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A Scoping Review on Technical Evaluation of Electromagnetic Field Emission In 5G Wireless Network and their Effects for Improved Performance

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Abstract
This paper focuses on the technical evaluation of electromagnetic field emission in 5G wireless network. The technological advancement due to wireless communications and the generation of 5G mobile technologies can influence the health risks connected with the radio frequency (RF) emissions of a 5G network. In this paper, the effects of radiation emission in cellular base stations are highlighted and possible solutions that can reduce the menace are discussed. Most transmitters in the base stations are placed near to residential buildings or commercial premises which exposes human being to electromagnetic radiation. The deployment of 5G generation will provide improvement in communication system with ability to handle a larger number of connected devices than 4G generation at average speed of about 1Gbps. In conclusion, electromagnetic field (EMF) can be evaluated by electric and magnetic components to analyze the metrics which characterize 5G exposure in the power density (PD), electromagnetic field and specific absorption rate (SAR).

Keywords: Electromagnetic field, Radiation, Specific absorption rate, Radio frequency, 5G wireless networks

1. Introduction

Electromagnetic fields consists of electric (E-field) and magnetic (H- field) components which take place in a constant strength to each other and oscillates at 90^0 degree to the direction of the energy and movement of wave. The electromagnetic spectrum based on its increasing frequency and wavelength was made of ultra violet, infrared, radio waves, micro waves, x-rays and gamma rays (Kousik *et al.,* 2022) Phalguni and Sujith, (2020) observed that cells exposed to ionizing radiation can die or become cancerous, thus posing a risk for the health effects. The electromagnetic fields that belongs to the non-ionizing radiation category constitutes of waves that does not carry sufficient energy to ionize cells, thereby shunning cancer and death for the unprotected cells. As a result of these, the waves can secure adequate energy to resonate the molecules that can generate a potential health problem.

This research paper showed that there is an increase in health threat as a result of excessive level of radiation exposure from the mobile phones and transmitting towers. When this radiation is immersed in human systems, it can develop some reactions which later become visible as a change in the regular working of the body. In the human body, these changes manifest themselves as symptoms such as radiation sickness, cataracts and cancer (Ilori and Adeleye, 2019). The radiating elements of antennas are mounted on the towers at the base stations. The average height of the antennas lies between 100 feet and 200 feet. Majority of the communication towers with sector

directional antennas are exposed to electromagnetic field due to minor and major lobe radiations of the antenna pattern (Xu *et al.,* 2022).

The transceiver stations with node B in 3G network equipment are designed to facilitate the transmission and reception of radio frequency electromagnetic wave signal between the user equipment and the cellular networks (Phalguni and Sujith, 2020)**.** The increase in request for high speed services has led to the development of forth generation (4G) cellular networks with higher bandwidth, data transfer speed and uninterrupted connectivity. The 4G network enhances capacity and speed services through several radio interface with telecommunication improvements. As a result of these, possible health hazards are a matter of concern for people in the area due to influence of electromagnetic radiation from 4G base station (Than and Mon, 2020).

The advancement of 5G mobile networks has improved in the telecommunications market with positive and negative consequences. Fundamental research has been conducted to gain knowledge associated with 5G technology of high band frequency into millimeter wave which is a new range of the electromagnetic spectrum (Tayaallen *et al.,* 2021). Ayodele *et al.,* 2024 evaluated the various techniques for the reduction of electromagnetic power density. Their work examined different techniques of reducing the electromagnetic power density around the base stations. The method adopted for the reduction of electromagnetic interference are filtering, grounding and shielding. The results obtained shows that the filtering, grounding and shielding gave the reduction of electromagnetic power density of $3.552Wm^{-2}$, $3.78Wm^{-2}$ and $3.755Wm^{-2}$ at a distance of 10m respectively.

Udo *et al.,* 2021 conducted a research on electromagnetic fields exposure and its effects on human body. The method adopted was carry out on measurements of power densities in seventy two houses between two communication companies. The distance between the mobile base stations from this houses was 200 – 2500 meters apart. The results obtained gave an average cumulative power density of $1.54005627200\mu W/m^2$ and $0.001429063200\mu W/m^2$ respectively. Juan, *et al.,* 2022 reveiewed the assessment of the 5G transmitters exposure with emphasis on challenges and solutions. The method used was to overview the existing methods in order to estimate the electromagnetic field exposure by describing the key concepts framing assessment such as precise beamforming, millimeter wave, multi-input and multi-output sytems. Recent wireless technologies was taken into consideration for computation of EMFs.

