (54 W) in both cases.

### 8.4.3 Introduction of the precautionary principle

The precautionary principle is one of many guides that society can use when deciding whether to take action to protect people from possible risk. It is essentially a “better safe than sorry” approach suggesting that action should be taken to avoid risk even when it is not certain to occur. All risks are to some degree uncertain, but the degree of uncertainty varies. Clearly, when the harm associated with a risk is slight and its occurrence very uncertain, little or no action should be taken. Conversely, when the harm is great and there is little uncertainty about its occurrence, significant action is called for. It is in the gray area where substantial harm is postulated, but certainty about whether it will occur is low – or where the degree of harm is low, but the certainty is high – that policymaking is more difficult, and some decisive rules are needed as a guide to action. The precautionary principle provides a framework that sets a basis for decisions concerning whether to act and what action to take in uncertain situations. Note, the precautionary principle must also be supplemented by other decision guidelines and risk evaluation (Adler et al. 2005; Fernandez et al. 2019).

The precautionary principle can be built into existing environmental and health policies. It can also serve as a complement towards the usual risk management measures that would otherwise only be taken after the causal link has been confirmed.

However, care must be taken when preparing precautionary measures. Not all assumptions about health risks prove to be substantiated. The uncritical application of precautionary measures can lead to indistinct benefits for the health and environment and introduce drawbacks to the society by setting unnecessary limitations. In addition, such measures can result in very different national policies, increased public concerns, and restrictions on the free movement of goods. Precautionary principal measures are always based on the assessment of all possible benefits and drawbacks, where all indirect effects should be considered (Boehmert et al. 2017; Covello 2011).

There has been extensive research performed on the potential health effects from exposure to mobile phone handsets. Available evidence up to 2011 was reviewed by the International Agency for Research on Cancer (IARC), a World Health Organization (WHO) agency. Based on this review, IARC classified RF-EMF as possibly carcinogenic or group 2B (Baan et al., 2011). This classification was mainly based on evidence from studies involving heavy, long-term use of mobile phone handsets using 1G, 2G & 3G technologies (IARC 2013).

The IARC 2B classification means that the evidence for the substance or physical agent causing cancer is limited and further research is needed. Other products such as pickled food, aloe vera, and dry-cleaning agents are also classified as 2B. RF EMF, due to other wireless systems and devices like base stations and various transmitters, is not formally classified by the WHO. However, given the dramatic expansion of wireless devices and systems along with RF EMF exposure over the last decade, exploring possible measures where costs are low is justified. Therefore, in this context, the RF EMF requires a comprehensive cost-benefit analysis.

Uncertainties about cost-benefit analysis will always remain. All crucial uncertainties and assumptions should be explicitly allowed and included in any cost-benefit analysis. The World Health Organization recommends (WHO 2007) the working assumption that measures that reduce any aspect of the public RF EMF exposure reduce the risk, if any. At the same time, WHO emphasizes that it is unlikely that any specific measure that reduces exposure would reduce precisely that relevant aspect of exposure that is associated with health risk.

The weight of political, environmental, social, and economic factors must be explicitly stated when choosing measures based on the precautionary principle. The key to stakeholders' trust is transparency. Therefore, when comparing costs and benefits to decide on appropriate precautionary measures, the following factors should be considered (WHO 2007; Gajšek 2005; WHO 2014):  the likelihood that there is a health risk at levels below the legal exposure limits is low, so we assume that measures are justified only where the costs are also relatively low or non-existent. The potential consequences of any health risks are high due to the high prevalence of exposure, and low-cost measures should be chosen wherever possible.

The technologies that are the source of EMFs bring great benefits to society; any reduction in these benefits because of precautionary measures, i.e., the delay in rollout of wireless networks, is likely to overshadow any benefit.

Therefore, precautionary measures in relation to base stations and their wireless networks, which involve additional high costs, are unlikely to be justified unless there are other reasons to do so. However, the EMF issues need to be addressed together with the useful aspects of advising and reducing public concerns when it comes to discussing changes to be established regimes or planning policies.

