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Examination of Electromagnetic Radiation Intensity of 5G Mobile Transceivers Based on Its Operational Techniques

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Abstract

Electromagnetic Radiation (EMR) absorption is a major worrisome for both network users and providers. Due to the technological progression that produced 5G networks, the proliferation of antennas and the multiplication of mobile transceivers of different brands around us every day give portable/mobile network operators multiple access to EMR. Mobile transceivers' operational techniques in energy radiation reduction are one of the key features to be examined in Fifth Generation (5G) systems to decrease the levels of Electromagnetic Radiation (EMR) around the users. In measuring electromagnetic radiation in terms of Power Density (PD) from mobile transmitters used, a Radio Frequency (RF) meter was employed, and the distance of 5 cm to 30 cm between the measuring equipment and the transmitters used with the help of a meter rule. During routing for connection, Itel gave the lowest radiation level of 0.3255mW/cm² and the highest radiation level is from Apple iPhone 12, which is 0.4400mW/cm². The results obtained were validated using the Excel package, and none of the transmitters used radiated above the international standard of non-ionising radiation level of 0.45 mW/cm². This is important for the reduction of EMR levels to avoid excessive absorption of electromagnetic radiation.

Keywords: *Electromagnetic Radiation, Intensity, Distance and Operational Techniques.*

1.0 Introduction

Electromagnetic radiation generally denotes the radiofrequency (RF) signals that contain data and speech amid portable transceivers through a base transceiver station (BTS). Radiofrequency signals, also known as carrier waves, are modulated and transmit the information needed in $3x10^8$ m/s, which is the speed of light [1]. This information can be communicated either in digital or analog form. This gives increase to digital and analog movable transceiver popularly known as mobile phones. Now, mobile telecommunication devices (MTD) have the ability to increase the carbon dioxide footprint in the atmosphere. Mobile network devices, though, make life easy for mobile network users in connecting with the world at anytime and anywhere, impacting people's lives every day, contributing to more than fifty percent of the electromagnetic radiation released into the atmosphere. Common transferable Internet facilities comprise interactive gaming, mobile networking, and online software streaming, among others. These result in a massive explosion of mobile traffic evolution in recent years in the global world. [2] Noted that the universal transportable traffic capacity in 2001 increased to 60 times compared to that of 2008 and 90 times compared to the present world because more devices, such as virtual reality, 3D video, and ultra-high-definition video as being connected through mobile systems, and numerous novel facilities will still be reinforced through these facilities. This resulted in a rapid increase in mobile traffic volume in this 5G network era, and major technologies of 5G networks are Ultra-Dense Networks (UDN), among others. In an Ultra-dense network, there is a tremendous increase in the number of base stations, which makes users connect to multiple cells and thereby improves the reliability of the signal [3].

1.1 Theoretical Assumption

Antennas are electronic devices used to transmit and/or receive EM signals in an unguarded medium, usually in free space or air. They are RF signal-dependent devices but reject RF signals outside the functional frequencies. Antennas are integral parts in mobile communication systems [4]. In a mobile transceiver, there is an in-built antenna which perform dual function of transmitting and receiving EM radiation in a multipath directional. Basically, when the antenna emits radiation into the air, two separate regions can be observed in the behavior of EM fields through the antenna, showing detailed features such as the near-field and far-field regions. In the near-field region, the concentration of emission is higher than in in the far-field region [5]. The mathematical representations are shown below.

$$\Pr = E^2/Zo \qquad (1a)$$
$$\Pr = ZoB^2 \qquad (1b)$$

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where:

E is the magnitude of an electric field in V/m, B is the magnitude of the magnetic field in A/m, Pr is the radiated power in W, and Zo = 377 Ω is the characteristic impedance. The concentration of emission at a distance interval from a transmitter base is unidirectional [6].

The square surface from the transmitting station is more affected by radiating power; As the body travels farther from the transmitting station, fewer lines, which indicate less energy received by the outward part. The remoteness sandwiched between the transmitting station and the capturing surface of an object determines the surface part that is visible to RF radiation [7].