Daniel *et al.,* (2023) investigated 42 base transceiver stations chosen from four main network providers such as MTN, 9mobile, Airtel and Globacom. The specific absorption rate (SAR) and average power density of the data collected from the base stations were calculated and observed that the average SAR for the chosen BTS facilities was below the international commission on non-ionization radiation protection's (ICNIRP) recommended limit. Yang *et al.,* (2023) analyzed the field strength results in both vertical and horizontal directions with measurements in several correlated base station scenarios. Their distribution parameters in the 5G mobile base stations assembled high voltage towers using ray tracing simulation approach. The specific aborption rate was used to evaluate the potential for heating effects using electronic devices that emit RF radiation. The outcomes were helpful in lessening the effects of electromagnetic radiation.

Sen *et al.,* 2024 investigated EMF exposure of commercial 28GHz frequency band. The method used involves measurements with 5G smartphones using two antennas. The results realized show that the electric field of 38 decibel was lower than the exposure limits. For traffic - off condition, there was no significant difference between the two antennas with electric field intensity of 3.6 decibel. Also, for traffic -on condition, the omnidirectional antenna arrests the radio waves with electric field of 7 – 13 decibel higher than when using the horn antenna. Meenu *et al.,* 2025 analyzed the intensity of electromagnetic waves emitted from communication devices with electric and magnetic fields generated from smart watch, mobile phones, laptop and mobile towers. When different communication equipment were placed near to the human body, EMF radiation was experienced. The results indicates the effects of electromagnetic radiation such as hypersensitivity signs on human being.

Previous studies, such as those done by Phalguni and Sujith (2020), Udo, *et al.*, (2021), Kousik *et al.*, (2022), Daniel *et al.*, (2023), Ayodele *et al.*, (2024) and Meenu *et al.*, (2025) focused their research works on electromagnetic field exposure but did not cover the deployment of 5G technologies. This work addresses these gaps through technical evaluation of EMF emission in 5G wireless network. This study provide a good insight on the health risks of individuals that are close to the mobile base stations from radio frequency emission.

2.0 Sources of electromagnetic interference

There are two sources of electromagnetic interference (EMI), namely natural and man-made. The natural source occur as a result of several phenomena like solar flames, static electricity and storms. The second type being the man-made can take place when electronic devices are affected by interference at the receiver end. It can be voluntary or involuntary sources. In voluntary sources, combat situations such as war confrontation, microwave devices and radar system will send out radiation to the energy location and equipment in order to nullify their activities. Again, for involuntary sources, the constituent component of a circuit can interfere with the working of another component in the circuit or nearby devices through conduction (Jamshed *et al.*, 2020). Examples of this type of sources are radio, microwaves, thermostats, medical and x-ray machines.

2.1. Bandwidth and duration of electromagnetic interference

Electromagnetic interference can also be categorize in terms of bandwidth. This bandwidth refers to the kind of radio frequencies that electromagnetic interference is practiced. The two classes of this type of interference are broadband and narrowband.

2.2. Broadband electromagnetic interference

These system occupies significant amount of magnetic spectrum and can not happen on discrete situation. This can originate from both natural and artificial sources and can come in a variety of shapes. Power line corona discharge are frequent sources of wide band electromagnetic interference. The majority of electromagnetic interference problems in digital devices falls on broadband electromagnetic interference.

2.3. Narrowband electromagnetic interference

This consists of narrowband frequencies that are formed by an oscillator circuits that arise from various types of transmitter distortion. The duration of electromagnetic interference refers to the time when interference was proficient. It can be grouped into two main categories, such as continuous and impulse electromagnetic interference.

2.3.1. Continuous electromagnetic interference

These interference is a persistent form of EMI when a source emits electromagnetic energy, thereby causing interference with other devices. It is always associated with steadily operating motors, power sources or electronic circuits.

2.3.2. Impulse electromagnetic interference

This is a type of electromagnetic interference that is characterized by intense bursts of electromagnetic energy which often occur within a brief period. It can be natural or man-made. Examples of impulse electromagnetic interference include lightening and switching systems.

2.4. Fifth generation (5G) exposure metrics

The electromagnetic field strength, specific absorption rate and power density are the metrics in 5G exposures on a wireless networks (Ajibare *et al.*, 2021).

