Human Electromagnetic Field Exposure in 5G at 28 GHz

Seungmo Kim and Imtiaz Nasim
Georgia Southern University

***Abstract*—The fifth-generation wireless (5G) has already started showing its capability to achieve extremely fast data transfer, which makes itself considered to be a promising mobile technology. However, concerns have been raised on adverse health impacts that human users can experience in a 5G system by being exposed to electromagnetic fields (EMFs). This article investigates the human EMF exposure in a 5G system and compares them with those measured in the previous-generation cellular systems. It suggests a minimum separation distance between a transmitter and a human user for keeping the EMF exposure below the safety regulation level, which provides consumers with a general understanding on the safe use of 5G communications.**

CONCERN ON HUMAN EMF EXPOSURE IN 5G

As a means to fulfill the latest skyrocketing bandwidth demand, the fifth-generation wireless (5G) is expected to achieve far higher data rates compared to the previous-generation wireless systems. However, the 5G's requirement of a very high data rate entails an increase in signal power received at a user's end, which in turn results in an increase in the amount of electromagnetic energy imposed on the user.[1–3] Not only that, this article identifies three technical features adopted in 5G, which can increase the human electromagnetic field (EMF) exposure "further."

First, the 5G targets to operate at *higher frequencies* (e.g., 28, 60, and 70 GHz[4]) in addition to the existing lower frequency bands for cellular communications. The advantages are 1) the availability of wide bandwidths and 2) the possibility of integrating a larger number of antennas in small dimensions.[4] At a higher frequency, however, the EMF "absorption" rate into human skin also rises.

Second, *larger numbers of transmitters* will operate. In 5G, more base stations (BSs) will be

Digital Object Identifier 10.1109/MCE.2019.2956223
Date of publication 11 May 2020; date of current version 9 October 2020.

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deployed due to employment of small cells. As a direct consequence, BSs serve smaller geographic areas and thus are located closer to human users, which again results in a higher chance of a human user being exposed to EMF.

Third, *directional beams* will be employed in 5G as a solution for faster attenuation of a signal power due to operation in high-frequency bands.[4] Notice that the main purpose of using such a multiple-antenna system is to increase the antenna gain. This higher concentration of electromagnetic energy results in a greater potential for an EMF to penetrate further into a human body.

CURRENT UNDERSTANDING AND EFFORT

While substantial attention has been paid to technical advancements that the 5G will introduce, the potential impacts that the technology may pose on human health have not been discussed as closely and thoroughly.

Health Effect

"Heating" of skin is one representative impact on a human body caused by EMF exposure. The temperature for a skin outer surface normally ranges from 30 to 35°C. The pain-detection threshold temperature for human skin is approximately 43 °C[14] and any temperature exceeding it can cause a long-term injury. Heating is considered as a significant impact since it can cause subsequent effects such as cell damage and protein induction.[5] It is also known that high-frequency EMF affects the sweat glands (which may serve as helical antennas), peripheral nerves, the eyes, and the testes, and may have indirect effects on many organs in the body.[6]

Recent studies showed health impacts of EMF in frequencies above 6 GHz. In a latest study,[7] EMF power transmitted to the body was analyzed as a function of angle of incidence and polarization, and its relevance to the current guidelines was discussed. Another study[8] determined a maximum averaging area for power density (PD) that limits the maximum temperature increase to a given threshold. Also, considering "bursty" traffic patterns in modern wireless data communications, an analytical approach to "pulsed" heating was developed and applied to assess the peak-to-average temperature ratio as a function of the pulse fraction.[9]

Acknowledgement by Organizations

The United States (U.S.) Federal Communications Commission (FCC)[10] and the International Commission on Non-Ionizing Radiation Protection (ICNIRP)[11] set guidelines on the maximum amount of EMF energy allowed on a human body. It is noteworthy that the FCC's guideline on specific absorption rate (SAR) is averaged over 1 gram (g) of tissue while that set by the ICNIRP is averaged over 10 g. It implies that the FCC's guideline is more conservative, while the ICNIRP allows for two to three times as much energy absorption.

