Recent Trend in Electromagnetic Radiation and Compliance Assessments for 5G Communication

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ABSTRACT

The deployment of the 5G networks will feature high proliferation of radio base station (RBS) in order to meet the increasing demand for bandwidth and also to provide wider coverage that will support more mobile users and the internet-of-things (IoT). The radio frequency (RF) waves from the large-scale deployment of the RBS and mobile devices will raise concerns on the level of electromagnetic (EM) radiation exposure to the public. Hence, in this paper, we provide an overview of the exposure limits, discuss some of the effects of the EM emission, reduction techniques and compliance assessment for the 5G communication systems. We discuss the open issues and give future directions.

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1. INTRODUCTION

The deployment of the 5G networks would feature high proliferation of base station (BS) in order to meet the increasing demand for bandwidth and provide wider coverage that will support more mobile users and internet of things (IoT). Apart from that, transmission using the millimeter wave bands and deployment of BS with massive antenna configurations, ultra-high densification of small cells access points and heterogeneous networks are expected to be part of the 5G networks. The millimeter-wave (mmWave) band is part of the radio frequency (RF) spectrum, comprised of frequencies between 30 GHz and 300 GHz. However, the recommended International Telecommunication Union- Radio have selected 24 GHz to 86 GHz for study purposes. The radio frequency (RF) waves from the large scale deployment of the BS and mobile devices will raise the level of electromagnetic (EM) radiation exposure to the public. This raises concern about the possible adverse health effects due to exposure of RF radiation from mobile communication systems. Subsequently, several studies have been carried out to investigate the effect of the EM emission, reduction techniques and compliance test for the communication systems. The EM radiation is considered carcinogenic to humans and it has been classified as Group 2B under the international agency for research on cancer (IARC) of the world health organization as reported in the 2011 [1]. The emission from mobile phones can cause health hazards due to the proximity of the antennas to the human body especially the head. Moreover, there are also concerns about EM exposure from BS. As a result, there exist several international and national EM radiation exposure guidelines, limits and compliance tests which have been introduced by relevant regulatory bodies. EM radiation metrics such as the specific absorption rate (SAR) and power density are used to measure the EM radiation in the near-field and far-field, respectively.

The SAR measurement is the merit that is currently used to regulate the safety limits for the exposure of the mobile phone radiation. It is a measure of the rate of absorbed energy inside the human body and it requires either expensive measurement systems or advanced numerical simulations. The power density on the other hand, is defined as the power per unit area normal to the direction of propagation. At frequency between 10 MHz and 10 GHz, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) basic restrictions are given in terms of SAR while for higher frequencies from 10 GHz to 300 GHz the basic restrictions are given in terms of free space power density.

Some of the projects which are involved in the investigation of possible health hazards, reduction of EM radiation and the transmit power of mobile communication systems are listed and discussed in [2]. They include the international EMF project [3], low EMF exposure future networks (LEXNET), energy aware radio and also neTwork tecHnologies (EARTH) and greentouch [4]. These projects consist of industrial partners, network operators, research centers and universities. Some of their aims incorporate reduction of EM radiation exposure, reduction of energy consumption, improvement in energy efficiency and development of international acceptable standards. Consequently, guidelines on the limits of EM exposure from mobile phones, BSs, and other source of EM radiation exposure have been reported in [5], [6]. These guidelines which are based on laboratory and epidemiological studies specify the maximum admissible exposure of people to EM waves of up to 300 GHz. The guidelines are applicable to both occupational and public exposure. The public exposure refers to members of the public who are of all ages and are unaware of such exposures. Thus, they take less precautions to minimize the EMF exposure. On the other hand, the occupational exposure refers to the EM exposure of adults who are not only trained and aware of the possible harzards, but also has taken the necessary precautions. The exposure limits for occupational and public exposures specified by different standardization bodies such as ICNIRP, FCC and National Radiological Protection Board (NRPB) are summarized in Table 1 for various frequency ranges.

