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OPINION ARTICLE

# 5G and human health

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## *Summary*

*The considerable characteristics of 5G technology (Fifth Generation of telecommunication) is the very high amount of data that can be transmitted in the time unit (data speed: Megabits per second - throughput) and the very low delay in data exchange (latency). ElectroMagnetic Fields (EMFs) are used for decades for communication reasons and broadcasting. 700 MHz and lower frequencies are currently being used in Digital TV. Low frequencies (800, 900 MHz) are also being used in previous (but still existing) technologies 2G, 3G, 4G, 4G+. 5G will exploit both low and high frequencies. 5G will be operation mainly in a low band (700 MHz) and a high band (3.5 GHz). In the near future mmWave bands will also be used above 6 GHz (for example 24 GHz, 28 GHz and above). Theoretical models and live measurements have consistently shown that the actual maximum power is always less than the 25% of the maximum peak power of a Massive-MIMO antenna.*

*ICNIRP has published in 1998 "Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz)". The current revision (2020) is based on the same criteria, but it exhibits more accuracy in dosimetry calculations, considering details and based on better biological rationale. mmWave bands (> 6 GHz) is a controversial issue for the population. Reports did not show adverse health effects in daily life under the safety limits. WHO is currently preparing a review about health risks assessment of RF exposure (including mm-Waves), which will be completed by 2022. There is no evidence of adverse health effects at exposure levels below the basic restrictions as described in the ICNIRP (1998) and ICNIRP (2020) guidelines and no evidence of an interaction mechanism that would predict that adverse health effects could occur due to radiofrequency EMF exposure below restriction levels. The new Guidelines provide protection against all adverse health effects, regardless of whether they are due to acute or chronic exposures, regardless of age or health status.*

*Radio and Microwave Frequencies, where mobile technology and Wi-Fi operate, are used in Medicine for therapeutic or diagnostic purposes. These bands are used for various application as Microwave Diathermy (same band as 2G, 3G and Wi-Fi technologies), Microwave induced thermo-acoustic echography (same band as 4G technology), Medical Imaging / localization of tumors (same bands as 2G, 3G, 4G and 5G technologies) and Medical Monitoring / Measurement of vital function as respiration and heart rate (same band as the forthcoming mmWave 5G). By utilizing new technologies that are involved in 5G communication (IoT and mmWave frequencies) healthcare systems can improve the quality of care, provide more personalized and preventive care and reduce the cost of care.*

***Key words:*** *5G, 5G and healthcare, 5G and human health, RF exposure, adverse health effect*

## Introduction – 5G Technology

### *Telecommunication Evolution*

The great characteristics of 5G technology (Fifth Generation of telecommunication) is the very high amount of data that can be transmitted in the time unit (data speed: Megabits per second - throughput) and the very low latency in data exchange [1-8].

*Latency* from a general point of view is the time delay between the cause and the effect of some physical change and in telecommunications is the responsiveness of the network, measuring the delay of transferring data to and from the user's device.

3G networks had a response time of one hundred milliseconds, 4G thirty milliseconds and

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5G one millisecond (virtually instantaneous). As a result, users are going to experience real time activities (remote surgery), virtual reality, connected devices services (Internet of Things – IoT), self-driving cars, and the introduction of Artificial Intelligence (AI).

5G ElectroMagnetic (EM) waves will be emitted in low, high and mmWave (very high) EM frequencies. There is an extensive research for 5G frequencies available in the scientific community. All reports and studies (positives & negatives) have been taken into account in order the safety standards (limits) to be implemented by National and International Authorities [9-15].

***Frequency spectrum to be used in 5G***

ElectroMagnetic Fields (EMFs) are used for decades for communication reasons and broadcasting. 700 MHz and lower frequencies are currently being used in Digital TV. Low frequencies (800, 900 MHz) are also being used in previous (but still existing) technologies 2G, 3G, 4G, 4G+. 5G will exploit both low and high frequencies. 5G will be operation mainly in a low band (700 MHz) and a high band (3.5 GHz). In the near future mmWave bands will also be used above 6 GHz (for example 24 GHz, 28 GHz and above).

- Low frequency (LF) band at 700 MHz will be used for coverage reasons, as penetration of low EM waves is effective and can be transmitted through buildings. Therefore, in indoor environment this is the ideal solution of providing 5G service.
- High frequency (HF) 3.5 GHz band will be operating in large scale. Providing network capacity (more users in the cell, high data rates).
- Very high frequencies (VHF - mmWave, above 24 GHz), will be used for very high data rates. VHF is not new, these frequencies are used for decades in radar, satellite, and microwave communications. It is an ideal band for communications between machines. This band exhibits high attenuation and is not appropriate for coverage.

