PERFORMANCE ANALYSIS OF ELECTROMAGNETIC RADIATION IN AN ULTRA-DENSE NETWORK USING MOBILE TRANSCEIVER BRANDS AND MODELS

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ABSTRACT

The developments have been truly alarming since the inception of mobile wireless technology which has been beneficial in many ways and this has also increased the general population exposure to electromagnetic radiations as electromagnetic radiations are the major means of transmission in this new technology. There have been many advancements in the technology such as 5G networks in an ultra-dense network (UDN) which leads to the increased possibilities of exposure to the radiations. The constant exposure to the radiations will lead to health hazard of mobile network users. The major mobile equipment (ME) emitting electromagnetic radiation is mobile transceiver and 99% of the populace are using this equipment. Therefore, in this study conducted the electromagnetic (EM) radiation performance of this equipment using 50 of its brands and models and analyzed the results based on the International Commission on Non-ionizing Radiation Protection (ICNIRP) reference level of 0.45mW/cm^2. One of the physical quantities used in measuring the electromagnetic radiation in this research is Power Density (PD). The measurements were taken using Radiofrequency Meter (RFM) TM-96, 9V DC and Spectrum Analyzer (NA-773, 144/430 MHz) during Call connection (Driving for Connection and Routing for Connection), Call Establishment (Dialing and Ringing) and Call Conversation (Dialer and Receiver) at interval of 5cm to 30cm from the equipment using 5G networks. In trying to reduce the level of electromagnetic radiation absorption by the mobile network users, it was found in this research that the radiation levels were increased during Call Establishment at both Transmitting and Receiving ends than during Call Conversation but much higher during Call Connection at the Transmitting End only i.e. during Driving for Connection, all at 5cm proximity to the mobile users.

***Keywords**: Electromagnetic Radiation; Ultra-dense Networks; Mobile Transceivers; 5G; Power Density.*

I. INTRODUCTION

Since the inception of mobile wireless communication, the level of Information and Communications Technology (ICT) in Nigeria has changed and in torn increases the economic activities in the country. Since the Global System for Mobile (GSM) launched, mobile transceiver system has greatly become the most popular method of voice communication in Nigeria, growth has been so rapid that Nigeria has been rightly described as "one of the fastest growing GSM markets in the world" of telecommunication (Oluwafemi, *et al.* 2019) Indeed, these developments have been truly alarming, according to statistics from the Nigerian Communications Commission (NCC), compared with just about 450,000 working lines from NITEL in 2001, by August 2004, the GSM operators had recorded over seven million subscribers (Joseph, 2017). In June 2018, they recorded over twenty million subscribers (Olorunfem, 2018). The figure rises to twenty-eight million at the end of 2022. Expectations are that the figure should rise thirty-two million by the end of 2024, due to massive expansion programs launched with different generations from first generation (1G) to fifth generation (5G) by the operators in Nigeria. Mobile transceiver is one of the major mobile equipment that transmitting larger percentage of electromagnetic (EM) radiation which has becomes an integral part of our day today life (Oluwafemi, *et al.* 2020).

The massive use of this equipment raises the question on how to reduce the level of exposure to electromagnetic radiation since too much exposure to EM radiation can cause ill-health to the users in this ultra-dense networks in 5G networks. The electromagnetic radiations emitted have a hazardous effect on the human body and health according to (Agburu *et al*. 2022). To avoid these problems, the international body on non-ionization radiation have set a maximum limit of specific amount of power density radiation absorb at a specific period of time. One of the physical quantities adopted in measuring the electromagnetic radiation in this research is Power Density (PD) measured in mW/cm^2. This shows how much energy the body tissue absorbed when exposed to electromagnetic radiations (GSMA, 2014)

Many researches are been carried out to find a means to reduce the level of electromagnetic radiations on mobile network users. In this paper we are directing our efforts to analyze the performance of electromagnetic radiation reduction using mobile transceiver equipment. The electromagnetic radiation performance were observed in this equipment when sectioned the mobile equipment's operation into three at both ends. Our paper distinguishes itself from the other published paper with its feature of distinguishing the three sections of this equipment's operations at both ends distinctively using 5G in ultra-dense networks. As it shows, the radiation was at its peak levels when mobile transceiver is seeking fall connection at the transmitting end which is called driving for connection.