2.4.1. Electromagnetic field strength

The electromagnetic field strength refers to the intensity of the electric and magnetic fields at a given point in space and time. In this study, the radio frequency produces electromagnetic field that can extent through out its surroundings. However, its comprises of both electric and magnetic fields components. Again, both electric and magnetic components can be projected over a time interval. However, when electromagnetic field are calculated based on the field conditions, the electric and magnetic fields are required to describe the field strength. At any given time, the electromagnetic field can be calculated as average value from various points in space. The averaged electric field strength E_{ave} over a given volume V can be calculated using root mean square as given in equation (1).

$$E_{ave} = \sqrt{\frac{1}{V}\int E^2 dv} \quad (1)$$

Where E is the electric field in volt per meter (V/m).

2.4.2. Specific absorption rate

The specific absorption rate (SAR) is a measure of the rate at which energy is absorbed per unit mass by a human body when exposed to a radio frequency electromagnetic field. In terms of biological tissues, the expression for SAR is given in Equation (2).

$$SAR = \frac{\sigma}{\rho_d}\,|E|^2 \quad (2)$$

Where σ is the electrical conductivity in S/m and ρ_d is the mass density in kg/m^3.

Specific absorption rate can also be express by considering the temperature rise of a body tissue, This is shown in Equation (3).

$$SAR = C\frac{\Delta T}{\Delta t} \quad (3)$$

Where C is the specific heat in joules (J), ΔT is the temperature rise in Celsius and Δt is the exposure duration in seconds (Abdul-Al *et al.,* 2022).

2.4.3. Power density

The power density is the third metric used to measure the level of exposure of electromagnetic field. This can be the absorbed power density P_{ab} or the incident power density P_{inc}. The expression for the absorbed power density P_{ab} is shown in equation (4).

$$P_{ab} = \iint_X^Z \frac{1}{X} R_e[E \times H^*]ds \quad (4)$$

Where E is the electric field, H^* is the magnetic field, ds is the integral variable vector and P_{ab} is the absorbed power density in w/m^2.

The incident power density P_{inc} refers to the modulus of the complex poynting vector and it is expressed as given in equation (5).

$$P_{inc} = |E \times H^*| \quad (5)$$

Equation (5) can be simplified under far field condition as shown in Equation (6).

$$P_{inc} = \frac{[E]^2}{Z} = [H^*]^2 \times z \quad (6)$$

Where z is the characteristic impedance of the free space whose value is 377Ω and P_{inc} is the incident power density in w/m^2

Also, the absorbed power density is inter related to the incident power density and it is shown in equation (7).

$$P_{ab} = (1 - |\tau_c|^2) \times P_{inc} \quad (7)$$

Where τ_c is the reflection coefficient which depends on numerous physical factors.

3. EMF emissions and the effects of radiation

Electromagnetic field emission is unveiled by man-made and natural energy. The two classes of electromagnetic radiation comprises the ionizing and non-ionizing. From a research it is evident that the ionizing radiation has a capability to eradicate the electron which is from the atom's orbit of an atom, where it becomes an ionized atom to cause health hazard (Farhana *et al.,* 2019). Moreover, radioactive materials like uranium and radium, as well as medical devices such as x-rays machines and computed tomography scanners are common examples of ionizing materials. However, non-ionizing materials are substances that do not have enough energy to remove electrons from atoms. This type of radiation includes forms like microwaves, radio waves, visible light, ultraviolet and infrared radiation. Presently, most societies depends on communication devices such as mobile phones for exchange of information in their homes, schools and work places. These mobile phones normally produce electromagnetic waves like x-ray and visible light. However, the range of electromagnetic radiation falls between the ionizing and non-ionizing ranges of frequency (Kousik *et al.,* 2022). For mobile communication, the range of frequency is between 450MHz -2200MHz.

Specific absorption rate measures the number of RF fields between 1MHz and 10GHz. Individuals exposed to 4W/kg of radio frequency fields in the specific absorption rate experience a number of negative impacts (Abdul-Al *et al.,* 2022). Similarly, the radio frequency fields at 10GHz are absorbed at the skin's surface and only a little amount of energy reaches the deeper tissues, whereas RF fields exposed at power densities more than 100W/m^2 cause serious health impacts such as eye cataracts and skin burns (Simko and Mattsson, 2019). Government authorities and most organization developed general guidelines regarding electromagnetic field exposure for the public and their employees. The reference levels on general public exposure root mean square value (rms) for telecommunication services is given by the International Commission on non-ionizing radiation protection (ICNIRP) are shown in table 1.

Table 1. The reference levels for telecommunication services on general public exposure root mean square (rms) values (ICNIRP, 2019).