Also, the U.S. Food and Drug Administration (FDA) states that the current understanding on adverse impacts of EMF emissions on human health is insufficient to conclude whether exposure to the emissions is safe or not, and thus, additional research is needed to address the current gaps in the literature on human health safety in use of wireless systems.[12]

Meanwhile, the World Health Organization (WHO)'s International Agency for Research on Cancer (IARC) classifies EMF exposure as possibly carcinogenic.[13]

Measurements

PD and SAR are the two most widely accepted metrics to measure the intensity and effects of EMF exposure.[15] However, selection of an appropriate metric evaluating the EMF exposure still remains controversial. The FCC suggests PD as a metric measuring the human exposure to EMF generated by devices operating at frequencies higher than 6 GHz,[10] whereas a recent study suggested that a guideline defined in PD is not efficient to determine the impacts on health issues especially when devices are operating in a very close proximity to the human body such as in an uplink.[14]

However, PD cannot evaluate the effect of certain transmission characteristics (e.g., reflection) adequately. Thus, temperature elevation and SAR at a direct contact area are proposed as the appropriate metric for EMF exposure above 6 GHz.[16] This article chooses SAR as a more

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adequate metric than the skin temperature, which is subject to be dispersed during propagation and affected by the external atmosphere (i.e., air temperature).

Every wireless device should pass compliance tests before going to the market. An international standard entitled IEC62232[17] has been acting as a key reference in compliance tests for BSs and user equipment (UE). It focuses on change of characteristics in radio frequency (RF) field with distance from an RF source. Relevant studies are also found. Exposure to RF EMF from a UE[18] and that from a BS[19] are studied.

Reduction of Human EMF Exposure

Albeit not many, schemes for EMF emission reduction in a wireless system have been studied.[20,21] Note that the human exposure can be reduced if a BS adopts a power control or adaptive beamforming technique.[22] Also, the exposure level can be reduced when multiple spectrum bands are combined for coordinated use. The reason is that with a higher carrier frequency, a wireless system should reduce the cell size, which leads to more severe threats to human health.

Focus of This Article

Four points on which this article puts particular focus are highlighted as follows.

First, we discuss the human EMF exposure in the *downlink* as well as the uplink. Most of the prior work studies the uplink only, while hardly paying attention to EMF emissions generated by BSs in a 5G network. Recall the aforementioned changes that the 5G adopts: 1) operation at higher carrier frequencies; 2) reduction of cell size (which leads to increase in number of BSs); and 3) concentration of higher EMF energy into an antenna beam. They all imply that in 5G, unlike the previous-generation wireless systems, the downlink can also be a threat to human health as well as the uplink.

Second, we suggest that *both SAR and PD* should be used to display human EMF exposure for a wireless system. The reason is that SAR captures an amount of EMF energy that is actually "absorbed" into human tissues, whereas PD is an efficient metric only to present the EMF energy being introduced to a human user.

Third, we present an *explicit comparison* of human EMF exposure in 5G to those in the currently deployed wireless standards. For 5G, we adopt the system model defined in the Third-Generation Partnership Project (3GPP) 5G New Radio (NR).[23] Meanwhile, currently operating technologies are represented by 4G[24] and 3.9G.[25] Notice that 4G represents the 3GPP's Long Term Evolution (LTE)-Advanced, and 3.9G is the last release by the 3GPP before 4G was deployed (from which the name "3.9G" originated).

Fourth, we consider the maximum possible exposure that a human user can experience. In other words, no technique for mitigation of received power is considered in this article's system model. It is for advising the consumers with most conservative perspectives in using 5G wireless.

CASE STUDY MODELS

In order to understand how much EMF energy is imposed on a human user in a 5G wireless system, this article suggests two "comparative" case study models: 1) among different wireless systems—i.e., 5G, 4G, and 3.9G, and 2) between downlink and uplink.