II. MOBILE TRANSCEIVER IN GSM NETWORK

The Mobile Station (MS) consists of not only Mobile Equipment (ME) but also the Subscriber Identity Module (SIM). The ME is referred to as mobile handset (Oluwafemi & Adeoye, 2020). The ME is identified by a number that is primarily used for security purposes which is known as International Mobile Equipment Identity (IMEI) (Abubakar *et al.* 2019)

A SIM is a smartcard that is inserted into the ME to draw signals into the ME. Each SIM card has an International Mobile Subscriber Identity (IMSI), a number that identifies the subscriber to the network signals thereby allowing access to subscribed network services (Agber, & Akura, 2013).

Base Transceiver Station (BTS) is the inter-link for the Mobile transceivers to the network substations (Al-Zahrani et al. 2022). It responsible for all communications with the MS through wireless/air interface using electromagnetic radiation. Importantly, the transmitting power of a BTS determines the cell size which is known as the network coverage area.

This typical example of mobile transceiver is shown in Figure 2.1. An activated mobile transceiver is called MS, is basically comprises of ME and SIM (Anita. & Fredrick, 2019).

SIM + ME = MS

Figure 1.2: Component of mobile transceiver (activated handset) (Oluwafemi, *et al.* 2020).

In this research, the intensities of power density emission from fifty mobile transceivers selected based on different brands and models were analyzed and based the results on the established standards on non-ionizing radiation energy internationally.

III. MATERIALS AND METHOD

A. Materials

The different brands and models of mobile transceivers which operate in one or all the MTN, GLO Airtel and 9Mobile GSM network operators were placed facing the field strength in X, Y, Z directions in an ultra-dense networks In 5G networks at 5cm measurement intervals starting from 5cm until it reached a distance of 30cm (Bashir et al, 2018) Prior to the taking of the actual reading, points of 5cm spacing was marked using meter rule. The materials used were broadband RF meter (TM-96,9V DC); spectrum analyzer (NA-773, 144/430 MHz), meter rule and selected mobile transceivers found in Nigerian telecommunication market base on their brands and models with SIMs from four major network providers in Nigeria which are MTN, GLO, AIRTEL and 9MOBILE (Yusuf et al, 2023)

a. Broadband RF Meter (TM-96, 9V DC)

The broadband RF meter was used to measure the intensity of power density radiation in mW/cm^2 radiated from mobile transceiver selected for the study (Yusuf et al, 2023). Depending on the distance, this equipment measures radiation within the frequency range of 100 kHz and 60 GHz (Yusuf et al, 2023).

b. Spectrum Analyzer (NA-773, 144/430 MHz)

The spectrum analyzer was used to monitor RF signal frequencies and it responds to a signal of frequency range of 10 MHz to 18 GHz (Yakubu & Abubakar, 2019). The spectrum analyzer determines the frequency and PD of EM radiations (Yunas et al, 2015)

c. Selected Mobile Transceivers in 5G Networks

Different brands and models of mobile transceiver used in Nigeria Telecommunication market were selected. These selected mobile transceivers in 5G networks were fully charged to avoid the risk of low battery level and switching off during the process of radiation measurements (Colombi et al, 2018) The mobile transceiver that were considered for the study are shown in Table 3.1

d. Mobile Transceiver Brands used in Nigerian Telecommunication Market

Top ten (10) mobile transceiver brands in Nigerian Telecommunication Market approved by Nigerian Communication Commission, NCC are Nokia; Tecno; Samsung; Huawei; Itel; Infinix; Gionee; iPhone; Oppo and Vivo brands. The Table 3.1 below shows the lists of some mobile transceivers used in Nigeria that were used in this paper.

