Health Risks from Exposure to Electromagnetic Waves Radiation from 5G

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Abstract— **This work shows a compilation of the results of different studies related with the affectations in living organisms produced by electromagnetic waves radiation based on their power and frequency ranges. Currently, the growing of the population throughout the planet makes necessary an analysis of the nature of these electromagnetic waves and their effects on living beings, specially in wireless communications field. The information to be transmitted requires that the next generation of mobile telephony (5G) uses bands with frequencies higher than those used by the current generation and previous generations for its operation; for this reason, it is necessary to establish frequency ranges that could be considered non-harmful for living beings. In the present work, a detailed study was done about electromagnetic waves, including the frequency bands that were previously and currently used in mobile telephony, and some of their effects on living organisms, with the aim of publicizing some of the possible consequences of the evolution of mobile telephony on them.**

Keywords - 5G; electromagnetism; frequency; electromagnetic radiation.

I. INTRODUCTION

The present work deals with the effects of electromagnetic waves radiation on living beings. Electromagnetic waves have the main characteristic of not needing guided medium for propagation; unlike other wave types (such as sound, which needs a material medium to propagate), electromagnetic waves can be radiated in vacuum or in various materials and environments. In [1], electromagnetic wave radiation is defined as a combination of oscillating electric and magnetic fields that propagate through space carrying energy from one place to another. The radiations, ordered according to their wavelength (λ), make up the electromagnetic spectrum, which is discussed in Section II of this work. The wavelength of an electromagnetic wave (λ) is related to its frequency (f) and propagation speed (v) according to:

$$\lambda = v / f. \tag{1}$$

In free space, the propagation speed of electromagnetic waves is equal to the speed of light c; so,

c=light propagation speed= 299 792 458 m/s,
(aproximately $3x10^8$ m/s).

Therefore, for the radiation of electromagnetic waves:

$$c = \lambda f \tag{2}$$

Since the light speed is constant, as the frequency increases (and the wavelength decreases at the same proportion), the radiated energy increases.

X-rays, radio waves, infrared rays, ultraviolet rays, and visible light are some of the most important types of electromagnetic radiation, and humans have learned to usefully produce and control them.

In this paper, we study the electromagnetic waves from the point of view of their frequency values according to their uses and their Ionizing and Non-ionizing quality. Some of their effects on living organisms are mentioned, and a reference is made to used frequencies in cell phones. The objective and the main contribution of this work is to present some of the results of previous studies about potential risks of the fifth generation of cellular telephony (5G); although there are no solid conclusions or hard data about the effect of this generation, it is already possible to know some of potential risks. In this work, information from previous and current works was collected and presented, indicating the proper references.

The rest of this paper is organized as follows: Section II describes electromagnetic waves in a general way and mentions some of their uses and their effects on living organisms according to their frequencies. It also describes certain characteristics of ionizing radiation and non-ionizing radiation. Section III deals with the generations of mobile phones and some of the frequencies used so far. Section IV talks about the situation regarding 5G, showing the results of different studies that have been done in this regard, which is the reason for this work. Finally, conclusions are given in Section V.

II. Electromagnetic Spectrum, Effects on the Body, Frequencies and Risks

Electromagnetic spectrum is the set of frequency values of electromagnetic waves that humans have been able to detect and measure. Within this electromagnetic spectrum are (in order of lowest to highest frequency) radio waves (used for wireless communications, such as radio transmissions, TV, mobile telephony and mobile Internet), microwaves (used for detection radars and domestic microwave ovens), infrared light, visible light, ultraviolet light, X rays and Gamma rays. Figure 1 illustrates the electromagnetic spectrum, showing the frequency range for each classification.

Within the same electromagnetic spectrum, also considering lower and higher frequency, ionizing radiation and non-ionizing radiation are considered. Remember that an ion is an atom that has lost or gained electrons; ionizing radiation is electromagnetic wave radiation which frequency (and energy) is as high that it acquires the ability to extract electrons from atoms of matter through which it passes. Ionizing and non-ionizing radiation mainly depend on where they come from.