Table 1. Summary of Exposure Limits

Body	Metric	Frequency	Public values	Occupational values	Remarks
ICNIRP	SAR	≤10 GHz	0.08 W/kg	0.4W/kg	Whole body averaged over 10g,
	SAR	≤10 GHz	2 W/kg	10 W/kg	Localized head/trunk
	SAR	≤10 GHz	4W/kg	20W/kg	Localized limbs
	Power density	≥ 10 GHz	10 W/m^2	50 W/m^2	Averaged over 20cm^2
Body	Metric	Frequency	Public values	Occupational values	Remarks
FCC	SAR	≤ 6 GHz	0.08 W/kg	0.4W/kg	Averaged over 1g
	Power density	≥ 6 GHz	10 W/m^2		Averaged over 1cm^2
Body	Metric	Frequency	Public values	Occupational values	Remarks
NRPB	SAR	≤ 10 GHz	0.1 W/kg	0.4W/kg	Whole body
	SAR	≤ 10 GHz	2 W/kg	10 W/kg	Localized

There are different methods that have been proposed to reduce the EM radiation of 5G communication systems. Some of these methods which have been identified in the literature include SAR shielding, power control, beamforming and massive MIMO. In addition, product compliance assessment tests are required for the telecommunication products emitting RF EMFs in order to comply with the relevant regulatory exposure limits. Compliance assessment method for 5G radio BS is currently an active research area. Hence, in this paper, we provide an overview of some of the effects of the EM emission, reduction techniques and compliance test for the 5G communication systems. We discuss the open issues and future direction for EMF assessment and compliance test. The rest of this paper is organized as follows. In Section 2, the methods for EM radiation metrics are presented. Methods to reduced EM radiation exposure for 5G networks are discussed followed by EMF compliance assemment methods. Section 3 takes a look at the open issues and future directions. Section 4 concludes this paper.

2. METHOD AND EM RADIATION METRICS

2.1. EM Radiation Metrics

Physical quantities like the SAR, electric field strength, magnetic field strength and power density are used to specify EM radiation exposure. In literature, the popular metrics used are the SAR and power density for the near-field and far-field, respectively. The near-field and far-field are two different regions that define the electric and magnetic fields based on distance from the antenna as shown in Figure 1.

The near field region begins from the antenna up to $2D^2/\pi$ and it is divided into two areas which are the reactive and radiative areas (where D is largest dimension of the antenna). The reactive near-field region begins from the antenna up to the distance $\lambda/2\pi$, where λ is the wavelength. The SAR, in watts per kilogramme of body weight (W/kg), is typically used to measure the EM radiation exposure level in the near-field region averaged over time, (minutes). SAR is mathematically expressed as:

$$SAR = \frac{\delta}{\delta t}\left(\frac{\delta W}{\delta m}\right) = \frac{\delta}{\delta t}\left(\frac{\delta W}{\rho \delta V}\right) \quad (1)$$

where W, m, V, and ρ are the energy absorbed by the body, mass, volume and density of the body, respectively.

The far-field region begins at a distance greater than $2D^2/\pi$ from the transmitting antenna. The EM radiation in the far-field is commonly measured in terms of power density in W/m^2 and is expressed as

$$S = HE = \frac{E^2}{Z_o} = \frac{E^2}{377} \quad (2)$$

Where Z_0 is the characteristic impedance and H,E denote the magnetic and electric fields, Respectively.

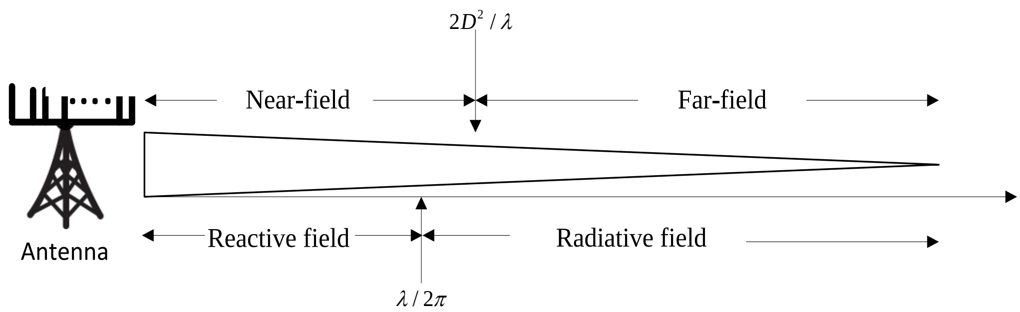

Figure 1. Illustration of EM radiation fields

2.2. Biological Effects of EM Radiation

In order to create an effect in the biological material, EM wave needs to deposit enough energy above the thermal kinetic energy to alter some structure significantly. The biological and health effects of EM radiation on human body have been investigated in several literatures. These include investigation in different parts of the human body such as head [7-10], and also fetus[11], [12]. The effect can be assessed by observing the increase in temperature using the SAR when the exposure is more than 6 minutes.The effect on a fetus in a maternal abdomen which is exposed to EM wave from a portable antenna shows that the SAR is affected by distance and penetration path from the antenna [11]. However, the SARs in the fetus are lower than the RF safety guideline for occupational exposure. The simulation results in [10] demonstrate that the existence of a metallic object between mobile phone and human head can cause the increase of SAR in the head. Other works have examined the effects of EMF on both children and adults[13]. These studies employ different types of antennas and different operating frequencies.