The recommendations based on precautionary measures to reduce public RF EMF exposure, which can be carried out by government authorities and mobile network operators, are described:

**a) Governmental and local authorities**

An effective system for providing information and communicating health risks between scientists, government, industry, and the public helps to raise awareness of programs dealing with EMF exposure and reduces mistrust and fears.

The public needs to be fully informed about the current state of science. The public must be informed, in particular, of the identified and confirmed health effects due to EMF exposure from various technology. Thus, increasing the amount of public information – especially about new technologies (5G!), exposure scenarios, and the possibilities for reducing RF EMF exposure in everyday life – will allow people to develop their own precautionary measures if they choose to do so.

Based on the preparation of an environmental impact assessment or expert assessments, it shall be ensured that the international EMF exposure limits are not exceeded when placing new wireless system facilities and devices that are accessible to the public.

Create a register of EMF sources and data on exposure assessment for the specific territory or whole country (i.e., Republic of North Macedonia). In this way, the public could, to a large extent, determine through publicly available data what the EMF exposure in their environment is and gain insight into areas where EMF exposure is already excessive today. It should be noted that no additional sources are allowed at this location in the future.

The Local authorities and the public must cooperate in the process of installation of new EMF sources in an environment (power lines and transformer stations, radars, base stations, broadcasting transmitters): the aesthetic aspect and the sensitivity of the public must be considered when deciding on the installation location. Open communication in the planning phase increases public awareness and acceptability for intervention.

When planning and granting building permits, it is necessary to determine its compliance zone for a new EMF source according to national or international exposure limits, considering all relevant EMF sources at the selected location.

Further research needs to be supported and funded.

The local government should include provisions related to spatial planning acts of facilities and devices of wireless systems – reasonable admissibility of facility placement that will enable the development of telecommunication infrastructure and such spatial conditions that will require quality and favorable architectural and environmentally friendly solutions.

**b) Mobile network operators (MNO)**

It is necessary to strictly observe the legislation in the field of protection against EMF: it should be based on the current state of science with a high, built-in, safety factor with the purpose to protect the human health of every member of society.

MNO should minimize emissions from new installations in accordance with the precautionary principle and within technical possibilities. In their work they should comply with the provisions of the **Code of Good Practice** [6] on the rollout of the EMF sources.

EMF sources should be optimized – location, orientation, transmitting power, and antenna height, including radiation pattern – in such a way as to ensure optimal signal coverage with the lowest possible total EMF exposure. Those locations where the public RF EMF exposure is kept to a minimum should be preselected.

The installation of wireless EMF sources should receive special attention in areas of special sensitivity or where children are present, for example in the vicinity of kindergartens, schools, and hospitals. Optimal placement of devices and systems (e.g., adequate transmitting power, antenna height, and radiation pattern) can reduce the public RF EMF exposure.

When installing devices that are a source of RF EMF (e.g., base stations), care should be taken to install them at reasonable costs in places where exposure of the public is minimal. Although the RF EMF levels around these devices are not considered risky, the aesthetic aspect and the sensitivity of the public during the implementation phase should also be considered. Only open communication between the owners of the RF EMF source, local authorities, and the public in the individual stages of planning will help to understand the issue and increase openness for the installation of a new system.

Priority in the deployment of new RF EMF sources should, therefore, be given to solutions based on dialogue between MNO, local communities, and the public – ensuring that schools, kindergartens, nursing homes and healthcare facilities are away from such devices at a specific distance where exposure limit values will not be exceeded.

Manufacturers of the electronic and wireless devices should achieve the lowest possible exposure in its vicinity with the appropriate technical design. Appropriate labeling of devices is also important, which allows users to choose devices (i.e., mobile phones) with the lowest specific absorption rate (SAR).