As a result, this spectrum is not “a new thing” in our daily environment [1, 3, 7, 16].

***New technologies to be used in 5G***

*‘Massive’ MIMO technology*

5G will use ‘Massive’ Multiple In – Multiple Out (MIMO) antennas [17]. In other words, 5G data will be emitted by multiple radio elements located in the same antenna and the signal will be received also by multiple radio elements in the user equipment (mobile phone). Currents technologies use 2x2 MIMO (2 transmitters – 2 receivers) or 4x4 MIMO. In 5G networks, 64x64 (MIMO) or 128x128 MIMO (Massive MIMO) will be used providing very high data rates.

There is a significant benefit for users as the number of those who can connect to the network at the same time increases, while the speed remains high and constant. In terms of physical dimensions, overall, the size of the 5G Massive MIMO antennas will be equivalent to 4G, (with higher frequency). At the same time, each element is smaller allowing more elements (over 100) for the same dimensions.

*Beamforming*

Due to Beamforming / Beam steering technology, the signal is transmitted in directed beams focusing only to the mobile user. Beam steering technology uses sophisticated signal processing algorithms to determine the most convenient signal path for the user to reach. The radio signal is strong, and the beam is narrow reducing the RF exposure to the non-users. Beamforming also contributes to reducing the undesirable radio signals interference.

*Efficiency*

5G is more efficient. 5G networks are designed to be very efficient in spectrum usage and operating functions [7]. Network (antennas) and device (mobile phone) achieve efficiency with low power and this means low levels of EMF exposure. Higher frequencies generally mean shorter ranges (strong attenuation in materials) and due to the increase of the available bandwidth (5 MHz in 3G, 20 MHz in 4G, 100 MHz in 5G), they provide higher data rates.

5G systems will consist of high technology devices and wiring that will provide wide coverage while minimizing power consumption. In addition, 5G using Time Division Duplex (TDD) technology, the downlink data exchange process between the base station and the terminal [18] will take a short time. This technique allows the reuse of frequency channels in space, resulting in significantly higher spectral performance.

## 5G and EMF Exposure

Active and Passive exposure are the two categories into which wireless communications are divided. *Active* exposure is caused by a wireless device used by a person to its own body. *Passive* exposure refers to the ambient exposure (e.g. from base stations or wireless devices in the surrounding area, other than its own device). Active exposure should concentrate the scientific concern than passive exposure due to the close range between the source and human body [19].

Before analysing the impact of the new 5G radio techniques in the environmental RF exposure, it is essential to compare the RF exposure imposed by a 4G base station to a 5G one in a building located at 100 m distance. Data have been acquired by ANFR (Agence Nationale des Fréquences, France) during 2019.

A 4G antenna is operating with a maximum power of 60 Watts and a maximum Gain[1] of 18 dBi. The attenuation in the air (measured at 6 min interval) is -4 dB. Glass (windows) contributes to attenuation with -2 dB additionally. Thus, in a building at 100 m distance from a 4G base station, the RF exposure is approximately 1.7 V/m. On the other hand, a 5G antenna is operating with a maximum power of 200 Watts and a maximum Gain of 24 dBi. The attenuation in the air (measured at 6 min interval) is -13.5 dB (higher frequencies exhibit higher attenuations). Glass contributes to attenuation with -2 dB additionally. Time Division Duplex (TDD) technology imposes also a -1.25 dB decrease in the output power. Thus, in a building at 100 m distance from a 5G base station, the RF exposure is approximately 1.8 V/m. Therefore, the expected RF levels are the same and well below the ICNIRP's 2020 safety limits.

5G technology will impose new challenges in assessing RF exposure in the environment. New radio techniques, modern antenna systems and the variety of practices in our daily life may or may not alter the current RF background.

## New Techniques in 5G and Exposure

*Use of Massive MIMO technology*

MIMO technology as already described uses multiple radio elements in the antenna (64 or 128 for the 5G). In the same time two new features (techniques) are implemented. The spatial multiplexing (this means that independent data are transmitted via multiple paths) and the beamforming (where the antenna beam is directed to specific areas where the mobile users are found). Even if the total power of a 5G base station is increased compared to the 4G, these two new techniques keep the exposure levels comparable to the legacy. The radiation patterns are adjusted in a smart way in time and space keeping the exposure in safe and low levels.