5G versus 4G versus 3.9G

Commonly, for all of the three systems, we assume a fully loaded network in order to understand the "worst case" of EMF exposure. As mentioned earlier, none of the three systems is supposed to adopt any "adaptive" techniques—namely, power control and adaptive beamforming. That is, there is no particular method applied to reduce the amount of EMF energy being imposed on a user at a certain time instant. The rationale is to provide the "most conservative" suggestion on consumer safety, leaving room for a safety margin.[18]

Figure 1 depicts the difference in the cell size among the three wireless standards. As mentioned in the "Concern on Human EMF Exposure in 5G" section, a 5G system adopts the smallest cell diameter (i.e., 200 m) among the three systems, pursuing to form a small-cell network. This difference in cell size is a significant factor differentiating the level of human EMF exposure

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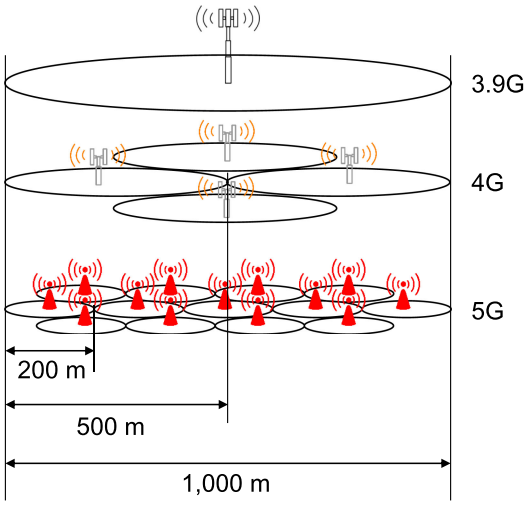


Figure 1. Comparison of cell size.

among 5G, 4G, and 3.9G, as discussed in the "Numerical Results and Discussions" section.

Downlink versus Uplink

Another case study is defined as a comparison between uplink and downlink in a 5G system. Figure 2 illustrates the geometric difference between the two directions of communication. In this case study, the user's head is placed between the BS and the handheld device, which represents a case where the impact of human EMF exposure is highlighted.

There is a key similarity between the downlink and the uplink: both adopt beamforming.[23] Accordingly, they both adopt directional antennas, which results in concentration of electromagnetic energy higher than 0 dB in an antenna beam.

The differences between downlink and uplink are as follows. First, in uplink, the equivalent isotropically radiated power (EIRP) that a transmitter generates is lower than that in a downlink. The reason is twofold: 1) an uplink requires a lower data rate than a downlink; and 2) a UE, as a transmitter, is less capable of accommodating as many antennas as a BS can. Second, a signal propagates shorter in an uplink than in a downlink. The inter-site distance (ISD) for a 5G cell is 200 m, as indicated in Table 1, which yields a cell radius to be 100 m. As a consequence, in downlink, the maximum distance that a user can be separated from a BS is 100 m. In contrast, in an uplink scenario, the maximum separation

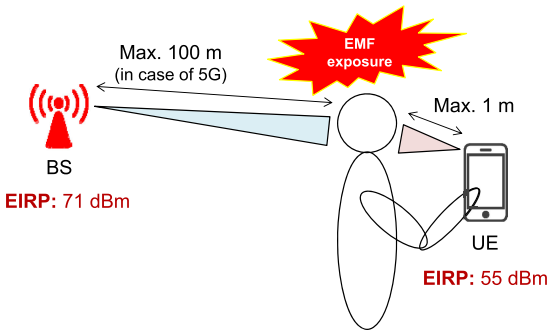


Figure 2. Comparison of uplink and downlink in 5G.

distance from the human user and the transmitter (a handheld device as being in an uplink) is supposed to be 1 m. When a handheld device is held in a user's hands, one can consider a number of representative scenarios such as directly contacting at an ear, moderate separation for texting or web surfing, and further separation with the use of an ear bud. The "maximum 1 m" in Figure 2 came from assumption of the last scenario that yields the maximum distance between the handheld device and the user's head. Third, an antenna beam in an uplink is less strong and sharp than that in a downlink. This is associated with the aforementioned geometric difference: a downlink beam is designed stronger and sharper for overcoming larger attenuation through a longer propagation.