## 8.5 Case study: Risk perception and management in relation to 5G

A section of the scientific community argues that there are negative impacts from RF EMF exposure and that these will increase with the implementation of the latest 5th generation (5G) wireless mobile phone technology. A 5G appeal was presented to the European Union in 2017. The signatories state that with the increasingly extensive use of wireless technology, especially when 5G is deployed, nobody will be able to avoid exposure to constant RF EMF because of the huge number of 5G transmitters – with an estimated 10 to 20 billion

[6] The basis for open dialog with the framework solutions could be founded by signing the **Code of Good Practice** by mobile networks operators. This Code is intended primarily to build the trust and open dialog between all the stakeholders involved. The Code improves the flow of information in the placement of different RF EMF resources in environment and establishes a good foundation for cooperation between the public, mobile network operators, governmental and non-governmental organizations, and the scientists. The experiences in some EU member states, where network operators have already implemented similar documents, show that the negative public attitude towards the placement of RF EMF sources (base stations) has significantly improved with the beginning of consistent implementation of the Code (Gajšek et al. 2011).

connections (to self-driving cars, buses, surveillance cameras, domestic appliances, etc.). In addition, the appeal states that many scientific publications illustrate RF EMF exposure effects such as an elevated risk of cancer, genetic damage, learning and memory deficits, neurological disorders, etc. The 5G appeal points out that there is not only harm to humans, but also to the environment. The appeal recommends a moratorium on the deployment of 5G for telecommunications until potential hazards to human health and the environment have been fully investigated by scientists independent of the telecommunications industry. In this regard, some scientists consider it necessary to establish new exposure limits that consider the new characteristics of exposure. Such limits should be based on the biological effects of RF EMF, rather than on the energy-based specific absorption rate.

The European Commission formally responded that the exposure limits set by the European legislation remain valid, and the primary responsibility for protecting the public from potential harmful effects of EMF remains with the Member States. At EU level, the Council Recommendation on the limitation of exposure of the public to electromagnetic fields (1999/519/EC) sets basic restrictions and reference levels as a common protective framework to guide the action of Member States for the exposure of the public to EMF.

Scientific Opinion produced by the independent Scientific Committee on emerging and newly identified health risks (SCENIHR 2015), is based on hundreds of peer-reviewed studies published worldwide and is the fourth opinion on EMF published since EU recommendation on EMF was adopted in 1999. The Committee's conclusion was as follows: “The results of current scientific research show that there are no evident adverse health effects if exposure remains below the levels set by current standards. Thorough examination of all pertinent, recent data has not produced any conclusive evidence about EMF being dangerous, which is reassuring. However, further research should be conducted, particularly as pertains to very long-term exposure and potential risks of exposure to multiple sources.” The recourse to the EU's Precautionary Principle to stop the distribution of 5G products that was the main goal of the 5G appeal appears too drastic of a measure. Moreover, the European Commission stated that it first needs to see how this new technology will be applied and how the scientific evidence will evolve. The EU will keep abreast of future developments in view of safeguarding the health of the European citizens at the highest level possible and in line with its mandate.

## 8.6 Statements provided by key international organizations in regards to health risks related to RF EMF exposure

In relation to RF EMF exposure and wireless technology and health, the general conclusion from the World Health Organization (WHO) is:

***“Despite extensive research, to date there is no evidence to conclude that exposure to low level electromagnetic fields is harmful to human health”*** WHO - About Electromagnetic Fields – Summary of Health Effects Key Point 6

***“Considering the very low exposure levels and research results collected to date, there is no convincing scientific evidence that the weak RF signals from base stations and wireless networks cause adverse health effects.”*** WHO Backgrounder on base stations and wireless technologies

On mobile phone safety the World Health Organization advises (WHO 2014):

***"A large number of studies have been performed over the last two decades to assess whether mobile phones pose a potential health risk. To date, no adverse health effects have been established as being caused by mobile phone use. While an increased risk of brain tumors is not established, the increasing use of mobile phones and the lack of data for mobile phone use over time periods longer than 15 years warrant further research of mobile phone use and brain cancer risk. In particular, with the recent popularity of mobile phone use among younger people, and therefore a potentially longer lifetime of exposure, WHO has promoted further research on this group. Several studies investigating potential health effects in children and adolescents are underway."*** WHO Fact Sheet 193 June 2014 - Electromagnetic fields and public health: mobile phones

Scientific Committee on emerging and newly identified health risks (SCENIHR 2015) in his opinion examines latest data on health impact of technologies:

***"The results of current scientific research show that there are no evident adverse health effects if exposure remains below the levels set by current standards. Thorough examination of all pertinent, recent data has not produced any conclusive evidence about EMF being dangerous, which is reassuring. However, further research should be conducted, particularly as pertains to very long-term exposure and potential risks of exposure to multiple sources."***

The International Commission on Non-Ionizing Radiation Protection, RF EMF guidelines (ICNIRP 2020):

***"A considerable amount of research has been conducted on the relationship between RF EMFs and health outcomes such as headaches, concentration difficulty, sleep quality, cognitive function, cardiovascular effects, etc. This research has not shown any such health effects. The only consistently observed finding is a small effect on brain activity measured by electroencephalography (EEG). The biological implication of these small changes is, however, unclear. For example, they have not been shown to affect sleep quality or be associated with any other adverse effects. The overall evaluation of all the research on RF EMFs leads to the conclusion that RF EMF exposure below the thermal threshold is unlikely to be associated with adverse health effects. "***

***"There is no evidence of adverse health effects at exposure levels below the restriction levels in the ICNIRP guidelines and no evidence of an interaction mechanism that would predict that adverse health effects could occur due to RF EMF exposure below those restriction levels."***

The International Commission on Non-Ionizing Radiation Protection, Statement principles for non-ionizing radiation protection, (ICNIRP 2020):

***"ICNIRP uses standard procedures to arrive at its guidelines for limiting exposure. These guidelines are established using a conservative approach, which means that compliance with the recommended exposure limits will provide a very high level of protection from substantiated adverse health effects due to the exposure."***

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# Chapter 9

## 9 Conclusions

Living organisms are exposed to electromagnetic fields (EMF) on a daily basis from a variety of sources, at different frequencies; from low frequency EMF originating from power lines, electrical appliances, machinery etc., to the most widespread radiofrequency (RF) EMF. The sources of these fields are partly from natural phenomena, and the rest of them are a consequence of the technological activities of man. Some of the most important sources of the RF EMF are the mobile telecommunications, other types of wireless communication systems, television and radio distribution, RF communication of police and fire crews, etc.

Depending on the field type, intensity and duration of exposure, there are different mechanisms of interactions between EMF and different biological systems. According to their influence on biological tissues, the EMF present in our environment are divided into two basic groups: ionizing and non-ionizing fields. In the electromagnetic spectrum, only EMF with frequencies above around 1016 Hz carry a sufficient amount of electromagnetic energy to cause an ionization. Ionizing radiation is high-frequency electromagnetic radiation that carries enough energy to break the molecular bonds and ionize atoms in tissues. RF EMF are non-ionizing fields with frequency range from 3 kHz (3.103 Hz) to 300 GHz (3.109 Hz) and do not carry enough energy to cause tissue ionization.

Construction of modern and stable electronic communication networks and implementation of services, especially through mobile networks, enables sharing rich media content, creation and development of new applications and innovative personalized services adaptable for different platforms, available to every user, regardless of the location or time. Taking advantage of mobile networks and technologies provides opportunities to reorganize the production and work processes in both the business sector and state administration, i.e. development of the economy and transition to knowledge-based societies. Hence the need exists for construction and maintenance of quality mobile telecommunications infrastructure. Every operator of electronic mobile communication network should own and build in its development and progress, infrastructure in accordance with the standards sizing it so as not to endanger the life of users and people in a general way of speaking, as well as the overall environment. Quality of the telecommunications infrastructure and network, nowadays, must be owned and upgraded by every operator of the electronic communication networks, because the rapid technological development requires fast and always active connections and communication through mobile networks, thus advancing and developing i.e. switching from development technologies from 4G to 5G and in the future from 5G to 6G etc.

The tension and even fear of new technologies (like the 5G technology) has been present in the public for ages. Scientists and creators of new discoveries and technologies, have always faced resistance in proving and realizing them. For example, Nikola Tesla's innovations in the field of electromagnetic waves, radio engineering and electricity were at first condemned, ridiculed and unacceptable to other scientists and the common people, and nowadays we celebrate and use the benefits of his discoveries. In that context, while mobile phones are used every day by almost everyone, there are activist groups and considerable media attention to RF EMF risk news. Public concerns about alleged harmful effects of the new 5G technology are rising along with scientific controversy. 5G technology is merely the fifth generation of mobile telecommunications network technology. 5G is just the name of a new phase in the development of the mobile network, with main technical requirements to provide much higher communication speeds, extremely low communication delays and significantly increased efficiency in the use of spectrum and other network resources.