*Densification of 5G base stations*

As already described, the 5G technology requires more base stations. This forms a controversial issue for scientists and public. Frequency bands in 5G exhibit high attenuation in the environment and building materials. As a result, more base stations are needed to provide coverage and capacity (high data rates demanded). More base stations means that each one has to cover a smaller area and this means that lower power is needed to achieve the purpose. Therefore, RF pollution is limited.

*mmWave frequencies*

mmWave are not new frequencies. mmWave frequency spectrum exhibits high absorption in the atmosphere and materials (body and buildings). This leads to more base stations needed in short distances between them in order to provide adequate coverage. Higher frequency or more dense networks does not mean higher exposures. The millimetre-wave (mmWave) band is part of the RadioFrequency (RF) spectrum, (frequencies between 24 and 100 GHz). At these frequencies, RF energy is absorbed superficially by the body (mainly by the skin). mmWave is non-ionizing radiation, and the only health concern is heat absorbed by the eyes and the skin.

There are several studies in the bibliography and current safety guidelines are protecting human health imposing conservative limits. WHO is conducting a further research in the frame of 5G era which will be completed in 2022. It must be noted that mmWave band is going to be used only for capacity reasons in areas with high data rates demand (such as airports, shopping malls etc.). These bands are not used for coverage (due to very large path losses / attenuation) and their impact is limited in a few decades of meters from the installation points. Small cells (targeting to short coverage range) are going to be installed. Thus, in our daily routine we are not going to be exposed by such frequencies. Moreover, compliance with safety limits will be ensured through RF measurements. Focus on the human exposure from mmWave radiation from mobile devices should be given. Studies are ongoing on that issue.

[1]Gain is calculated by comparing the measured power transmitted or received by the antenna in a specific direction to the power transmitted or received by a hypothetical ideal (spherical and isotropic) antenna in the same situation. Gain is measured in dB (decibels relative to an isotropic radiator). A change in power by a fac-tor of 10 is a 10 dB change in level.

*Millions of IoT devices*

The Internet of Things (IoT) describes the wireless network of physical objects - "things", such as devices, machines and appliances, that are embedded with sensors, software, and other technologies, for the purpose of connecting and exchanging data with other devices and systems over the internet. These include PCs, tablets, wearable health monitors, wireless inventory trackers, smart factory equipment, vehicles and other devices and machines equipped with IoT connectivity.

Machine-to-machine (M2M) refers to the activation of communication between two or more machines with limited human intervention. Monitors and sensors can also be connected wirelessly allowing wireless applications in health, water, electricity and agriculture.

IoT enabled devices [5] are expected to operate at low power (~ 0.15 mW) with a battery life of up to 10 years, due to the small amount of information transmitted, low power and discontinuity of transmissions. It is expected that a duty cycle of 10% will be applicable for such networks (duty cycle = percentage of transmitting period to the average measurement period). These devices do not require big data to be transmitted nor low latency to be achieved. For all these reasons very low power is needed to operate.

Another factor that limits the RF pollution from such devices is the distance between humans and those devices. Even a few meters (1-2) are providing protection and keep the exposure in very low levels (negligible). As a result, RF background is not expected to be changed. Minor increases may be measured locally but safety levels will not be exceeded with large safety margins.

### Actual and Nominal Power

Theoretical models and live measurements have consistently shown that the actual maximum power is always less than the 25% of the maximum peak power of a Massive-MIMO antenna. There are three main reasons why the actual power is so much lower than the nominal one.

a. Due to Massive MIMO (M-MIMO) and Beamforming technique, not all power will be focused to the same direction for several minutes.
b. 100% utilization is NOT expected 24 hours, 7 days per week.
c. Time Division Duplex technique will be used. So, downlink radiation (from the source to the user) is emitted only for some slots of time not continuously.

In June 2017, the International Electrotechnical Commission (IEC) published a new international standard [20] which introduces a more advanced procedure that statistically models beam-formed patterns, providing an appropriate exclusion zone for EMF compliance. This procedure defines the actual maximum output power of an antenna as the 95$^{th}$ percentile of the statistical distribution of the time-averaged output power at a given beam-steering direction.

In collaboration with vendors, operators ensure that M-MIMO antennas work in a safe-by-design operational mode, meaning that the antenna will operate under the actual maximum power threshold, not only during the 95$^{th}$ percentile of situations, but also in all worst-case scenarios.