Table 3.1 List of some mobile transceivers to be used (Agburu *et al*. 2022).

Mobile Equipment (ME)	Origin	Type allocation holder
Nokia	Hungary	Nokia (311 Models)
Oppo	China	Oppo (38 Models)
Tecno	China	Tecno (358 Models)
Samsung	Philipine	Samsung (191 Models)
Vivo	China	Vivo (36 Models)
Itel	China	Itel (107 Models)
Gionee	Canada	Gionee (42 Models)
Infinix	China	Infinix (83 Models)
Apple iPhone	China	Apple iPhone (24 Models)
Huawei	China	Huawei (139 Models)

e. Method

The performance of EMR was analyzed after taking the reading when mobile transceiver was seeking for connection (driving for connection and routing for connection) i.e. the period when no sound was not heard from both ends and the mobile user place the mobile transceivers closer to his/her ear (Joseph, 2017). When establishing a call (dialing and ringing) i.e. the period when there is ringing tones from both ends and the users place it closer to their ears (Olorunfem, 2018). When call conversation was made (dialer and receiver) i.e. the period when there is voice conversation between the person making request and the person responding to the request made. This was done in two stages: investigation of background radiation (BGR) to ensure that all the network providers are in full signal strength at that particular spot of the measurement (Colombi et al, 2018) and radiation levels from the mobile transceiver used with distance marked with meter rule (Dudnikova et al, 2015). Average of the measured radiation levels were determined to evaluate the radiation level of each of the mobile transceiver during different modes. The performance of electromagnetic radiation was investigated and analyzed in terms of the amount of radiation absorbed by the mobile network users using power density (PD) radiations. The amount of radiation received at a specific location from a mobile transceiver, such as the brain using 5cm measurement, is more efficiently measured in terms of power density (PD) over a specific area (Ioan & Claudiu, 2016).

f. The Percentage Decrease in Power Density Absorption

In this paper, we take the power density radiation (PDR) levels during call conversation of the mobile transceiver's users as the radiation reference level (Nasim, 2019).. At the call conversation, radiation levels are low (LR), during call establishment, radiation levels are high (HR) but during call seeking, radiation level are very high (VHR) at the transmitting transceivers.

The equation 3.1 was adopted:

$$PD = \frac{\triangle RL}{RLc} \times \frac{100}{1} \tag{3.1}$$

where;
PD = Power Density,
$\triangle$RL = Change in Radiation Level,
RLc = Radiation Level during conversation

$$\triangle RL = RLe - RLc \tag{3.2a}$$

$$\triangle RL = RLs - RLc \tag{3.2b}$$

RLe = Radiation level during call establishment,
RLc = Radiation level during call conversation,
RLs = Radiation level during call seeking.
For Nokia C10 with these PD at different mobile transceiver modes at 5cm distance from the users:

During call establishment mode:

$$PD = \frac{0.2850 - 0.2550}{0.2550} \times \frac{100}{1} = 11.76\%$$

There is 11.76% reduction in PD radiation absorbed when not place mobile transceiver closer to the ear during ringing by the mobile network users.

During call seeking mode:

$$PD = \frac{0.3650 - 0.2550}{0.2550} \times \frac{100}{1} = 43.14\%.$$

There is 43.14% reduction in PD radiation absorbed when not place mobile transceiver closer to the ear before ringing by the mobile network users.

The difference between PD radiation of Nokia C10 when seeking for connection and call establishment is 43.14% – 11.76% = 31.38% .

IV. RESULTS AND DISCUSSION

a. Results

The intensity of radiation from various mobile transceivers during call establishment were higher than when call conversation were on at both ends as shown in Table 4.1 The radiation were very high (VH) when seeking for connection (driving for connection) at the transmitting ends but very low (VL) when seeking for connection (routing for connection) at the receiving end. The same selected mobile transceivers brands and models were used (Ndukaku, 2018). The result shows that there is electromagnetic radiation reduction absorbed when mobile transceiver users were making conversation at both ends and also shows that mobile transceivers emit very low radiation during routing for connection. The Table 4.1 shows the results of the radiation levels of mobile transceivers brands and models at different modes of operations at a distance of 5cm.

