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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Scientific monograph

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short version

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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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Chapter 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.

Chapter 2 - Physical laws, sources and exposure assessment of Electromagnetic Fields

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). The power flux density of EMF is defined as power per unit area carried by the EMF and is expressed in watts per square meter (W/m^2), but milli-watts per square centimeter (mW/cm^2) and micro-watts per square centimeter (mW/cm^2) are also used (Janev 2002; Janev 2006; Sadiku 2014).

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).

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 10^{16} 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 (ELF) EMF, intermediate frequency (IF) EMF, RF EMF, infrared radiation, visible light and ultraviolet (UV) radiation.

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

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.

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 the 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-electro-shocks) 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.

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 a number of 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.

2.3.3 RF EMF Exposure assessment methodology

The level of exposure is a function of the power carried by the EMF and their 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 m^3), with a given density ρ (measured in kilograms per cubic meter - kg/m^3) (NCRPM 1981):

Equation 2.1: $$\mathrm{SAR} = \frac{d}{dt}\frac{dW}{dm} = \frac{d}{dt}\left[\frac{dW}{\rho \cdot dV}\right]$$

Equation 2.1 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.

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 2.2 presents the results of numerical calculations for SAR in the human head originating from the RF EMF at a frequency of 900 MHz.

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) (ICNIRP 2020).

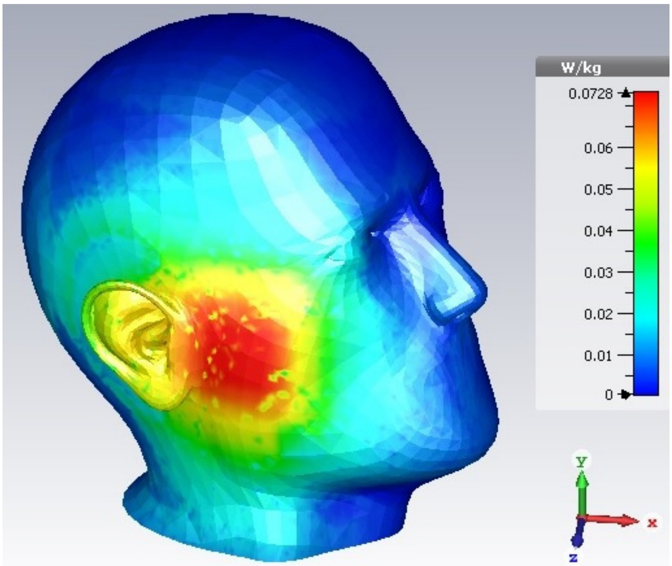

Figure 2.2: Simulated SAR values in human head from RF EMF at 900 MHz

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

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

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 as a consequence 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 in order to register its heating (but not damage) is between 10 and 100 W/m^2, depending on the conditions under which the tissue is exposed. Apart from the scientific publications in which the thermal impact is analyzed there is also a number of research papers in the field of the impact of the RF EMF on a non-thermal level (Imtiaz Nasim 2019). There is currently no scientific consensus on whether this type of impact could pose a risk to human health, especially for long-term exposure.

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).

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

Of particular interest to the public is research on the health effects of exposure to RF EMF due to wireless networks on humans.

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. A number of 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 (Sienkiewicz, Jones, and Bottomley 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).

A number of studies have been performed on the impact of RF EMF on the brain barrier. Changes in cerebral barrier permeability at low levels of specific rate of absorption (SAR) (Salford et al. 2003) have been reported in some scientific papers, while no changes have been reported in other publications (Finnie JW 2001).

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 (Feychting 2005).

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

Of particular interest to researchers because of their location is the type of tumors that appear on Schwann cells[2] that line the vestibuloclechial[3] nerve. 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, 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).

[2] Schwann cells - cells that secrete myelin and thus form the myelin sheath of the nerve

[3] Vestibulocchlear nerve - makes up the eighth cranial nerve and its function is necessary to maintain balance

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. The majority of studies show the absence of carcinogenic effects in the results of numerous animal experiments (ICNIRP 2020b).

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 2016), the findings do not show that RF electromagnetic fields are carcinogenic.

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.

However, the largest number of 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 Basic restriction values and reference level values recommended by ICNIRP and IEEE

Table 3.1 shows the basic restriction values recommended by **ICNIRP** in terms of specific absorption rate – SAR for occupational and general 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 of time. 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 – 300 GHz	0.08	--	--	20

Table 3.1: Basic restriction values for SAR and S_{ab} (ICNIRP 2020 b).

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 – 300 GHz	––	––	––	20

Table 3.2: Basic SAR constraint values of the current IEEE standard (IEEE 2019).

Table 3.3 and Table 3.4 show the reference levels recommended by the **IEEE** in terms of effective electric and magnetic field values and received power density[4], averaged 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.

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	
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 3.3: 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	

[4] S_E and S_H are power densities for a plane wave based on the intensity of an electric or magnetic field

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 3.4: IEEE reference levels for whole-body exposure (IEEE 2019)

3.4 European legislation

In the EU there is no mandatory legislation regarding the exposure of general public to EMF, however in 1999 the European Commission published recommendations regarding the exposure of general public to EMF (EC 1999) that it provides minimum protection of all EU citizens. However, member states have different legislation regarding general public exposure varying from some having strict limit values to some with no legislation at all.

The exposure of workers to EMF in all European countries must meet the requirements form the Directive 2013/35/EU, which sets the minimum requirements for protection of workers from risks emerging from EMF exposure at workplace. Limit values are considerably higher than those proposed in 1999/519/EC recommendation for general public.

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Chapter 4 - Development of mobile technologies

4.1 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 is 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.