Services	Frequency Range (MHz)	Electric field (V/m)	Magnetic field (A/m)	Equivalent plane wave thickness ($\mathbf{Wm^{-2}}$)
FM broadcast	88 – 108	28	0.092	2.0
VHF TV	54 – 88 174 – 216	28	0.092	2.0
UHF	407 – 806	29.8	0.099	2.0
Trunking 800MHz	806 – 869	30.0	0.13	2.05
Mobile telephony 800MHz	824 – 894	40.6	0.14	2.1
UMTS	1710 – 1900	30	0.19	2.5
LTE	2450 – 2700	30.5	0.20	2.5

The Institute of Electrical and Electronics Engineers (IEEE) and ICNIRP made recommendations restricting revised specific absorption rate by regional bodies to 0.4W/Kg for upper rate and 0.08W/Kg for lower rate. Table 2 indicates the health effects and specific absorption rate obtained from radio frequency exposure. Researchers observed that the exposure levels generated during the use of mobile phones were higher than those experienced from the base stations. The radio frequency contact has activated various health problems such as hypersensitivity, reproductive and neuro behavioural systems.

Table 2: Health effects and specific absorption rate (Farhana *et al.*, 2019).

S/N	Symptoms of RF health effect	Absorption rate (W/kg)
1.	Depression	0.0317
2.	Cancer	0.13 - 1.4
3.	Male reproductive system	0.0016 – 0.0105
4.	Ear burning	1.6
5.	Headaches	Above 0.01
6.	Sleeping disorder	Above 0.5
7.	Children sensitivity	0.0016
8.	Amnesia	Above 0.1

The electromagnetic fields normally cause health damage in the areas when high frequency heat up biological tissue and also when low frequency produce electric fields and currents in the human body. Its radiation in mobile services are obtained from two sources. These are radiation from base stations and cell phones. The various EMF sources, their operating frequency and transmission power are shown in table 3.

Table 3: Electromagnetic field sources, frequency ranges and their transmission power (Than and Mon, 2020)

EMF Sources	Operating Frequency	Transmission Power
AM/FM Tower	540 KHz – 108 MHz	1KW – 30 KW
TV Tower	48 MHz – 814 MHz	100 – 500 W
Wi-Fi	2.4 – 2.5 GHz	10 – 100 mW
Cell Tower	800, 1800, 2300, 2600 MHz	20W
GSM 900/CDMA	870 – 862 MHz	1 W
GSM 1800	1.77 – 1.85 GHz	2 W
DECT	1.88 – 1.9 GHz	10 – 250 mW

3.1 Electromagnetic spectrum

The electromagnetic spectrum is the full range of electromagnetic radiation organized by wavelength. This electromagnetic spectrum comprises of wavelength in the spectrum for both long and short wavelength and ranges from low energy, low frequency radiation that travels in long waves (radio waves and microwaves waves) to high energy, high frequency that travels in short waves (x-rays and gamma rays). Most researchers are of the view that non-ionizing radiation produces only thermal effects and also temperature sensitive biological structures comprising humans and process can develop injury at high exposure levels (Phalguni and Sujith, 2020). The electromagnetic spectrum uses millimeter wave ranges from 10 millimeter to 1 millimeter with large bandwidth. Also, this spectrum is subject to interference from trees, buildings and rainfall. As a result of inadequate coverage to implement fifth generation, antennas will have to be installed very close to one another capable of beam forming massive multiple input and multiple output (Udo *et al.,* 2021). However, electromagnetic waves always acquire enough energy to pulse the molecules which causes health problem like cancer. The radio frequency exposure from communication apparatus falls with the non-ionizing radiation group. Figure 1 shows the electromagnetic spectrum.