Table 4.1: Radiation levels of mobile transceivers brands and models at different modes.

Mobile Transceiver Brands and Models	**Power Density (mW/cm^2)**					
	Call Seeking		**Call Establishment**		**Call Conversation**	
	Driving	**Routing**	**Dialing**	**Ringing**	**Dialer**	**Receiver**
Nokia C10	0.3650	0.0185	0.2850	0.2800	0.2550	0.2552
Nokia C20	0.3220	0.0145	0.2480	0.2440	0.2081	0.2066
Nokia G10	0.3260	0.0175	0.3000	0.9909	0.2090	0.2245
Nokia G20	0.3950	0.0150	0.3650	0.3601	0.2280	0.2282
Nokia X20	0.3255	0.0225	0.2205	0.2200	0.1005	0.1000
Tecno Spark 7	0.2450	0.0145	0.1449	0.1356	0.1140	0.1139

Tecno Spark 8	0.3280	0.0140	0.1681	0.1584	0.1442	0.1442
Tecno Spark 9	0.3360	0.0165	0.1262	0.1256	0.0955	0.0957
Tecno Spark 9T	0.3900	0.0150	0.1945	0.1917	0.1481	0.1482
Tecno Spark X2	0.3205	0.0225	0.2912	0.2852	0.2106	0.2106
Samsung Galaxy A14	0.4350	0.0144	0.4120	0.4084	0.2408	0.2400
Samsung Galaxy A34,	0.3220	0.0144	0.2991	0.2597	0.1148	0.1126
Samsung Galaxy A54	0.3460	0.0143	0.3219	0.3126	0.2008	0.2082
Samsung Galaxy S23 Plus	0.3954	0.0144	0.2569	0.2553	0.1067	0.1067
Samsung Galaxy S23 Ultra	0.3265	0.0222	0.1560	0.1870	0.1387	0.1443
Huawei P8	0.4350	0.0130	0.3787	0.3707	0.2401	0.2386
Huawei P10	0.3220	0.0148	0.2761	0.2820	0.1289	0.1280
Huawei P20 Lite	0.3260	0.0165	0.1650	0.1610	0.1202	0.1300
Huawei P20 Pro	0.3950	0.0350	0.5407	0.5254	0.2245	0.2289
Huawei G8P	0.3255	0.0285	0.1300	0.1242	0.1190	0.1181
Itel A33	0.3250	0.0209	0.2953	0.2991	0.2528	0.2206
Itel A58	0.3220	0.0128	0.1458	0.1403	0.1317	0.1324
Itel A60	0.3260	0.0180	0.1503	0.1521	0.1297	0.1291
Itel S18	0.3950	0.0362	0.1587	0.1832	0.1480	0.1444
Itel P38	0.4255	0.0300	0.3125	0.3181	0.2952	0.2930
Infinix Note 12	0.3255	0.0230	0.1401	0.1483	0.1088	0.1064
Infinix Hot 30	0.3222	0.0144	0.2364	0.2520	0.2103	0.2153
Infinix Hot 30i	0.3460	0.0155	0.3110	0.3176	0.2124	0.2193
Infinix Zero Ultra	0.3250	0.0380	0.2144	0.2148	0.2074	0.2084
Infinix Smart 6	0.4255	0.0485	0.2200	0.2219	0.2181	0.2140
Gionee A1	0.4220	0.0330	0.1500	0.1450	0.1421	0.1440
Gionee S10	0.3220	0.0348	0.1484	0.1410	0.1392	0.1360
Gionee M6	0.3262	0.0185	0.1380	0.1342	0.1043	0.1042
Gionee M7	0.3900	0.0450	0.2188	0.2234	0.2096	0.2086
Gionee F20	0.3355	0.0385	0.1295	0.1239	0.1191	0.1152
Oppo A16	0.4220	0.0530	0.2404	0.2391	0.1953	0.1911
Oppo A17	0.3222	0.0448	0.3144	0.3172	0.2162	0.2222
Oppo A55	0.3266	0.0465	0.1148	0.1181	0.1124	0.1135
Oppo A57	0.3850	0.0450	0.2018	0.2502	0.2054	0.2000
Oppo A77	0.3555	0.0585	0.2800	0.2502	0.2304	0.2304
Vivo Y11	0.4255	0.0330	0.4009	0.4004	0.3702	0.3208
Vivo Y12	0.3111	0.0348	0.2410	0.2104	0.1790	0.1699
Vivo Y15	0.3266	0.0465	0.1237	0.1208	0.1196	0.1186
Vivo Y16	0.2951	0.0350	0.1952	0.1910	0.1513	0.1510
Vivo Y17	0.3225	0.0585	0.2544	0.2204	0.2060	0.2052
Apple iPhone 6	0.4450	0.0830	0.4006	0.4113	0.2602	0.2607
Apple iPhone 7	0.4220	0.0648	0.1270	0.1257	0.1025	0.1107
Apple iPhone 8	0.3233	0.0565	0.1964	0.1900	0.1041	0.0984
Apple iPhone 11	0.3333	0.0950	0.2165	0.2098	0.2041	0.2020
Apple iPhone 12	0.3265	0.0985	0.1251	0.1180	0.1105	0.1106