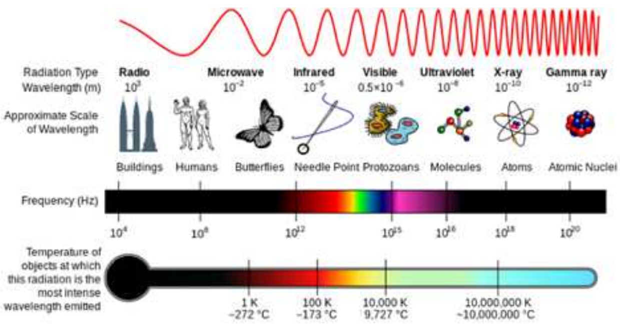

Figure 1: An electromagnetic spectrum illustration [2].

The frequency of non-ionizing radiation is below the ultraviolet light threshold, which means that visible light and wave radiation with lower frequencies fall into this group. Ionizing radiation is found from the ultraviolet frequency light and includes X-rays and Gamma rays.

Ionizing radiation. Ionizing radiation interacts with matter producing excitations and ionizations that induce energy changes at atomic or molecular levels. Directly ionizing particles are electrically charged particles, such as electrons, protons, and alpha particles, that have enough kinetic energy to ionize by collision. Indirectly ionizing particles are uncharged particles, such as neutrons and photons, that can set directly ionizing particles in motion (photons move electrons; neutrons, protons) or initiate nuclear transformation.

In medical applications, the most widely used particles are photons, called X-rays when they are generated electrically in X-ray equipment or linear accelerators, and Gamma rays when they come from radioactive material (such as Plutonium). The discipline that quantifies the amount of energy transferred and absorbed in the irradiated medium is Dosimetry, and the fundamental magnitude is the absorbed dose, which corresponds to the average energy (measured in joules) imparted by radiation at a volume of mass m (measured in kilos). The unit is the Gray (1 Gy = 1J/1kg), used with its multiples and submultiples. In radiation protection, special quantities and units are used, but all of them are based on this fundamental concept [3].

When the irradiated object is living matter, the molecular changes produced by these atomic interactions can interfere with some biological process. Unless a repair mechanism is possible, this interference will determine a permanent biological change, a change that will eventually manifest clinically. The physical processes of energy absorption and ionization occur in femtoseconds (10^{-15} s); the interaction of ions with molecules, in microseconds (10^{-6} s); chemical changes at the cellular level, in seconds; the biological effects, from minutes to years.

Although recent radiobiology studies have found post-radiation cellular responses that appear to lead to genomic changes and / or cellular effects from epigenetic processes, the critical structure at the cellular level remains the Deoxyribonucleic Acid (DNA) molecule. The action of radiation can be direct when the particle hits one of the components of DNA, or indirect when the interaction occurs in water and free radicals such as oxidrile and hydroxyl are formed, which migrate and interact with the DNA. The effects may consist of a single or double chain break, base changes, breakage of hydrogen bonds between the bases, etc.; the consequence is that the cell will undergo a mutation.

One of three things can happen:

a) The mutation is repaired (without errors) and the cell continues its functions as if nothing had happened.

b) The cell "dies" (in radiobiology cell death means permanent loss of clonogenic capacity) due to apoptosis, necrosis, or senescence.

c) The cell survives mutated, that is, there are "repairs" with errors [3]. This is the cause of mutations caused by exposure to ionizing radiation.

The above refers to ionizing radiation, that is, radiation whose frequency exceeds 10^{16} Hz. It is of vital importance (and the main objective of this work) to mention that frequencies lower than those found in visible light and infrared light are, therefore, non-ionizing radiation.

Non-ionizing radiation. Although non-ionizing radiation does not cause the aforementioned adverse effects, there are regulations (for each country internally and internationally) that determine maximum permitted levels of power with the aim of avoiding or minimizing possible damages caused by said radiation. Specific studies have been carried out to determine the possible damage to health caused by radio waves used for telecommunications.

The non-ionizing electromagnetic frequency spectrum is usually subdivided into low frequency from 0 to 3 kHz (US) or 10 kHz (EU), and high frequency or radiofrequency from 3 kHz – 300 GHz (US) or 10 kHz – 300 GHz (EU). In the low frequency range, research results show an increase in probabilistic effects. In the high frequency range upper than microwaves, the number of well documented probabilistic effects is poor.