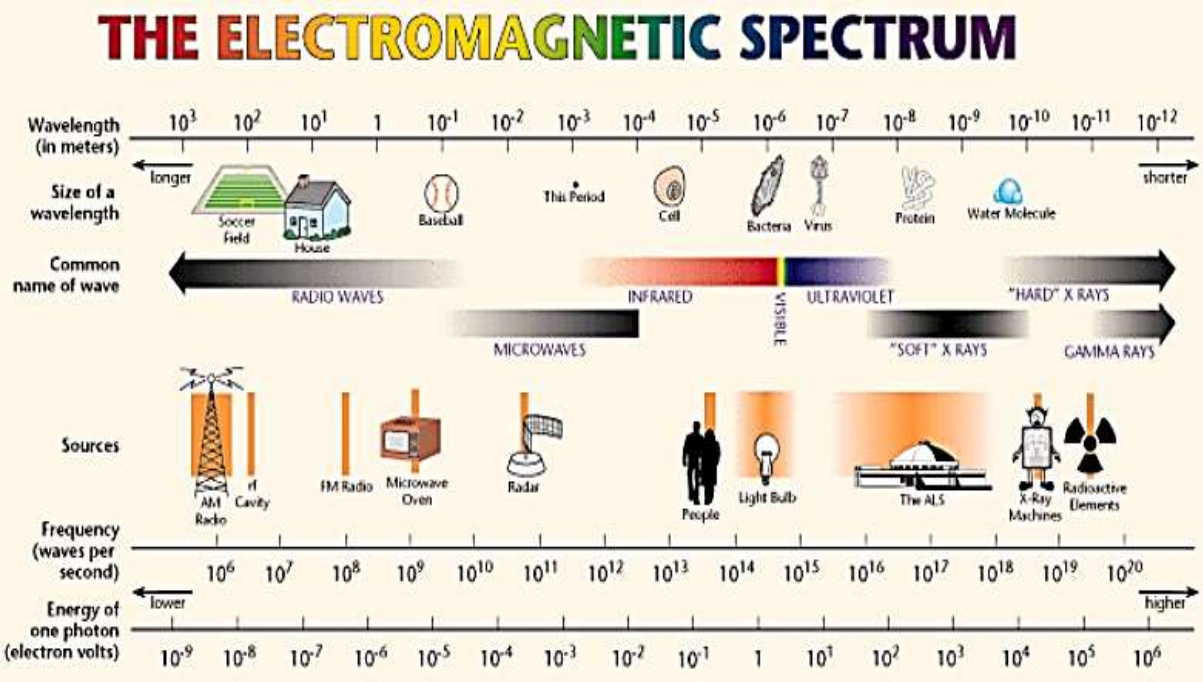


Figure 1: The electromagnetic spectrum (Jamshed *et al.*, 2020)

3.2. Health Effects on the Body from Radio Frequency Exposure

Majority of works done by researchers revealed that radio frequency signals produced from communication devices like mobile phones can disturb human health which lead to the cause of cancer. Governmental organizations and international scientific bodies have reviewed epidemiological studies of health and biological endpoints with the radio frequency exposures that would be encountered in environments nearby to the public (Yang *et al.,* 2023).

The fifth generation occur in the higher band of the frequency range of the millimeter wave and this signify that the wavelength of the electromagnetic wave take place in the millimeter range. Again, these waves are immersed within 1 to 2 millimeters of the human body and external covers of the cornea.

The consequence of brain syndromes like brain cancer and insomnia is critical issues in our culture. This paper highlights some of the health effects that are affected by the general public from radio frequency exposure.

Eye Defects

The high levels of radio frequency exposure with adequate high power density can cause numerous eye defects including retina damages, cornea issues and cataracts (Tayaallen *et al.,* 2021).

Male Fertility

The high levels radio frequency contact can be related with negative effects on reproductive wellbeing in terms of sperm fertility capability (Tayaallen, *et al.,* 2021).

Cancer

Cancer can disrupt normal body function, block channels and press on tissues that affect blood cell production. The mission of International Agency on Research on Cancer (IARC) is to coordinate and conduct research on the causes of human cancer, which is a mechanism of carcinogenics to individuals.

Electromagnetic Hypersensitivity

Some researchers have reported that radio frequency exposure causes numerous sensitivity symptoms to individual like burning sensations, rashes, fatigue, stress and headache (Lennart and Tarmo 2022).

Skin Effects

The radio frequency contact with high power concentration increases the temperature of a body cell. Again, confined heat exposure can be compensated by the human body temperature limit classification. The high amounts of absorbed radio frequency contact can cause a sensation of warmth in the skin causing slight skin burns (Yuan *et al.,* 2022).

Glucose metabolism

The radio frequency contact can interrupt the process of glucose metabolism in living systems and its effects are observed in human body when it is exposed to high stages of electromagnetic fields.

4.0. Conclusion

The variations in the field strength data can be attributed to moving objects, density of mobile phone users, environmental factors and spatial distribution of building in the affected areas. However, the measurement of electric field strength declines whenever the distance from the base station rises and vice versa.
Again, the amplitude of electromagnetic field exposure always depend on the number of transmitting towers, distance, height of the tower, and the direction of the base station. Some residential premises and commercial centers near cellular base station experience more power densities while others far away from the base station experience low power densities.

5.0 Recommendation

It is recommended that researchers should adopt other techniques to improve the performance of 5G Networks in wireless communications. We also recommend that network providers should resist from building mobile base station sand transmitters near to residential homes or commercial centers.

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