To this end, safe-by-design operation will be one of the requirements that Massive MIMO products will have to comply with. This "feature" will comprise a series of AI (Artificial Intelligence) -based algorithms able to detect if the time-averaged output power in any of the possible beam-steering directions grows above some pre-defined threshold, and, if so, apply mitigation actions on the scheduled power or the antenna gain to prevent the output power exceeding the actual maximum.

Therefore, the feature will ensure that Massive MIMO antennas comply with EMF limits in all situations included worst-case scenarios (high traffic conditions).

### EMF Safety Distances

Assessing the EMF compliance of this new kind of antennas poses a big challenge, as the traditional evaluation procedures were designed for fixed antenna patterns. These procedures cannot accurately model the behaviour of changing, conformed patterns and generate overly conservative exclusion zones around the antenna.

Following the "25% power" rule, we can conclude that safety distances from the new antennas are similar to the legacy ones. As a result, a 50 Watt (using the actual value) power antenna could lead to a minimum safety distance of 8.4 m for the general public (instead of 17.9 m if nominal power were considered).

### Planning 5G Networks under EMF Constraints

Designing 5G networks under strict EMF exposure limits is a difficult and complex task. The problem is exacerbated in densely populated urban areas where, on the one hand, 5G infrastructure of different operators must coexist, and on the other hand technologies older than 5G (such as 3G, 4G) increase the exposure of the population to EMF [21].

The International Telecommunication Union (ITU) has recently organized two workshops on the topic of 5G and EMFs. During these meetings, several researchers have argued that the adoption of the policy to reduce EMF exposure at significantly lower levels than ICNIRP reference levels,

a. may decrease the Quality of Service (QoS) experienced by users and
b. will increase the cost of installing and developing 5G networks, due to the inability to reuse existing sites, thus hindering the development of 5G infrastructure.

In particular, the EMF limits may be a barrier towards the deployment of 5G networks, especially in countries where the EMF limits are very restrictive. Currently, the EMF limits vary across the different countries due to political (not scientific) decisions or to different endpoints (thermal or non-thermal biological effects). As a result, the design must simultaneously incorporate recent national legislation, international guidelines and revisions to the EMF limits proposed by ICNIRP [10].

***Wearables devices and human exposure***

Portable devices (e.g. monitoring physical activity, smart watches) are now part of our daily lives in many areas. Mobile devices often use wireless technology. From simple daily use, the subsequent development was rapid with new orientations in healthcare applications, construction, etc. [5]. International public exposure limits apply even in the case of continuous exposure, 24 hours a day, and 365 days a year.

Portable radio transmitters use well-known technologies such as Wi-Fi and Bluetooth and operate at very low power (saving battery life). All these devices are of a very low power and short range and transmit only at short intervals and distances, for example, to a nearby laptop, tablet or smartphone. Those IoT devices whose operating frequencies are between 30 MHz and 6 GHz are covered by the existing international exposure limits. At higher frequencies, they are expected to meet the evolving standards for 5G devices.

## EMF Exposure Limits & Guidelines

During 2020, ICNIRP has published the report "Guidelines for Limiting Exposure to Electromagnetic Fields (100 kHz to 300 GHz)".

Previous ICNIRP guidelines were based on adverse health effects mainly caused by body temperature increase. It is confirmed since 1998, taking into account the total literature and science updates, that these guidelines are still valid, and no adverse health effect can be recorded when exposure remains in those limits. The current revision is based on the same criteria but it exhibits more accuracy in dosimetry calculations, considering details and based on better biological rationale.

Moreover, new technologies as the 5$^{th}$ generation of mobile communication (5G) provide a new exposure map for the human being. These new exposures fall in mmWave spectrum (> 6 GHz). This has been considered in the 2020 Guidelines.