b. Discussion of the Results

This shows that when connecting to the tower, the power of Mobile Transceiver is high (Neha & Jamia, 2017). It is also clearly seen from Table 4.1 that the amount of EMF radiations was far higher when the transceivers were seeking for connection. This means there is 43.14% reduction in PD radiation absorbed when not place mobile transceiver closer to the ear before ringing at both ends by the mobile network users. It also shown that when call conversation is on, it exposes mobile network users in an ultra-dense network areas to small amount of electromagnetic radiation. It means there is 11.76% reduction in PD radiation absorbed when not place mobile transceiver closer to the ear during ringing at both ends by the mobile network users. Table 4.2 analyzed the results obtained in table 4.1

Table 4.2: The analyses of Radiation levels of mobile transceivers at different modes.

Mobile Transceiver Mode	**Seeking for Connection**	**Call Establishment**	**Call Conversation**
Transmitting Mobile Transceiver	Driving for Connection. (VHR)	Dialing. (HR)	Dialer. (LR)
Receiving Mobile Transceiver	Routing for Connection. (VLR)	Ringing. (HR)	Receiver. (LR)

Note: VHR = Very High Radiation, HR = High Radiation, LR = Low Radiation, VLR = Very Low Radiation.

High power(s) are witnessed when seeking for connection and when dialing the GSM network, higher power is needed by the mobile station in reaching and picking a signal from the base transceiver station (BTS) (Rakesh & Haneet, 2020).. The apparent drop in power during conversation as shown is attributed to adaptive power control (APC) and discontinuous transmission (DTX). An APC minimizes transmitter power of the mobile transceiver and reduces multiple-access interference effect in order for the BTS to receive the usable signal (Roslan et al, 2015). The DTX turns off transmission during pauses within speech, which reduce mobile network users exposed to electromagnetic radiation during conversation. The said phenomenon is witnessed whenever a transmitting handset is placed next to a speaker (Vasudeva *et al*, 2016)) the cracking noise (adverse electromagnetic interference effects) in the speaker degenerates with time after connection acknowledgement.

V. CONCLUSION AND RECOMMENDATION

a. Conclusion

The measurements were carried out in a good network environment (ultra-dense networks area), and the result has shown that the power density of the mobile transceivers would increase since the mobile transceiver will have to use a lot of power in order to link up with the base transceiver station (Buckus *et al*, 2017). In this mode, there is a very high percentage increase in mobile network radiation which is inimical to human health.