The levels in the guidelines are conservative and should be reduced with a health factor. For high frequency, many countries have already applied a health factor. However, for low frequency where there is a weak evidence of probabilistic effects, no health factor has yet been implemented in regulations and laws [4].

Exposures to Microwaves (MW, 300 MHz-300 GHz) vary in many parameters: incident Power Density (PD), Specific Absorption Rate (SAR), frequency/wavelength, polarization (linear, ellipsoidal, circular, unpolarized), Continuous Wave (CW) and pulsed fields, modulation (amplitude, frequency, phase), far field/near field, Static Magnetic Field (SMF) and stray Electromagnetic Fields (EMF) of Extremely Low Frequency (ELF, 3-300 Hz) at the location of exposure, overall duration and intermittence of exposure (interrupted, continuous), short-term acute and prolonged chronic exposures. With increased SAR, so-called thermal effects of MW are usually observed that result in significant MW-induced heating. SAR is the determinant main factor of thermal MW effects. The SAR based safety limits intends the protection from the thermal MW effects and damaging absorption, which depends of polarization, frequency, age, sex, and pregnancy status. In addition, the mobile phone SAR values are usually obtained when the phone is positioned about 2 cm from the head, a condition, which is not usually maintained during mobile phone calls. Other aforementioned physical variables of MW exposure have been linked to occurrence of so-called Non-Thermal (NT) biological effects, which are induced by MW at intensities well below measurable heating. The classification of MW effects into thermal and non-thermal is not based on physics of interaction between MW and biological tissues, but rather reflects experimental observation of heating induced by MW exposure, which at SAR levels higher than 2 W/kg may result in thermal injury. Slight temperature increase is also observed in the head tissues during exposure to mobile handset radiation, but this increment is too weak to produce thermal injury and even to be sensed by the exposed subjects while some mobile phone users reported sensation of warmth around the ear.

Some authors have reported pioneering data on the NT effects of Millimeter Waves (MMW, 30-300 GHz, wavelength 1-10 mm in vacuum, to be used in 5G mobile communication) upon exposure of various biological objects. Webb was the first to establish the highly resonant effects of ultra-weak MMW on the induction of λ-phage in lysogenic bacterial E. coli cells. These findings were subsequently corroborated by independent research groups. In these and subsequent studies, the observed spectra of MMW action were found to have the following regularities:

(1) Strong dependence on frequency (frequency windows of resonance type),

(2) Specific PD threshold below which no effect was observed, and above which the effects of exposure depended only weakly on power over several orders of magnitude (so-called sigmoid or S-shaped dependence).

(3) Occurrence of MMW effects depended on the duration of exposure, a certain minimum duration of exposure was necessary for an effect to manifest itself.

These important regularities of NT MMW effects have previously been confirmed by independent laboratories.

Since that time, multiple studies performed by diverse research groups over the world have provided strong evidence for the NT MW effects and have also indicated that there are several consistent regularities in occurrence of these effects:

(i) Dependence on frequency of “resonance-type” associated with relatively narrow frequency windows.

(ii) Dependence on modulation, pulse modulated MW being usually more effective as CW MW.

(iii) Dependence on polarization, right -or left- circular polarization being more defective then opposite circular and linear polarization specifically for each resonance.

(iv) Power windows and sigmoid dependence on PD within specific intensity windows including super-low PD comparable to intensities from base stations.

(v) Thresholds duration of the exposure (coherence time).

(vi) Dependence on post-exposure time, intermittence and duration of exposure resulting in interplay between accumulated effect and adaptation to exposure.

(vii) Dependence on cell density suggesting electromagnetic cell-to-cell interaction during exposure.

(viii) Dependence on several physiological conditions during exposure, such as concentration of divalent ions, oxygen and radical scavengers, stage of cell growth.

(ix) Dependence on genotype.

Cell type, sex, age, individual differences, SMF and stray ELF EMF during exposure can be important for the NT MW effects. The data showing dependence of MW effects on extremely low frequency and static magnetic fields at the location of exposure, suggested as a strategy for reducing health effects from MW of mobile communications [5].