***Differences in basic restrictions from previous guidelines***

Differences between 1998 and 2020 guidelines can be summarised in a few bullets:

a. Foetus is being considered as general public. In that case, the pregnant worker (occupational exposure) is subject to public restrictions and not to occupational ones.
b. New radio technologies with emissions greater than 6 GHz bring new restrictions in the 2020 Guidelines. Moreover, brief EMF emissions (< 6 minutes) should not have any adverse health effect. In that case transient temperature rise must not cause pain or other health effect.
c. The whole-body exposure restriction (SAR) is applicable up to 300 GHz whereas in 1998 guidelines this restriction ended in 10 GHz. This extension to the basic restrictions ensures that new technologies in mmWave will not cause temperature rise. Moreover, the averaging time was increased from 6 to 30 minutes in order to cope better with the body temperature increase mechanism.
d. Concerning the Local Exposure, SAR was applied up to 10 GHz, and 'Power Density' above 10 GHz. This frequency (10 GHz) is called 'transition frequency'. Different quantities are used because SAR may underestimate superficial exposure at higher frequencies, whereas power density may underestimate deeper exposures at lower frequencies. Although there is no ideal transition frequency, ICNIRP (2020) has taken a pragmatic approach and reduced the transition frequency from 10 GHz to 6 GHz because it provides the most accurate account of exposure overall.
e. About the "Microwave hearing effect". In ICNIRP (1998) a restriction was set to prevent from this sensory effect. As no adverse health effect can occur, in 2020 guidelines this restriction is not considered. Additionally, the brief exposure guidelines provide adequate protection so as no health effect can occur even for these emissions.

f. Absorbed Power Density' replaces the quantity 'Incident Power Density' met in ICNIRP 1998. Absorbed Power Density is a measure of exposure of the body whereas the Incident Power Density can be reflected away from the body at a 50% percentage.
g. Concerning brief local exposures. Some intense RF exposures may result in local tissue temperature increase. This can occur for frequencies above 30 GHz. ICNIRP (2020) added restrictions to ensure that brief exposure intervals cannot result in major temperature rise. Specific Energy Absorption (SA) is considered up from 400 MHz to 6 GHz. Above 6 GHz of the guidelines use Absorbed Energy Density ($U_{ab}$).

## 5G and adverse health effects following RF exposure

It is important to note the difference between an adverse health effect and a biological effect. The biological effect is reversible, in short time without medication, exploiting the human physiology principles. For example, running increases the body temperature during our exercise. Sweating and relaxation help to thermal dissipation and decrease in heart rate. In a human adult we record energy generation about 1 W/kg at rest, 2 W/kg standing and 12 W/kg in running conditions. All these are biological effects. A health effect diminishes our wellbeing. Medication or medical actions are needed in order to cope with the effect.

The purpose of ICNIRP is to reduce public and occupational exposure to EMF in the 100 KHz - 300 GHz radio frequency band, thus providing protection against adverse health effects in humans under realistic conditions. A thorough evaluation of the extensive literature from dosimetry and cell research to cancer epidemiology underpins the Guidelines produced by ICNIRP.

Guidelines for limiting exposure are based on preventing human being from thermal effects and relevant adverse health effects. As a result, by complying with ICNIRP's guidelines, it is ensured that no adverse health effect can occur due to core temperature rise. A lot of studies have been carried out based on the possibility of other adverse health effects named as "non-thermal".

### *Thermal effects*

According to Hirata [22], a temperature rise of 1°C can occur when the human body is exposed to RF fields within the 100 kHz to 6 GHz range of at least 6 W/kg SAR for 1 hour and in an external environment of 28°C. This conclusion refers to healthy adults and children. For elderly people with lower sweat capabilities the SAR can be lower, at least 4.5 W/kg. ICNIRP's guidelines (both 1998 and 2020 issue) propose a SAR whole body limit at 0.08 W/kg in order to be conservative and eliminate thermal effect probability for the population at any environmental or health condition.

### *Non-Thermal effects*

Regarding the possible non thermal effects, current state of knowledge does not support correlation between RF exposure levels and adverse health effects. We can refer to alleged health effects based on Chiaraviglio et al. health risks review [21] and ICNIRP's 2020 guidelines edition:

*Skin effects*

RF exposure in high power density may lead to a localised rise of tissue temperature that can be compensated by the human thermal regulation procedures. In high doses, mild skin burns may occur.

*Ocular effects*

Cataracts, retina damages and cornea issues are included in adverse health effects occurring in high exposure levels.

*Male fertility*

Few studies conclude that high levels of RF exposure may lead to negative effects on the reproductive system. The current state of knowledge does not support a proven association between RF and such effects.

*Electromagnetic Hypersensitivity*

There are studies that report symptoms such fatigue, stress, headaches but the current state of knowledge does not support a causal association between RF exposure levels and symptoms.

*Brain activity and cognitive performance*

The experimental and/or epidemiological state of evidence does not support that RF fields may affect cognitive functions relevant to health.