NUMERICAL RESULTS AND DISCUSSIONS

Now, we evaluate human EMF exposure for the three wireless systems (i.e., 5G, 4G, and 3.9G) via Monte Carlo simulations in the case studies defined in the "Case Study Models" section. Specifically, to consider the variation of a mobile user's relative location in a cell, both PD and SAR are "averaged" in 10 000 experiments, each of which generates 10 UE per sector. Also, a cell is assumed fully loaded; the calculation considers a time length that is enough for all the 10 UE that are served based on TDD.

5G versus 4G versus 3.9G

In the simulation of the first case study, the Urban Macro (UMa) system layout is assumed, which is commonly defined in all of the three wireless standards that this article refers to, as already

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Table 1. Parameters for case study in 5G, 4G, and 3.9G.

Parameter	Value		
	5G[23]	4G[24]	3.9G[25]
Carrier frequency	28GHz	2 GHz	1.9 GHz
System layout	Urban Macro (UMa)	Urban Macro (UMa)	Urban Macro (UMa)
Inter-site distance (ISD)	200 m	500 m	1 Km
Bandwidth	850 MHz	20 MHz	20 MHz
BS max antenna gain	8 dBi per element	8 dBi per element	17 dBi
BS transmit power	18 dBm per element	44 dBm	43 dBm
BS number of antennas (w/ separation of $\lambda/2$)	256 and 64	4	4
BS antenna height	25 m	35 m	32 m
BS noise figure	5 dB	5 dB	5 dB
UE max antenna gain	20 dBi	1 dBi	1 dBi
UE transmit power	35 dBm	23 dBm	33 dBm
UE number of antennas (w/ separation of $\lambda/2$)	16	4	1 (omnidirectional)
UE antenna height	1.5 m	1.5 m	1.5 m
UE noise figure	9 dB	9 dB	9 dB
Cell sectorization	3 sectors/site		
Deployment	Outdoor 100%		
Duplexing	Time-division duplexing (TDD)		
Transmission scheme	Single-user (SU)-MIMO		

shown in Table 1. See the following specifications for technical details: 5G,[23] 4G,[24] and 3.9G.[25]

In Figure 3(a) and (b), there is a BS located at "0 m" mark for all 5G, 4G, and 3.9G systems. Now, a mobile user is moved from the 0 m mark to the 1000 m mark. Since each of 5G, 4G, and 3.9G systems adopts a different cell radius (also known as ISD), the downlink signal that the UE receives gets bounced up as it passes another BS standing at different distance marks. This experiment setting is to highlight the impact of adopting smaller cells in 5G. Comparing 5G to 4G in both Figure 3(a) and (b), despite faster attenuation than 4G due to operation at a higher frequency, PD and SAR in 5G are kept elevated more frequently, as the UE meets the next BS in a shorter distance. That is, in a 5G network, a consumer is likely to be exposed to high EMF energy more consistently. Nevertheless, it is easier to apply a "compliance distance"[17] in a downlink than in an uplink. Thus, this article suggests 1) an overhaul of the compliance distances defined in different standards and 2) the consumers' discretion on being close to a BS.

Compare black and blue curves in Figure 3(a) and (b). It is evident that the difference between 5G (with 256 antennas) and 4G is larger in SAR than that in PD. This is explained by the formal expression of $\mathrm{SAR}(d,\phi) = 2\mathrm{PD}\,(d,\phi)\,(1-\mathcal{R}^2)/(\delta\rho)$, where $\mathcal{R}$ is the reflection coefficient,[14] ρ is the tissue mass density ($1\ \mathrm{g/cm^3}$ is used), and δ is the skin penetration depth (10^{-3} m is used).[14] Recall that 5G and 4G operate at 28 GHz and 2 GHz, respectively. The SAR is inversely proportional to the penetration depth, and hence, a shallower penetration occurring in 5G yields a higher absorption.