The benefits of this new technology are huge and as time goes by, it will be implemented in every area. In addition to telecommunications, it is already used in the machine and mechanic industry, and will be used in medicine, pharmaceutical industry, large warehouse management, etc. 5G technology is still in the process of evolving. There are certain measurements and tests for the functioning of 5G and what it would mean in people's lives and we could get the right picture in several years. Every technological innovation requires a lot of investments and testing, supported by numbers and statistical data, on the basis of which reports of all kinds are made. Through 5G, customers would receive much better telecommunications services, more efficient production in many industries, smart cities projects, smart homes, with other words, most of the functions performed by people, for private work or during their work responsibilities will be much easier, simple, fast, functional and useful. The scientific papers in the field of 5G are becoming more numerous every day in order to present the application and benefits of 5G technology, and the scientists are concentrating on finding segments where it would be implemented to make people's lives easier. Simply put, 5G will be the technical platform for the next industrial revolution.

North Macedonia has always had, has and will have huge potential and capacity for implementation of projects related to the ICT field, including of course 5G technology. Starting with the construction of the first mobile network in the 90s, numerous projects have been implemented in the field of telecomunnications. Furthermore, through monitoring of the development of all innovative solutions in the field of telecommunications, North Macedonia introduced almost immediately after their commercial deployment in the world. In that process, recommendations from telecommunications organizations and international standardization bodies are regularly followed. Operators under the supervision of the Agency for Electronic Communications of North Macedonia (AEC) are developing and modernizing their own networks, in order to achieve the appropriate quality of services received by the end users. In order to control the work of the operators, AEC, as an independent telecommunication Regulatory Body, continuously conducts measurements of the quality of services provided by both network operators, on the entire territory of North Macedonia and publishes the results of those measurements on the AEC website: www.komuniciraj.mk.

Regarding 5G technology, it can be anticipated that the biggest challenge for network operators would be the financial capacity and practical design of the base stations themselves for greater coverage. For a start it can be realized city by city and the package offered to users with adequate financial offer, according to the system invested-received. An important part of the process is also the positive advertisement and whether this type of advertisement will be more convincing than the negative allegations related to the technology.

In the past period in Europe there are no canceled procedures for assigning radio frequencies for 5G. Due to the situation with the Corona i.e. COVID-19 (SARS-CoV-2) virus, which Europe and the world is dealing with, and due to procedural errors in the procedures in some European countries, they are only put on hold or in the status of correction of the procedures and they will continue until their full completion. In some countries these procedures have been completed and the 5G radio frequencies have been successfully assigned.

On the other hand, it can be said with certainty that 5G technology has nothing to do with COVID-19. COVID-19 has been found to be a virus, mutated from another pre-existing virus, which in most cases attacks human respiratory organs. There is no scientific basis to consider the allegations that 5G technology is somehow related to the COVID-19 virus.

Health-related conclusions are drawn from studies performed across the entire radio spectrum but, so far, only a few studies have been carried out at the frequencies to be used by 5G. However, the introduction of new technology that uses existing radio frequencies does not change the characteristics of the frequencies. This means that the recommendations of international organizations covering frequencies up to 300 GHz remain in force. The main mechanism of interaction between RF EMF and the human body is tissue heating. RF exposure levels from current technologies result in negligible temperature rise in the human body. 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). With the recent popularity of mobile phone usage among younger people, and therefore a potentially longer lifetime of exposure, the World Health Organization keeps promoting further research about the exposure of this specific group. Several studies investigating potential health effects in children and adolescents are underway.