III. MOBILE PHONE GENERATIONS AND USED FREQUENCIES

So, given the growing concern about the damage that new wireless communication technologies could produce in the organism, the question continues: are current wireless communications dangerous or not?

The technological advances in the field of wireless communications are the result of a growing demand not only for the number of devices that are simultaneously available to users, but also for the increasingly diverse services that these devices are capable of providing. The first mobile phones used the frequency bands of the available radio transmissions, so there were no frequencies for their own use, nor the technology to develop networks for exclusive use. Later, other frequency bands were available; the available technologies known as "generations" of mobile telephone networks have been distinguished by the uses and the services that these networks are capable of providing to users.

The aforementioned generations are known as 1G, 2G, 2.5G, 3G and 4G. 4G, currently in use, has its own update, 4.5G, and tends towards 5G.

The migration from each generation to the next has been mainly conditioned to the type of access scheme used and the services that the new generation is capable of providing. These services determine the need to have higher frequencies each time.

As networks evolved, it was necessary to have ever increasing frequencies due to the nature of the content; from voice in real time it evolved to point-to-point text, then to the transfer of image, audio and video files, and currently to the transmission of them in real time (streaming), instant messaging, traffic information for GPS applications, or community video games, to name a few examples. All of this would be impossible if only the 1G frequency bands were used; in addition, frequency modulation was used for those transmissions, which would greatly limit the incorporation of the mentioned content. Then, from the evolution of services and devices, the need arises to use higher frequencies, for which it is essential to assess the risks to health and physical integrity that this implies, not just for people, but in general to alive organisms.

Some signals from Global System for Mobile Communication (GSM) 2G, and Universal Mobile Telecommunications System (UMTS) 3G mobile phones were tested in referred research [5]. Contrary to GSM phones, mobile phones of the 3rd generation irradiate wide-band signal. UMTS MWs may result in higher biological effects due to the presence of selective resonance frequency windows.

Most current discussion regarding MW health effects is focused on the 5G mobile communication, which is promptly enrolled in different countries and uses frequency ranges similar to 2G/3G/4G plus MMW. It follows from available studies that MW, under specific conditions of exposure at ultra-weak intensities below the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, can affect biological systems and human health. Both positive and negative effects were observed in dependence on exposure parameters. In particular, MMW inhibited repair of DNA damage induced by ionizing radiation at specific frequencies, modulations, and polarizations.

While MMW are almost completely absorbed within 1-2 mm in biologically equivalent tissues, it may penetrate much deeper in live human body. Biological objects including human being are not in thermodynamical equilibrium. Thus, except for considering penetration of 5G/MMW into biologically equivalent tissues being in thermodynamical equilibrium, the response of live human body should also be considered. Alive body represents a complicated system with fundamental frequencies; many of them lie in the MMW range. In particular, the acupuncture system (meridians of organs) has been considered as a waveguide system for these MMW fundamental modes in the Soviet/Russian literature.

From this point of view, MW penetrates human body far deeply as compared to "dead" models. Electromagnetic origin of Chinese meridians has been studied in several Soviet research teams. For example, Sit'ko et al. described the frequency of 56.46 GHz, which was found during an ordinary search for therapeutic frequencies based on sensorial reactions of a patient with duodenal ulcer. Negative sensation (defined as spastic contraction of musculus quadriceps femoris) was repeatedly observed under applying MMW at this frequency. This sensory reaction allowed tracking the Chinese stomach meridian by using a static magnet at 4 mT. Exposure at the frequency of 56.46 GHz has worsened health condition of the patient. Thus, this exposure was aborted, and the patient received treatment at the resonance therapeutic frequency found by typical positive sensations. After successful healing the duodenal ulcer at the MMW resonance therapeutic frequency, the negative response of the patient to the frequency of 56.46 GHz disappeared.

When a very fast RF pulse enters in a human body, it generates a burst of energy (a Brillouin precursor) that can travel much deeper than predicted by the conventional models. Brillouin precursors can be formed by high-speed data signals as used in 5G.