Figure 4 compares the depth that an EMF penetrates into human skin among the three wireless systems of 5G, 4G, and 3.9G. Note that the level of SAR varies according to a number of disparate

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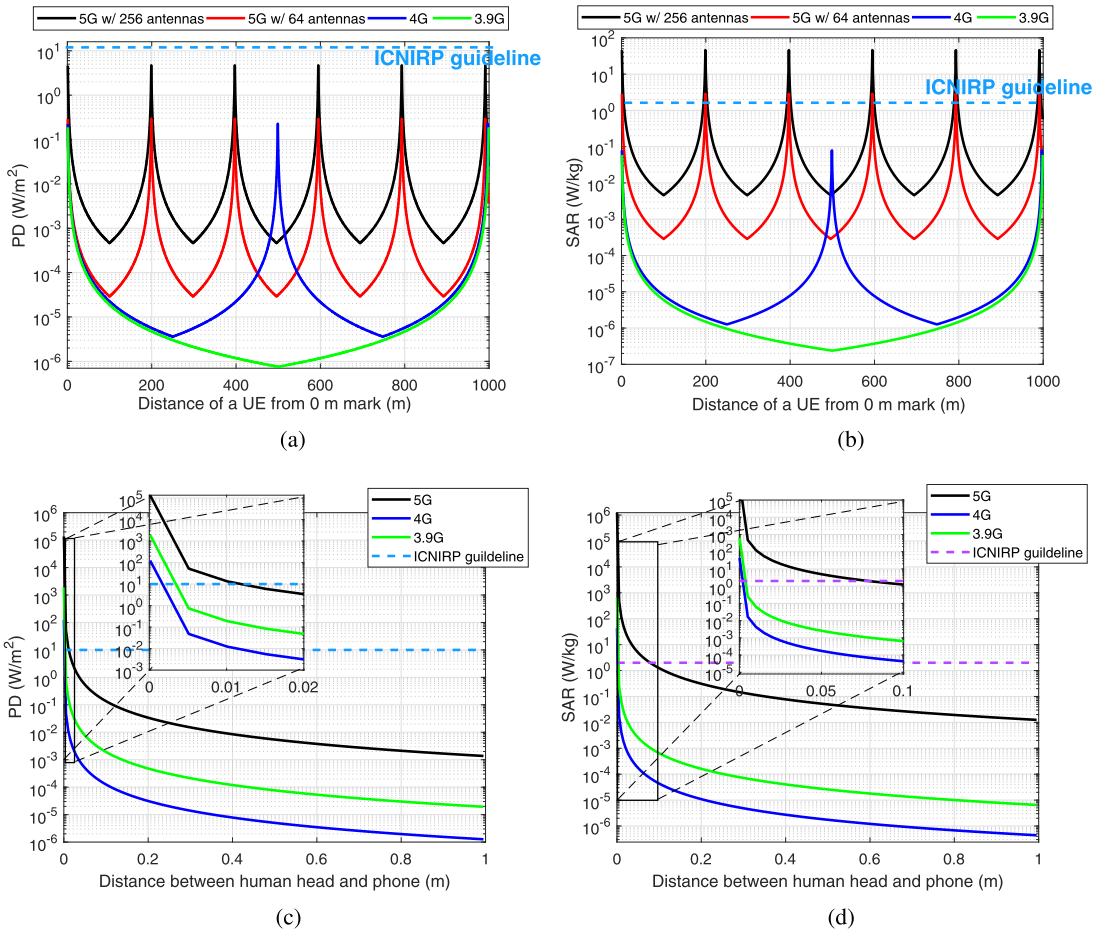


Figure 3. Comparison of human exposure levels. (a) Comparison of time-averaged PD in downlink. (b) Comparison of time-averaged SAR in downlink. (c) Comparison of time-averaged PD in uplink. (d) Comparison of time-averaged SAR in uplink.

variables–i.e., type of material, frequency, etc. The example shown in Figure 4 presents a measurement of SAR being introduced on human skin at the distance of 10 cm from a transmitter in an uplink. It clearly shows a scenario where the current belief is not valid; the fact that a high-frequency EMF cannot penetrate deep into human skin does not mean that it is not dangerous. Specifically, although the penetration is limited only at the skin surface, the SAR (illustrated as a heat map in Figure 4) can be higher within the concentrated area, which can cause subsequent health problems such as skin heating.