The results of current scientific research on possible health risks of RF EMF exposure show that there are no evident adverse health effects if exposure remains below the exposure levels set by current international guidelines. Thorough examination of all pertinent, recent data by expert members of international standardization bodies has not produced any conclusive evidence about RF EMF being dangerous. The official standpoint of the World Health Organization is that considering the very low exposure levels and research results collected to date, there is no convincing scientific evidence that the weak RF signals from base stations and wireless networks cause adverse health effects. However, it is recommended by the majority of the relevant organizations that further research should be conducted, particularly in the area of very long-term RF EMF exposure and potential risks of exposure to multiple sources.

# About the authors

**Doc. dr. Gajšek Peter** – studied Electrical Engineering at the University of Ljubljana, Slovenia. After graduating in 1991 he was employed by the Institute of Public Health of the Republic of Slovenia as an advisor to the Director. There he performed numerical and experimental studies in EMF dosimetry. In 2001 he received his PhD on a dissertation concerning dielectric properties of the biological tissues and EMF absorption. Since 2003 he holds the position of the director of the Institute of Non-Ionizing Radiation and is primarily involved in non-ionizing radiation research and consulting. As a Scientific Advisor of several Expert Committees, he has written several advisory reports and scientific papers on the health effects of low and high frequency electromagnetic fields. From 2004 he serves as an Assistant Professor at the University of Ljubljana and University of Nova Gorica covering the aspects of non-ionizing radiation and health risks. He is a member of several national and international organizations in the field of non-ionizing radiation. He has been a board member of the Slovenian Society for Radiological Protection, national coordinator of Slovenia to the COST BM0704 and member of the International Advisory Committee of the International EMF Project with WHO. Dr. Gajšek is also a member of CENELEC/TC 106 X, EBEA and BEMS and has been a reviewer for several journals in the field of bioelectromagnetics.

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**Assoc. prof. dr. Raković Valentin** – currently holds the position of associate professor at the Institute of Telecommunications at the Faculty of Electrical Engineering and Information Technologies (FEEIT), Ss Cyril and Methodius University in Skopje, and the head of the laboratory for Wireless and Mobile Networks at FEEIT - Skopje. He received his Dipl.-Ing., M.Sc. and Ph.D. degree in Telecommunications at the Faculty of Electrical Engineering and Information Technologies, Ss Cyril and Methodius University in Skopje, in 2008, 2010 and 2016 respectively. Dr. Rakovic also worked as a visiting research fellow at Georgia Institute of Technology, GA, USA, in 2019. His research work focuses on the areas of wireless network virtualization, cognitive radio and heterogeneous networks, radio resource management, signal processing, radio environment modeling and mapping, space division multiple access techniques as well as prototyping of wireless networking solutions. He has (co-) authored more than 70 publications in international conferences and journals. Dr. Rakovic has been part of the teams awarded with the best demo/prototype awards on IEEE DySPAN 2011 and 2015, and has been awarded with the Ss. Cyril and Methodius award for best scientist in the field of technical sciences in 2016. He is an IEEE senior member.

**Mag. Tomaž Černe** – graduated in the filed of geodesy at the University of Ljubljana - Faculty of Civil and Geodetic Engineering in 2001. In 2009 he obtained the title of Master of Science in the field of municipal engineering at the same faculty. Since 2001, he has been employed by IGEA d.o.o., where he leads projects in the field of spatial planning, land policy, spatial information systems and investment engineering for the public and private sectors. In the areas related to spatial planning, land policy and the spatial information system he cooperates with the Chamber of Engineers of Slovenia and the Surveying and Mapping Institute of Slovenia. From 2006 to 2012, he was an assistant at the Faculty of Civil Engineering and Geodesy in the field of communal economy, urban economics and spatial planning, and he still cooperates with the faculty in these fields. He is currently appointed as a college lecturer of Urbanism, Environmental Protection and Legislation and Environmental Charges and Financing. He is registered as a Researcher in a research and development unit in the field of geographic information systems, code: 22682. Since 2006 he has been the President of the Spatial Planning Section of the Association of Surveyors of Slovenia. He is also a member of the board of directors of the Slovenian Real Estate Association FIABCI Slovenia.