*Symptoms and wellbeing*

There are no reports referring to symptoms or well-being degradation. Pain could be a symptom in high exposure levels.

*Neuroendocrine System*

Some epidemiological studies reported effects in melatonin levels, but the results were not confirmed, and many conflicting conclusions were recorded. In animal studies effects were reported at high exposure levels (~4 W/kg). No consistent other evidence for other hormones.

*Neurodegenerative diseases*

There is no human experimental studies. No adverse effects on neurodegenerative diseases have been substantiated following experiments in rats and a Danish epidemiological cohort study.

*Cardiovascular / Autonomic Nervous System / Thermoregulation*

Excessive body heating can damage cardiovascular system. By complying with ICNIRP's limit, the human body can never experience core temperature elevation. Bear in mind that the SAR limit is 50 times below the value that can produce temperature elevation of 1°C. Few epidemiological studies are available. No one of them demonstrates adverse health effects. In summary, no effect can be described in in exposures below 4 W/kg (ICNIRP's limit is 0.08W/kg).

*Immune System and Haematology*

Inconsistent studies show transient effects in immune system and haematology. The animals' or in vitro available reports cannot be substantiated. Few human studies exhibit no effect.

*Fertility, reproduction, and children development*

A number of animal studies reported association between EMF exposure and effects on reproduction or development (fetal malformations, losses, reduced weight, male fertility). All these studies have serious limitations in methodology. Well-defined studies didn't show any effect below the SAR value of 4 W/kg. Epidemiological studies are available and some of them reported effects in female or male fertility. Comparing these studies, a lot of limitations in design and exposure levels are met. Consequently, the conclusion is inconsistent, and no evidence can be provided. Maternal phone use (few studies) during pregnancy is not associated with effects on child's neurodevelopment.

*Cancer*

A large body of literature is available concerning cellular and/or molecular processes than can be associated to cancer induction or development. Studies of cell proliferation, differentiation and apoptosis-related processes, proto-oncogene expression, genotoxicity, abnormal oxidative stress, and DNA strand breaks have been taken into account. International Agency on Research on Cancer (IARC) categorised in May 2011 non-ionizing RF radiation from cell phones (not base stations) in Group 2B as "Possibly carcinogenic to humans". This classification was based on an increased risk of glioma associated with wireless phone use.

There are two animal studies investigating carcinogenicity following a long-term exposure to RF associated with mobile phones and base stations First, by the U.S. National Toxicology Program [23, 24] and second from the Ramazzini Institute [25]). They exhibit inconsistencies and important limitations that affect the usefulness of their results for setting exposure guidelines. So, it is not possible to claim that health effects may appear in real 5G deployments:

- Very high exposure levels were used producing excessive temperature rise. These exposure levels cannot be met in mobile communications. For example, an RF source in NTP study reaches 3800 Watts while in Ramazzini's study the level is 100 Watt. It is worth mentioning that a 5G Base Station operates at 200 Watt while a 5G terminal can use 0.2 Watt [21].
- Distances between rat cages and RF source are different between studies and real environment. 2.0 to 2.2 m is the distance in the experimental field while the human being cannot be found at a distance less than 10 – 15 m. Exclusion zones are implemented in real environment in order for a Base Stations to be licensed.

Population based studies include Interphone Study, Danish cohort study, CEFALO case control study [26, 27]. By reviewing all available literature ICNIRP concludes that epidemiological studies do not provide evidence of a carcinogenic effect following RF exposure below the guidelines. Consequently, no effects on the induction or development of cancer have been substantiated.

### *New 5G band in mmWave and health*

mmWave bands (> 3,5 GHz) is a controversial issue for the population. The reason is that these frequencies have not been used in communications until now. The truth is that biological impact from mm-Waves have already been studied in the previous years although not in the context of communications. Reports did not show adverse health effects in daily life under the safety limits. WHO is currently preparing a review about health risks assessment of RF exposure (including mm-Waves), which will be completed by 2022.

Deployment of Base Stations operating on mm-Waves will be initially limited (e.g., hot spots where high data traffic is met such as airports, stadiums, shopping malls). The antennas will be small (micro) operating in low power. These bands will be used only for short range services where high speed rates (high capacity) are needed as mentioned above. They are not going to be used for 5G coverage for example inside homes, buildings. Moreover, their penetrating ability is too low (high field attenuation). 5G in the majority of cases will be realized in sub-6 GHz bands (700 MHz and 3.5 GHz).