Downlink versus Uplink

Figure 3(c) and (d) compare PD and SAR in uplink to the ICNIRP guidelines set at 10 W/m^2 and 2W/kg, respectively. PD and SAR are remarkably higher in uplink than those in downlink, shown via a comparison of the results for uplink to those for downlink shown in Figure 3(a) and (b). It is attributed to smaller separation distance between a transmitter and a human body. Imagine one talking on a voice call; it is a "direct" physical contact of the phone and the head!

Also, it is significant to notice that no regulation exists at 28 GHz where this article investigates for 5G. As such, we refer to the ICNIRP's guideline that is set to be 2 W/kg by ICNIRP[11] at a frequency "below 10 GHz." In Figure 3(d), it provides a ""inferred" understanding on SAR in an uplink. The zoom-in look shown in Figure 3(d) suggests that in 5G, use of a handheld device within the distance of 8 cm causes an EMF absorption exceeding 2 W/kg, which would have

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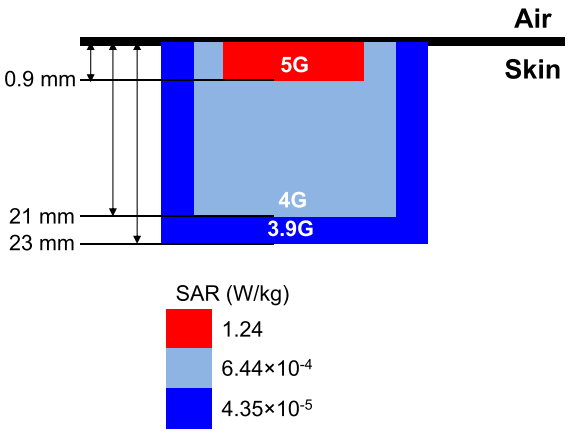


Figure 4. Comparison of EMF penetration depth into human skin and SAR.

been prohibited if the carrier frequency was lower than 10 GHz. This implies the gravity of human EMF exposure in an uplink of 5G.

CONCLUSION

This article has discussed human EMF exposure in 5G operating at 28 GHz, while most of the prior work focuses only on the technological benefits that the technology brings. Considering the significance of wireless technologies in our daily life, the potential danger of using them should also be emphasized for sustainable advancement of the technologies. In this article, the first case study has demonstrated how much EMF exposure is caused in a 5G system compared to 4G and 3.9G. Then, the latter case study has suggested an adequate separation distance from a transmitter, in order to keep a human user from being exposed to EMF below a regulatory guideline. This article is expected to ignite continued interest in overarching research on the design of future wireless systems that achieve high performance while keeping consumer safety guaranteed.

However, considering the gravity of this issue, we suggest several directions to be achieved in our future research.

- *Human EMF exposure mitigation strategy:* We are particularly interested in exploiting the technical features in future wireless systems—i.e., a larger number of BSs within a unit area. Such a paradigm change will enable a holistic, network-based approach to mitigate the EMF exposure as an optimization problem with a set of constraints representing the PD, SAR, and skin-temperature elevation.
- *Further studies regarding exact human health impacts caused by EMF exposure:* The particular focus will be put on 1) skin dielectric effect with respect to frequency and 2) the effect of radiation when the body is covered with clothing or garment materials.

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Seungmo Kim is currently an Assistant Professor with the Department of Electrical and Computer Engineering, Georgia Southern University, Statesboro, GA, USA, and the Director of the New-Era Wireless (NEW) Laboratory, Buffalo, NY, USA. Contact him at seungmokim@georgiasouthern.edu.

Imtiaz Nasim is currently pursuing his Ph.D. degree in Florida International University. He received his M.S. degree in electrical engineering from Georgia Southern University, Statesboro, GA, USA, in 2019. Contact him at in00206@georgiasouthern.edu.

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