**Dr. Valič Blaž** – studied Electrical Engineering at the University of Ljubljana, Slovenia. After graduating in 2001 he was young researcher at the University of Ljubljana, Faculty of Electrical Engineering, Laboratory of Biocybernetics. His main research interest was numerical calculations of electromagnetic phenomenon on the cell level, tissues level and whole human body levels. He obtained his PhD in 2006 on the numerical dosimetry of humans with different implanted devices and structures. Later he has joined the Institute of Non-Ionizing Radiation, where he is head of the laboratory. His expertise includes numerical dosimetry, measurement procedures, large scale calculations, accreditation requirements and quality system. He is member of EBEA and BEMS, CENELEC/TC 106 X and reviewer for several journals in the field of bio electromagnetics.

## About the institutions

**AEC – Agency for Electronic Communication** – The Agency for electronic communications was established with the Law for electronic communications in 2005, as an independent regulatory body of the electronic communications markets. Guided by the goal of regulating the electronic communications market in a systematic manner, the Agency has strictly defined objectives that it strives to achieve. Among these is the objective of establishing and maintaining a competitive market in which end users can use electronic communication services with highest quality and at best possible prices. The mission of the Agency is to create favorable conditions for effective and sustainable competition on the market for electronic communications that will serve the interests of the users, economy, and communications industry through effective, transparent, adequate and proactive use of regulatory tools.

**INIS – Institute of Non-Ionizing radiation** – Institute of Non-ionizing radiation (INIS) is an independent non-government organization for the research and development in the interdisciplinary field of non-ionizing radiation. Inside the Institute a well-trained group of experts is capable to handle most demanding development and research tasks about technical, administrative, legal and health management of electromagnetic fields and optical radiation. As internationally well recognized partner in the field of environmental and health protection together with well-educated and trained experts, wide international links and up to date laboratory equipment we are well prepared to respond to different answers regarding the electromagnetic fields and optical radiation in the living and working environment.

**Ss. Cyril and Methodius University in Skopje** – the oldest higher educational institution in North Macedonia. An autonomous institution that provides teaching, scholar and applied activities in technical, natural sciences and mathematics, bio-technical, artistic, medical and social sciences. The following faculties constitute Ss. Cyril and Methodius University in Skopje: "Blaze Koneski" Faculty of Philology, Faculty of Agricultural Sciences and Food, Faculty of Architecture, Faculty of Civil Engineering, Faculty of Computer Science and Engineering, Faculty of Dentistry, Faculty of Design and Technologies of Furniture and Interior, Faculty of Dramatic Arts, Faculty of Economics, Faculty of Electrical Engineering and Information Technologies, Faculty of Fine Arts, Faculty of Forestry, Faculty of Mechanical Engineering, Faculty of Medicine, Faculty of Music, Faculty of Natural Sciences and Mathematics, Faculty of Pharmacy, Faculty of Philosophy, Faculty of Physical Education, Sport and Health, Faculty of Technology and Metallurgy, Faculty of Veterinary Medicine, Iustinianus Primus Faculty of Law and St. Kliment Ohridski Faculty of Pedagogy. Ss. Cyril and Methodius University is also the home of several specialized institutes: Institute of Agriculture, Institute of Cattle-breeding, Institute of Earthquake Engineering and Engineering Seismology, Institute of Economics, Institute of Sociological, Political and Juridical Research and several public scientific institutions: Institute of Macedonian Literature, Institute of National History, Krste Misirkov Institute of Macedonian Language, Marko Cepenkov Institute of Folklore. Ss. Cyril and Methodius University provides long-life and continuing education for all students on the basis of equality and their academic results regardless of their ideological, political, cultural and social origin.

**IGEA** – Geographic Information Systems (GIS) have always been the core expertise of IGEA's business activities since its establishment in 1989. In recent years, our wide range of knowledge and experiences have been upgraded into a comprehensive consulting, technical services an IT development in real estate registration, infrastructure management and spatial planning. With the view on further content and technological development and deep understanding of the current situation we can design and implement successful and efficient solutions to our customers. IGEA is one of the few companies that is developing a national land cadastre system in several countries: Slovenia, Croatia, North Macedonia and Serbia. In North Macedonia and in Serbia it has also local companies. IGEA and its employees have wide range of quality and professional certificates and references.