To what extent the 5G technology and the Internet of Things will affect the human health is definitely not known. However, based on possible fundamental role of MMW in regulation of homeostasis and almost complete absence of MMW in atmosphere due to effective absorption (which suggests the lack of adaptation to this type of radiation), the health effects of chronic MMW exposures may be more significant than for any other frequency range. From the health perspectives, implementation of the 5G technology is premature. Extended research with chronic exposure of human cells, animals and man is needed to exclude the potentially harmful of 5G signals [5].

IV. 5G TECHNOLOGY

So, about 5G and its technological requirements, a large amount of new and harmonized spectrum is needed for mobile services, which is essential to ensure that 5G services can meet expectations and develop its full potential. 5G technology needs spectrum in three key frequency bands to provide greater coverage and include all use cases. The three bands are below 1 GHz, from 1 to 6 GHz, and above 6 GHz.

a) Below 1 GHz: This spectrum will be used to provide broad coverage in urban, suburban, rural areas and contribute to the support of Internet of Things services.

b) 1 to 6 GHz: This spectrum offers a good combination of coverage and capacity benefit, and includes the range between 3.3 and 3.8 GHz, which is expected to be used to develop the first 5G services.

c) Above 6 GHz: This spectrum is required for ultra-fast broadband speeds contemplated for 5G. The focus will be on the bands above 24 GHz, including the 24 GHz and / or 28 GHz bands, which have sparked growing interest and can be easily implemented on the same device, due to their proximity. Furthermore, there is some interest in exploring the bands found in the frequencies from 6 to 24 GHz [6].

According to [7], exposure of humans to MMW can occur through 5G devices with frequencies above 6 GHz, and may be primarily on the skin and, to a lesser extent, on the eyes. This is due to the very low penetration depth of this

MMW. Therefore, it is important to investigate whether there are any health-related effects on the skin and/or effects associated with the skin. These include acute skin damage from tissue heating (burns), but possibly also less acute effects (such as inflammation, tumor development, etc.). Such effects could appear after prolonged and repeated heating of superficial structures (the skin). This would mean that there are thermal effects that are not due to acute but chronic damage. It may also be that local exposure causes energy deposition in the dermis of the skin, which may be so great as to affect nerve endings and peripheral blood vessels through warming mechanisms. That study typically used exposures around 60 GHz at a power density of 10 mW/cm^2 on the skin in the sternum area to produce systemic effects. The aim was to treat certain diseases and complaints. The idea was that the treatment induces the release of the body's own opioids and additionally stimulates the peripheral nerves. The stimulation would depend on a local thermal effect, which, due to the frequencies, induces locally high SAR values, even at low power densities, thus warming the tissue.

Due to the contradictory information from various lines of evidence that cannot be scientifically explained and given the large gaps in knowledge regarding the health impact of MMW in the 6–100 GHz frequency range at relevant power densities for 5G, research is needed at many levels. It is important to define exact frequency ranges and power densities for possible research projects. There is an urgent need for research in the areas of dosimetry, in vivo dose-response studies, and the question of non-thermal effects. It is therefore recommended that the following knowledge gaps should be closed by appropriate research:

• Exact dosimetry with consideration of the skin for relevant frequency ranges, including the consideration of short intense pulses (bursts).

• Studies on inflammatory reactions starting from the skin and the associated tissues.

• In vivo studies on the influence of a possible tissue temperature increase (e.g., nude mouse or hairless mouse model).

• In vivo dose-response studies of heat development.

• Use of in vitro models (3D models) of the skin for molecular and cellular endpoints.

• Clarification of the question about non-thermal effects (in vitro).

An unrealistic scenario, however, is that MMW exposures at realistic power densities could cause systemic body warming in humans. Any local heat exposure would be dissipated by the body's normal heat regulation system. This is mainly due to convection caused by blood flow adjacent to the superficial skin areas where the actual exposure takes place. In summary, it should be noted that there are knowledge gaps with respect to local heat developments on small living surfaces, e.g., on the skin or on the eye, which can lead to specific health effects. In addition, the question of any possibility of non-thermal effects needs to be answered.

Since the ranges up to 30 GHz and over 90 GHz are sparingly represented, the authors in [7] mainly cover studies done in the frequency range from 30.1 to 65 GHz. Also, the majority of studies with MMW exposures show biological responses. From this observation, however, no in-depth conclusions can be drawn regarding the biological and health effects of MMW exposures in the 6–100 GHz frequency range. The studies are very different and the total number of studies is surprisingly low. The reactions occur both in vivo and in vitro and affect all biological endpoints studied.