Thermal effects cannot be recorded when complying to the ICNIRP's guidelines. Thermal effects could be derived after incident power density (IPD) above 5–10 mW/cm2. High-intensity mm-waves exhibit severe impacts on human skin and cornea following a dose-dependent formula: heating sensation can be occurring at low-power density, while pain could be experienced at higher exposures. Physical damages are met at very high emissions powers.

It has been reported that in mmWave range non-thermal biological effects can be induced.

According to ICNIRP (2020) and many researchers [e.g., 28, 29] the following conclusions have been reached:

a. *Regarding the health effects 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 quality of the presented studies, Conclusions are difficult to be presented due to studies limitations in design.*
c. *"Non-thermal" effects, cannot be substantiated based on the available literature as the studies cannot provide a clear explanation on the RF fields' action mechanisms. Non thermal effects include impacts on protein and DNA as well as on cell reproduction.*

The mm-wave spectrum has been used for a variety of health treatments in Eastern Europe, including cancer treatments and pain relief (analgesia).

## Healthcare and 5G

Radio and Microwave Frequencies, where mobile technology and Wi-Fi operate, are used in Medicine for therapeutic or diagnostic purposes. These bands are used for various application as Microwave Diathermy (same band as 2G, 3G and Wi-Fi technologies), Microwave induced thermoacoustic echography (same band as 4G technology), Medical Imaging / localization of tumors (same bands as 2G, 3G, 4G and 5G technologies) and Medical Monitoring / Measurement of vital function as respiration and heart rate (same band as the forthcoming mmWave 5G). All of these applications lead to the conclusion that the human body can be safely exposed to non-ionizing radiation emitted below the ICNIRP safety limit without any adverse health effects.

By utilizing new technologies that are involved in 5G communication (IoT and mmWave frequencies) healthcare systems can improve the quality of care, provide more personalized and preventive care and reduce the cost of care. Specifically:

### *Expanding Telemedicine*

Effective telemedicine requires the establishment of a network that supports high quality near real-time video, for video-based medical consultations. 5G will help enable the speed and computing capabilities of the existing telemedicine. In addition, with the help of 5G, the medical services of a health care provider (e.g. a hospital) will be extended beyond its headquarters by providing services in remote areas (e.g. low video latency with a patient and the doctor in in rural areas or in a small island). When healthcare systems utilize this technology, patients can have access to specialists otherwise not available and often get treated sooner. Additionally, medical staff members collaborate more efficiently.

### *Remote patient monitoring*

The development of wireless communication and wireless body sensor networks (WBSNs) have greatly helped in the remote diagnosis and monitoring of patients [30, 31]. 5G exhibits very low delay in data transmission (very low latency < 1 msec). Moreover, it provides very high-speed data rates (Gbps). These conditions facilitate remote health care as well as remote surgery.

5G will support larger blocks of data transference, increase data transfer capacity utilizing wider bandwidth, enable better connections on mobile devices, and enable healthcare workers to give near real-time remote care. By using IoT devices, healthcare providers can remotely monitor patient vital signs, including drug delivery and customization based on near-real-time data collection and analysis.

### *Augmented and virtual reality*

5G will take advantage of Virtual Reality (VR) and Augmented Reality (AR) to enhance clinicians training and education and to care for patients. While spatial computing, VR and AR are already being used in healthcare on a limited basis, 5G may eventually further enhance a doctor's ability to deliver, less invasive and innovative treatments. Among 5G's many potential applications, some of the most exciting involve its role in simulating complex medical scenarios and enabling alternative treatments for the critically ill.

### *Artificial intelligence*

Many key healthcare functions are beginning to use artificial intelligence (AI) to determine potential diagnoses and decide on the best treatment plan for a specific patient. Additionally, AI can help predict which patients are more likely to have post-operative complications, allowing healthcare systems to provide early interventions when necessary.

The large amounts of data needed for real-time rapid learning require ultra-reliable and high-bandwidth networks. Additionally, providers often need to access data from their mobile devices. By moving to 5G networks, healthcare organizations can use the AI tools they need to provide the best care possible – from wherever they are in the hospital or clinic.

### *Data analysis*

5G will allow a larger data volume and data exchange with high security to achieve improved resolution. Medical data can be used with reduced operating costs and improved efficiency. Analytical data and AI data can be used for diagnostic procedures and obtaining treatment plans for patients.