From the obtained results, mobile transceiver users who put the mobile transceiver closer to his/her ear for long before the mobile transceivers establish calls and call conversation will definitely exposed to higher electromagnetic radiation levels. The mobile transceiver during call seeking especially during routing for connection (at the receiving ends) also radiate small amount of electromagnetic radiation (Edewor, & Imhonopi, 2013).. The accumulation of health effects from these may include heating and tingling of the exposed tissues especially the ear and thighs, headache and psychological disorders as reported by (Ombati *et al*, 2017).

b. Recommendation

Finally, for the safety of the lives of mobile transceiver users, the following recommendations are made:

i The mobile transceiver users should allow the mobile equipment to establish calls before putting it closer to the ear.
ii The mobile transceiver users should keep a reasonable distance from the mobile transceiver when not in use.
iii The mobile transceiver's producers should always make the full information of the power density radiation of their products available to the users.

REFERENCES

Abubakar Y., Abbas Z. & Yunusa Z. (2019). *"*Easy determination of Radiation Absorption in brain tissue from mobile phone using element method", Pp 9, 147-154

Agber, J. U. & Akura, J. M. (2013). "A High-Performance Model for Rainfall Effect on Radio Signals". *Journal of Information Engineering and Applications*: pp 1-12

Agburu A. O. A., James G. B., Caleb A. A., Siyaka O. S., & Yunusa Y. S. (2022). "Performance Assessment of the Quality of Service of a GSM Network in Jigawa State Nigeria" *3rd International Conference on Applied Engineering and Natural Sciences, ICAENS*

Al- Zahrani A. Y., Yu F. R. & Huang M. (2022). *"*A joint cross-layer and co-layer interference management scheme in hyper-dense heterogeneous networks using mean-field game theory" *IEEE Transactions on Vehicular Technology, Vol. 65, Pp. 1522-1535*

Anita F. A. & Fredrick O. U. (2019) "Assessment of radiofrequency radiation levels of mobile phones and evaluation of specific absorption rate to tissues of human head layers" *FUW Trends in Science & Technology Journal, e-ISSN:* 24085162; p-ISSN: 20485170; Vol. 4 No. 3 pp. 643 – 650

Bashir M. A., Oyedum O. D., Tyabo M. A. & Muraina N. (2018). "Assessment of human exposure to RF radiation from mobile transceiver stations". *Physical science international journal* 18(3): 1-5, 2018

Buckus R., Baltrenas P., Skeivaias J., Grubliauskas R. & Cretescu I. (2017). "Mobile Phones Electromagnetic Field Radiation Research and Analysis of its Dispersion by applying MATLAB7 software". *Environmental engineering and management journal* 16 (5): 1177-1184.

Colombi D, Thors B, & Tornevik C., (2015). "*Implications of EMF exposure limits on output power levels for 5G devices above 6 GHz"*, IEEE Antennas and Wireless Propagation Letters.

Colombi D., Thors B., Tornevik C., & Balzano Q., (2018). "RF energy absorption by biological tissues in close proximity to millimeter-wave 5G wireless equipment", IEEE Access.

Dudnikova A., Dini P., Giupponi L. & Panno D. (2015) "Multi-Criteria decision for small cell switch off in Ultra-Dense LTE Networks". *International Conference on Telecommunication, IEEE (ConTEL).*

Edewor, P. A., & Imhonopi, D. (2013). "The health risks of global system of mobile communication (GSM): Perceptions of health professionals and radiation experts in Ogun State, Nigeria". *International Journal of Social Sciences and Humanities Review, Vol. 4,* No. 2. Pp. 72-78.

GSMA Intelligence, (2014). Understanding 5G: Perspectives on future technological advancements in mobile, White paper

Ioan E. M., Claudiu P. (2016), “Assessment of GSM HF-Radiation impact levels within the residential area of Craiova city”. Procedia Environmental Sciences 32 (2016) 177 – 183.