There does not seem to be a consistent relationship between intensity (power density), exposure time, or frequency, and the effects of exposure. On the contrary, and strikingly, higher power densities do not cause more frequent responses, since the percentage of responses in most frequency groups is already at 70%. Some authors refer to their study results as having "non-thermal" causes, but few have applied appropriate temperature controls. The question therefore remains whether warming is the main cause of any observed MMW effects?

In order to evaluate and summarize the 6–100 GHz data in this review, in [7] the following conclusions was reached:

a) Regarding the health effects of MMW in the 6–100 GHz frequency range at power densities not exceeding the exposure guidelines the studies provide no clear evidence, due to contradictory information from the in vivo and in vitro investigations.

b) Regarding the possibility of "non-thermal" effects, the available studies provide no clear explanation of any mode of action of observed effects.

c) Regarding the quality of the presented studies, too few studies fulfill the minimal quality criteria to allow any further conclusions [7].

In [8], authors have investigated the effects of 5G radiations for different frequency candidates on human brain. This has been achieved by using Computer Simulation Technology (CST) software by conducting simulations on a Specific Anthropomorphic Mannequin (SAM), shown in Figure 2. A SAM is a model designed according to different international standards representing the average material properties of the head by calculating the SAR, in order to check whether the resulting exposure is safe or not by comparing it to the safety limit of exposure to high frequency radiations set by different international standards.

The most affected areas are the ones proximate to the antenna. It can be concluded that the SAR for first and second candidate are above the safety exposure limit set by the Federal Communications Commission (FCC) of 1.6 W/kg for 1g averaging mass since the results obtained had SAR values of 2.501 and 2.702 W/kg at 29 and 33 GHz respectively. However, the results of SAR obtained for 10g averaging mass are considered below the safety exposure limit according to ANSI/IEEE standards since the safety exposure limit of such standards is 2.0 W/kg for 10g averaging mass while the results obtained were 0.6291 and 0.45045 at 29 and 33 GHz respectively. 87/5000. Moreover, the impact was negligible in areas not surrounding the mobile device.

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Figure 2. Specific Anthropomorphic Mannequin, SAM [8].

More studies should be done in order to determine the SAR values for the other candidates and to study the impact of such waves on the human's head while taking into consideration more parameters in order to obtain accurate and reliable results [8].

In [9], energy absorption mechanisms and near-field body-antenna interactions were studied at frequencies of relevance for 5G. While at the lower frequencies (e.g. 2 GHz) and for short separation distances, the energy deposition is dominated by the coupling of the reactive near-field, at 24 GHz and above this factor is small and it becomes negligible for device to body separation distances larger than 1 cm.

For the investigated frequency range, the largest increased power absorption, compared with the zero-order interaction, was found for an exposure scenario with significant multiple reflections between the antenna and the body surface: part of the reflected energy at the skin interface interacts with the antenna and is scattered back towards the body. The presence and relevance of this phenomenon is dependent by the antenna design, the separation distance and operating frequency. This effect is expected to be visible only for electrically large antennas and it decreases with increased separation distance and frequency. Despite the multiple reflections, the spatial energy distribution (the topography) was found to be well characterized by the free-space incident field.

The effect of multiple reflections, when present, contributes to a change in the input impedance of the antenna. For an antenna designed for free space conditions, the induced mismatch contributes to a lowering of the output power compared with the free-space condition which, in part, mitigate the effect of enhanced power absorption.

At or around the millimeter wave range, the electromagnetic fields from the antenna in free space can be used to characterize the energy absorption in the skin also for devices intended to be used in close proximity of the body. In addition, since the contribution from coupling of the reactive near-field is small, free-space power density seems a reasonable quantity to characterize exposure in the 'higher' frequency range of interest for mobile communications (24 GHz to 100 GHz). Overall, in relation to the wide safety margins typically included in the exposure limits, the effects of near-field body interactions are negligible when evaluating compliance at the mmW [9].