The 5G network will support the connection of systems that can be used to power large analytical data as well as smartphones and mobile applications, cloud services, devices, sensors, machines. With the help of 5G, data can be distributed at multiple points of care. 5G technology will help implement innovations in hospital care logistics, remote surgeries, remote diagnoses, and improved patient engagement.

### *Large file transfers*

5G high data transfer rates (Gbps) will contribute to huge medical images transmission exhibiting exceptional network performance.

Many image machines are typically very large files, and often must be sent to a specialist for review. For example, the PET scanner generates extremely large files - up to 1 gigabyte of information per patient per study. In 4G these files take much longer times or are unable to be transferred. Medical imaging transfer will enter a new era exploiting 5G capabilities.

### *Decentralizing the healthcare model*

5G will further accelerate the industry trend toward providing care “closer to the patient” and outside the hospital setting through urgent care centers, walkin clinics, outpatient surgery centers, and home healthcare settings. Advances in medicine, technology, the rising costs of healthcare, have encouraged the proliferation of independent and/or satellite centers. 5G will support this decentralized healthcare system by helping to make operations more reliable and accessible.

Future 5G capabilities could generate significant improvements in many health scenarios, including the management and tracking of hospital assets, live-stream video conferencing with low latency, assisted living and remote monitoring of health or wellness data, faster remote access to electronic health records, enable more efficient data transfers through mobile apps, improve online and live remote consultations, and remote medication [32]. Additionally, 5G can offer 5G Mobile Systems for ultra-reliable low latency communications applied to the healthcare use cases, Wireless Tele Surgery (WTS) - using a mobile console and robotic platforms with video, audio and haptic feedback and Wireless Service Robots (WSR) - companion robots or service robots performing tasks of social caretakers, professional personnel, or family members. By offering these features, 24 hours, 7 days per week, remote patient monitoring solutions could soon become a reality.

## Conclusions

5G frequencies (including mmWave) are a subset of a wider range of radio frequencies, a range for which there is decades of vast clinical and research experience in terms of its effects on the health of exposed individuals.

Analyzes and meta-analyzes of these clinical and research results have not provided evidence or even indications that any exposure below the safety levels as defined by the ICNIRP Guidelines poses any known health risks to adults or children. It is emphasized that, while maintaining a satisfactory level of communication, 5G devices automatically minimize the transmitted power to the lowest possible level. The transmitted power of the device is controlled by the network.

All the data analyzed above, relative to the 5G technology led to the following statements:

### *Statements*

1. 5G (technology) uses radio frequency spectrum like existing mobile technologies and many other radio services e.g., TV, FM, emergency and commercial radio services, microwave links & satellite. 5G will operate at 700 MHz, 3.5 GHz and in mmWave bands (i.e., 27GHz).
2. 5G antennas dimensions do not differ from 4G

or 3G networks. 5G can provide communications of very high-speed data rates (Gigabites per second vs Megabites per second in 4G). Moreover, the latency (delay in data transmission is extremely low providing the chance of real time data exchange.

3. Exposure levels: No major changes in 5G (low and high frequency) are expected. The existed reference levels and basic restrictions remain valid as issued by ICNIRP in 2020. Typical EME (EM exposure) levels from all networks (3G, 4G, 5G) and devices in everyday use will remain very low. Thousands of times below the safety limits (in house and office environment). New Radio techniques, such as TDD, MIMO and Beamforming will contribute to decrease in EMF human exposure.
4. In future 3G will be closed while lot of 4G traffic will be offloaded to 5G.
5. New ICNIRP guidelines concerning the range 100 kHz to 300 GHz are issued. The new publication has replaced the 1998 guidelines [9]. No major changes were recorded. Mobile communications remain under the same limits. There is no evidence of adverse health effects at exposure levels below the basic restrictions as described in the ICNIRP (1998) and ICNIRP (2020) guidelines and no evidence of an interaction mechanism that would predict that adverse health effects could occur due to radiofrequency EMF exposure below restriction levels. The new Guidelines provide protection against all adverse health effects, regardless of whether they are due to acute or chronic exposures, regardless of age or health status.
6. The main mechanism of imposing adverse health effects is the body heating. Under the existing guidelines in all technologies (2G, 3G, 4G, 5G), temperature rise is negligible.
7. As the frequency increases, the penetration ability of RF is decreasing. mmWave are attenuated on the body surface. No adverse health effect is substantiated using 5G and mmWave technology.

## Conflict of interests

The author declares no conflict of interests.

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