2.3. EMF Reduction Techniques

The BS communicates with the mobile phones wirelessly over an RF channel and the operating frequency used by a network depends on the technology and operational license. The evolution of the cellular networks over the years from 1G, 2G, 3G, 4G to 5G has brought about reduction in transmission power of the BS resulting to lower reduced EM radiation exposure levels and increased throughput. Different techniques have been developed to reduce the EM radiation exposure. Some of the techniques are massive MIMO, power control, SAR shielding, and beamforming.

Massive MIMO - is a communication system where a BS with a few hundred antennas array simultaneously serve many tens of UTs, each having a single antenna, in the same time frequency resource [14], [15]. In massive MIMO, the BS employs large array of active antennas in order to achieve directional beam towards UTs. The benefit of the massive MIMO system is the reduction in the transmit power.

Power Control– is a process that involves the adjustment of the output transmit power levels of BSs or mobile stations in order to maximize the received power of the desired signals. This helps to reduce power consumption as well as interference. The reduction in power helps to reduce the EM exposure levels.

SAR Shielding – is a process that involves the use of metamaterial attachment or ferrite materials between mobile phone and head to reduce SAR. The use of ferrite materials and metamaterials in the reduction of SAR has been reported in [16-18]. The ferrite materials are characterised by low conductivity which leads to smaller induced currents when exposed to EM waves while the metamaterials have special resonant characteristics that produce a negative permittivity or negative permeability.

Beamforming– is a process where RF radiation is focused in a particular direction through the use of large antenna arrays. This can be done through switch beamforming or adaptive array beamforming. The ability to focus signals towards desired users is considered to have the advantage of minimizing or eliminating EM radiation towards unintended users. The study on effect of beamforming for SAR mitigation is reported in [19], [20].

2.4. EMF Compliance Assessment

Manufacturers are concerned with the risk of non-compliance to EM exposure limits. Hence, the manufacturers carry out product compliance test to determine the compliance boundary outside of which the RF EMF exposure is below the relevant limits. The evaluation of EM radiation exposure in a body can be categorized into physical model and computational techniques [2]. The physical model encompasses the use of a phantom to simulate SAR or current density in the body while the numerical model encompasses theoretical calculation such as the finite-difference-time-domain method (FDTD) [21-23], [13]. Furthermore, the European standard CENELEC EN 50383 [24] has provided a guideline on how to combine exposures on multiple electromagnetic (EM) sources in terms of SAR and power density antenna systems and the product compliance assessment methods. The different approaches for combined exposure are categorized into experimental and numerical/computational techniques. Numerical simulations have been employed to conduct compliance assessment of a BS antenna using electromagnetic simulation software (example FEKO). The model of the BS antenna is created and meshed according to the numerical algorithm employed. The simulation can be conducted by using different numerical methods or solvers such as the (method of moments) MoM, multi-level fast multipole method (MLFMM), finite element method (FEM), finite difference time domain (FDTD), physical optics (PO), and uniform theory of diffraction (UTD). The choice of solvers determine the performance accuracy in terms of reduction of side lobes, directivity gains and amount of resources used during simulation (such as simulation time, computational memory and disc storage requirements). Meticulous selection in numerical methods is required for appropriate antenna types and sizes.