Joseph I. (2017), “Electromagnetic Field Radiation Exposure Assessment from mobile phone based on call related factors”. *An international review on modeling and simulation.* 10(5): 335-362.

Lan, J.Q., Liang, X., Hong, T., Du, G.H., (2018), “The effects of glasses on the SAR in human head resulting from wireless eyewear devices at phone call state, Progress in Biophysics and Molecular Biology”. Pp 10.1016 pbiomolbio.2018.02.001

Nasim, I., (2019). "Analysis of Human EMF Exposure in 5G Cellular Systems" Electronic Theses and Dissertations. 1923. https://digitalcommons.georgiasouthern.edu/etd/1923.

Ndukaku O. (2018), “Long-Term Health Impacts of Cell Phone-Driven Radiofrequency Radiation Exposure in Humans”

Neha & Jamia (2017). “Electromagnetic pollution its impact and control” *International Journal of Engineering Applied Sciences and Technology. Vol. 2, Issue 7, ISSN: 2455-2143, Pp. 61-65.*

Olorunfemi E., Ojo J., Aboyeji O. S., Akeju M. & Okezie C. (2018). “Determination of Electrical Radiation levels from cell phones and GSM masts in Ile Ife, Southwest Nigeria”. *Physical Science International Journal.* 18(3): 1-5.

Oluwafemi I.B., Adeoye J.O., Faluru A.M. & Obasanya T.D (2020). “Investigation of Factors Affecting Power Density Radiation of Mobile Phones”, *International Journal of Engineering and Technology (ITET), ISSN: 9(1): 223.*

Oluwafemi I.B., Faluru A.M., Ibikunle A.F, & Adeoye J.O (2019). “Investigation of Radiofrequency Exposure Levels from Different Mobile Telecommunication Base Stations in Ado-Ekiti, Nigeria”, *European Journal of Scientific Research (EJSR), ISSN: 1450-216X/1450-202X.*

Oluwafemi, I.B. & Adeoye O.J. (2020). “Mobile Phone Radiofrequency Radiation Assessment Based on Call-Related Factors and Physical Condition from Selected Mobile Phones”, *European Journal of Engineering Research and Science (EJERS). ISSN*: 5(3): 343-347

Ombati W., Kinyua R., Mutuku J. & Ogongo C. (2017). “Jomo Kenyatta University of Agriculture and Technology Annual Scientific Conference (315).

Omelu, N. C. (2018). Long-Term Health Impacts of Cell Phone-Driven Radiofrequency Radiation Exposure in Humans [Unpublished doctoral dissertation]. Walden University. United State of America

Rakesh K. & Haneet K. (2020). “Electromagnetic Radiation Reduction in 5G Networks and beyond using Thermal Radiation Mode” *Publisher: IEEE.*

Roslan U., Shahirah S. S., Atiq W. A., Zainol A. I., Wan Zul Adli Wan M. & Nor Hazmin S. (2015), “Radio frequency interference: the study of rain effect on radio signal attenuation”, *Malaysian journal of Analytical Science. ISSN* 1394 – 2506.

Vasudeva K., Simsek M. Perez D. & Guvenc I. (2016). “Analysis of handover failure in heterogeneous networks with fading”, *IEEE Transactions on Vehicular Technology, Pp. 1*

Yakubu A. T., & Abubakar B. Z. (2019). "Long-term adverse health effects of mobile phones". International journal of Economic Studies, 8(1), 107-118

Yunas S., Valkama M. & Niemela J. (2015). "Spectral and Energy Efficiency of Ultra-Dense Networks under different deployment strategies" *IEEE communications magazine, Vol.53, Pp. 90-100*

Yusuf A.S., Fabien H. & Muhammed A. (2023). "A survey of electromagnetic radiation exposure reduction in mobile communication system" *IEEE communications magazine, Vol.83, Pp. 80-90.*