Now, according to [10], to provide context for understanding how the strength of wireless signals from a 5G small cell transmitter diminishes with distance, they calculated typical exposures from 60-watt ERP 5G source at 39 GHz mounted on a pole 25 feet above ground. The example described here is one application of a 5G wireless technology; other applications may differ in the details. The exposures in Figure 3 are expressed as a percent of the FCC's maximum permissible exposure limit on power density of exposures of the general public (1 mW/cm^2), applied to the range of frequencies between 1.5 and 100 GHz. This is a convenient way to compare exposures from RF sources operating at different frequencies and exposure limits.

Figure 3 illustrates the signal strength from an example 5G small cell antenna mounted on a telephone pole (transmitting at 39 GHz). In addition, the signal strengths shows that exposures to RF from the small cell antenna are very low and diminish quickly with distance. RF signals from the small cell antenna measured inside buildings would be even lower. The calculated exposure in Fig. 3 at 50 feet is 0.7% of the FCC's standard directly in the main beam of the antenna, assuming all transmitted power is focused in a single direction; exposures outside the main beam of the antenna are lower. Small cell antennas are mounted far above the ground; therefore, exposure is in what is termed the far field. At farther distances, the exposure is progressively lower, becoming less than 0.1% at 150 feet and vanishingly small at 500 feet.

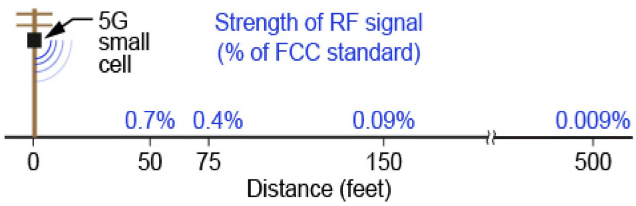

Figure 3. 5G signals from a pole-mounted small cell antenna as a function of distance [10].

Another way to compare the RF exposure of common devices or sources is to rank them by relative intensity. Figure 4 shows the contribution of eight common sources of RF exposure expressed as a percent of the FCC limit. Figure 4 illustrates that the RF signal at a middle distance from 5G small cell antenna is roughly 5 times lower than a cordless phone and 20 times lower than a cell phone, both of which are typically used close to the body, but is higher than some other common sources of RF. These values represent typical exposure levels. If a person was to use a cell phone near a 5G small cell antenna, then the cell phone may only need to transmit at a low power level to communicate over the shorter distance, and RF exposure from the cellphone could be lower. It may be surprising to some that the human body and the earth itself are sources of exposure throughout the RF frequency range, including at 5G frequencies.

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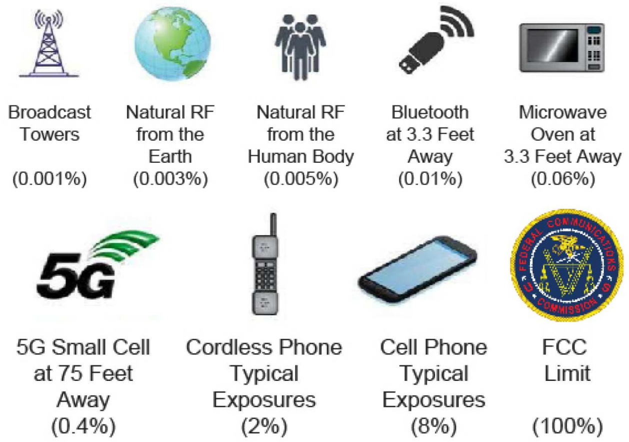

Figure 4. Ranking of common examples of RF sources by percent of FCC limit from lowest (left) to highest (right) [10].

To date, the only confirmed biological difference between exposures to RF frequencies less than 6 GHz and RF frequencies above 6 GHz is that at the higher frequencies the body's electrical properties better limit energy deposition to a shallow depth, largely confined to the skin. Thus, at frequencies above 6 GHz the hazard to be avoided is painful heating of the skin.

Fixed small cell wireless communication installations—such as small cell antennas—that operate in compliance with the regulations of the FCC will produce RF exposures well within the recommended exposure limits of the FCC, ICNIRP, and IEEE. Research to date does not provide a reliable scientific basis to conclude that the operation of these facilities will cause or contribute to adverse health effects in the population. Research on RF will continue, as often occurs with new technologies, but not because public health authorities have established that the use of RF communication technologies today causes adverse health effects [10].