The use of large array BS antennas and the application of millimetre wave band for 5G networks pose new challenge in RF EMF assessments. One of the challenges is the mutual coupling between the antenna arrays and determination of the field distributions. In RF EMF assessments for large array multiport antennas, the combined exposure from all ports needs to be considered. Hence, different assessment methods for antenna array intended for beamforming applications have been investigated in [25-29]. The author in [25] shows that accurate and efficient EMF compliance assessments can be conducted by using embedded element approach. In the embedded element approach, each array element is excited sequentially while other elements are terminated in matched loads. This approach is suitable for small array antennas like the current 4G communication MIMO systems which require maximum of eight antennas. In [27], numerical EMF exposure assessment are carried out by using a conservative field procedure and combined with the embedded element approach in EMF assessment.The numerical results are in agreement with reference measurements. While this particular procedure is suitable for MIMO arrays, it is rather costly in terms of assessment time and resources for very large array antennas. Degirmenci *et al.*[29], proposes approximate methods for EMF compliance assessments of large array antennas. The accuracy of the approximate methods in terms of front compliance distance is measured as the relative difference with respect to the reference method results and expressed as [29]:

$$RD(CD, CD_{ref}) = \frac{CD - CD_{ref}}{CD_{ref}} \times 100 \quad (3)$$

where *CD* is the compliance is distance of the approximate method and, CD_{ref} is the compliance distance of the reference method.

The approximate method is motivated by the impedance characteristics of the sum of the embedded fields of all array elements. The result in [28], [29] shows that the approximate method has significantly improved the assessment time when compared to the embedded element approach combined with a conservative field combining technique.

3. OPEN ISSUES AND FUTURE DIRECTION

In this section, we discuss the open issues and provide future direction in EM radiation and compliance assessment for 5G communication systems. Some of the open issues discussed are compliance assessment, proliferation of mobile devices and small cell access points and millimetre wave. In addition, future direction is also presented.

3.1. Compliance Assessment

Accurate determination of compliance boundary may be quite complex for large array of RBS.The combination of massive MIMO transmitting at millimetre wave bands will introduce different configurations and array sizes of BS. Different array shapes and sizes such as cylindrical, spherical, circular, rectangular and linear, have been proposed for massive MIMO BSs as shown in Figure 2. The simplified and accurate method to determine compliance boundary that is applicable to all large antenna array needs to be considered. Furthermore, simplified methods for EMF exposure of this large arrays antennas also need to be further investigated.

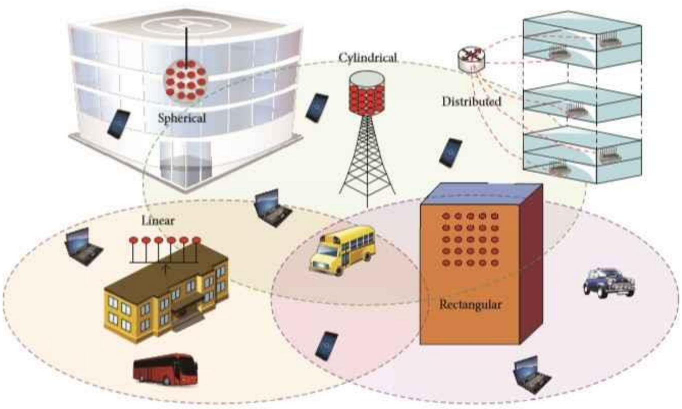

Figure 2. Illustration of massive MIMO antennas

3.2. Proliferation of Mobile Devices and Small Cell Access Points

The introduction of internet of things and increased number of mobile devices using RF communications will continue to raise concerns on health hazards due to EMF exposure. More studies based on practical measurements are needed to examine these effects.

3.4. Millimetre Wave

The effect of EM radiation for 5G communication systems in the millimetre wave has been investigated in [30]. A temperature based technique for the evaluation of safety compliance is proposed. The result of the study shows that about 34% to 42% of the incident power is reflected at the skin surface at 60 GHz. More work concerning the millimetre wave are needed to establish the effect on human body and different transmit power and different antenna types.

3.5. Future Direction

In the future, more work are expected in analysing the effects of EM radiation form massive deployment of IoT and proliferation of mobile devices. In addition, more work on the numerical efficient methods for compliance assessment of EMF exposures for RBS with large antenna arrays needs to be carried out. The choice of methods need to take into consideration the accuracy and effect of antenna correlation of determining the compliance boundary of the RBS operating with large array at millimetre wave. More measurement campigns are expected in order to verify the proposed numerical methods.

4. CONCLUSION

An overview of EM radiation and compliance assessments for 5G communication systems have been presented in this paper. Other than that, the description of the EM radiation metrics which include SAR and power density, near-field and far-field have also been discussed in this paper. Apart from the summary of the effects of EM radiation from publish works that have been cited in this paper, methods to reduce EM exposure and EMF compliance assessment have also been discussed. Finally, open issues and future direction have also been presented.

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