4.2 UMTS radio interface

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.

4.3 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. Each frame is spited in 10 sub-frames that are consisted of two consecutive slots, and have duration 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.

4.4 5G radio interface

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 38.201 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.

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 due to the fact that 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 similar to 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).

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Chapter 5 - How to deploy mobile networks

5.1 Exclusion zones

The exclusion zones of mobile systems heavily depend on the underlying regulation for maximal EMF power density limit (W/m^2), 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).

5.1.1 Indoor deployment

Table 5.1 depicts the RF EMF power density limits for three distinct scenarios based on the ICNIRP (ICNIRP 2020) 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/m^2]

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 and the average EIRP discussion in the previous section.

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 Table 5.2, which is based on the rules developed in (ITU-T K.100 2019) and (IEC 62232 2017).

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)

5.1.2 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 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 in order to ensure the safety of the public due to RF EMF exposure.

5.1.2.1 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.

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

6.1 The beginnings in 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, 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 have the opportunity to 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 - 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

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. 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 can not replace them.

6.3 Objectives for the introduction of 5G

It is very important to note that in North Macedonia the testing of 5G network placement was started by the Operators of public mobile electronic networks such as A1 Macedonia and Makedonski Telekom, and in that context the activities of mobile network operators were reduced to testing 5G on 14.07.2020 at 3.7-3.8 GHz (by A1) and on 31.10.2020 at 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 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, in order to clarify certain dilemmas that appear in practice as unclear and create certain confusions and misunderstandings.

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.

6.5 Challenges in the implementation of 5G in North Macedonia

In order 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.

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Chapter 7 - Importance of spatial management in the context of EMF

The rapidly growing number of electromagnetic fields (EMF) sources 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 as well as public acceptability.

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. Quality spatial data infrastructure is required to find optimal solutions and take the right decision in all spatial management processes. 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).

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.

7.1 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.

7.2 Electronic communication networks spatial data infrastructure in North Macedonia

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

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

Register of planned investments in electronic communication network is operated by Agency for Electronic Communications of The Republic of North Macedonia (hereinafter: AEK). Data are public and available via web GIS viewer.

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

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 the city of Skopje and includes a total of 2293 outdoor sources with all important technical details. The registry is based on the available data from the registries of AEK and mobile operators (only operator Makedonski Telekom).

Based on the data from the prepared registry the exposure to RF EMF was calculated for the whole city of Skopje. The results show that the exposures are higher in the vicinity of locations with FM and DVB-T transmitters (Vodno mountain and Srednje Vodno) and in the city centre, where the density of base stations is the highest. Additionally on a total of 21.705 locations the RF EMF measurements have been performed focused on locations where calculated values of the RF EMF are the highest and where powerful RF EMF sources are present.

	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. 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.

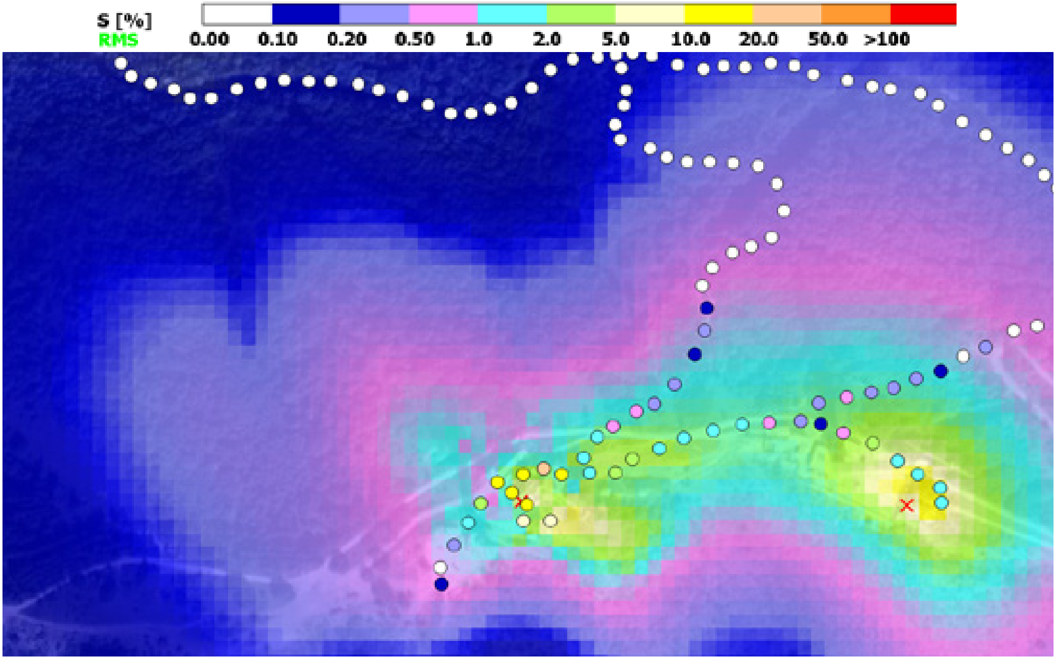

Figure 7.4: Calculated and measured RF EMF values, normalized to the ICNIRP guidelines for general public, covering the Vodno location, where FM and DVB-T transmitters are located. Measured values are presented with circles, bot calculated, and measured values use same colour scale.

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

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 in order 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.

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.

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."

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.

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. 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 - regulators

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. 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 taken into account 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, taking into account all relevant EMF sources at the selected location. 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. 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 taken into account. 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.

8.1 Bibliography

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Chapter 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. 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. 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.

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 technologies, have always faced resistance in proving and realizing them. 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.

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. 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.

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.

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