On the other hand, based on the discussions carried out in [11], there are clearly some open questions regarding exposure levels and assessment in 5G and future wireless devices:

• Multiple antennas technology is one of the key enablers of 5G for achieving high data rates, but it will increase the exposure in near field. For instance, what would be the number of antennas that can be placed on a user device while maintaining a safe exposure level? In addition, the way in which the position of the hand(s) on a multi-antennas wireless device affects the SAR, needs to be evaluated.

• In the first stage of 5G implementation, 5G networks will operate in parallel with current mobile systems, with an unavoidable global increase in the exposure level that needs to be measured.

• The number of smart IoT devices, in the close proximity of people, is likely to increase exponentially in the future and the impact of these devices on exposure needs to be assessed.

• The deployment of small cells helps to reduce the levels of transmit power, but what about dense or very dense deployment of small cells? Will it increase the overall aggregated power as compared to a macro cell and create more EMF exposure? This should be properly explored.

• The current safety rules regarding RF exposure do not specify limits above 100 GHz whereas spectrum use will inevitably move to these bands over time. Hence, there is a need for further investigating the effects of exposure at these frequencies and, then, defining new safety limits.

A comprehensive survey on the assessment, evaluation, limitation, and mitigation of exposure risk for current and future wireless devices and equipment is provided in [11]. From a human health point of view, it appears that the possibility of a brain tumor has been the main cause for concern related to the extensive use of wireless devices, although the effects of EMF exposure in new parts of the body are now being investigated (for example, eyes). Meanwhile, with the advent of 5G, more efforts have been made to understand the thermal and non-thermal effects of mmWave exposure on the human body. Regarding EMF exposure assessment, the most common metrics and assessment frameworks used in wireless communications to measure exposure were presented. It was also explained how new and more generic metrics have been defined by combining existing metrics to better reflect the exposure of large geographic areas and it was argued that a generic metric to measure individual exposure would also be of interest. Existing exposure guidelines were also reviewed and explained how they can be updated to better reflect the true nature of EMF exposure, i.e. better considering the duration of exposure. Finally, some insights were provided on how key 5G enabling technologies such as densification, massive MIMO, and mmWave, will affect EMF exposure in the near future; for example, the dense deployment of small cells and IoT devices is very likely to increase overall environmental exposure. There could be some technical opportunities in 5G to raise awareness of wireless users' exposure and allow them to decide if they want to reduce it at the cost of, for example, lower Quality of Service (QoS) [11].

V. CONCLUSIONS AND FUTURE WORKS

The laws to establish regulations about the maximum limits allowed for 5G technology depend on the local regulations of each country; however (and although the effects of non-ionizing electromagnetic waves on living organisms are known), the large number of variables and factors that intervene in the process makes it very difficult and premature to know what will happen when 5G technology is implemented. The truth is that, due to the working frequencies that are considered for the entire network, it is possible to estimate that the risk is relatively low. Currently, 2.4 GHz frequency is used for most digital communications, so the frequency ranges are far from the frequency values considered highly dangerous. Although the transceiver antennas are not entirely innocuous, their distance from the users makes them safe, while security measures must be strictly monitored for mobile devices, since they are used personally.

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The present work is a compilation of some research reports carried out by different authors and institutions; although different procedures were carried out for their respective contributions, and these contributions provide valuable information on the subject, all authors agree on at least two conclusions:

• Health risks from exposure to radiation from electromagnetic waves of 5G technology are directly related to the distance to the transmitting stations, since the intensity of the signals emitted is inversely proportional to said distance, in addition to depending on the environment and transmission conditions, so each case is particular.

• It is necessary to carry out more exhaustive investigations, which will be achieved over time; to date, 5G technology has not yet been implemented in commercial services, and the real risks can be measured effectively to the extent that there is more infrastructure for this new generation.

Future work will consist of monitoring and making a permanent observation and measurement in specific situations; however, the experience that we have concerning electromagnetic waves and previously existing networks means a base from which it has been possible to start.

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