A significant volume of EM radiation is focused close to the transmitting source, which is directly related to the radiating power and is inversely related to the square of the distance, [8]. Therefore, the inverse square law is specified in Eq. 2.

$$I = \frac{P_r G_o}{4\pi r^2} \tag{2}$$

where:

I is the EM radiation intensity (mW/cm²), Pr is the power radiation (mW), r is the remoteness from the radiating source (cm), and G_0 is the determined gain.

The radiation power in Eq. 3 decreases as the body moves away from the source. Thus, the highest concentration of radiation is observed very close to the object/mobile phone user [1, 2]. The power concentration of the mobile phone decreases as the gap between the telephone and its user increases, Eq. 3.

$$\rho = \frac{Pr}{Ae} \tag{3}$$

where:

ϱ is the power concentration.

Ae is the effective aperture.

$$Ae = \frac{Gr\lambda^2}{4\pi} \tag{4}$$

From Eq. 5, the effective area enclosed by the mobile telephone depends on the wavelength of the EMW in meters (m), [9].

$$EIRP = P_t G_t \tag{5}$$

where:

EIRP is the effective isotropic radiated power and G_t is the transmitted antenna gain in dB, and P_t is the transmitted power in Watts (W).

EIRP is the signal quality released from the source, and this quality rests on the power of the transmitted antenna and gain, as revealed in Eq. 6.

$$\mathrm{Pr} = g(d) P_t G_t G_r \tag{6}$$

where:

g(d) is the gradient and G_r is the received antenna gain.

$$g(d) = \frac{(h_t . h_r)^2}{d^n} \tag{7}$$

$$\mathrm{Pr} = \frac{(h_t . h_r)^2}{d^n} P_t G_t G_r \tag{8}$$

where:

h_t is the transmitted antenna height, h_r is the received antenna height, both in meters (m), and d is the distance between the transmitted antenna and received antenna in meters (m).

The antenna height also affects the power concentration received from the transceiver's station [10]. From Eq. 9, the higher the antenna, the better the received RF signal from the base.

We assumed that;

$$g(d) = kd^{-n} \tag{9}$$

where:

n stands for the propagation constant that hinges on the environmental factors.

$$SIR = \frac{P_r}{\sum_1^X Pr} \tag{10}$$

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But in a cellular mobile configuration,

$$SIR = \frac{R^{-n}}{(D-R)^{-n} + (D+R)^{-n}} \qquad (11)$$

where:

SIR is the signal-to-interference ratio, D is the re-use distance, R stands for the cell's radius, and n also stands for the number of the reuse cell. Eq. 12 shows that the signal quality reaching the mobile phone increases with an increase in the re-use distance of a cell.

$$p_r = \frac{p_t G_t A_e}{(\frac{4\pi R}{\lambda})^2} \qquad (12)$$

where;

$$G_r = \frac{4\pi A_e}{\lambda^2} \qquad (13)$$

$$P_r = \frac{P_t G_t G_r}{(\frac{4\pi R}{\lambda})^2} \qquad (14)$$

$$P_l = (\frac{4\pi R}{\lambda})^2 \qquad (15)$$

where:

P_l is the power density Loss, R is the distance from the mobile phone, and λ is the wavelength of the radiation; the farther the distance, the more the losses along its path Eq. 16.

$$P_l = 10log_{10}\left(\frac{4\pi Ae}{\lambda^2}\right) dB \qquad (16)$$

This path loss in Eq. 16 is in decibels (dB) and is not a loss in the sense of power being absorbed; it accounts for the way energy radiates as an EM wave travels from the source [8].

1.2 Specific Absorption Rate Calculation

When the EM wave penetrates through the human tissue, the energy of EM waves is engrossed by the users [4]. The value of SAR describes the interaction between the EM waves and the biological tissues and can be described as the radiated power dissipation normalized by the thickness of the material [2]. SAR is the proportion of the power received in the tissue to the density of that tissue [5].

$$SAR = \frac{\delta}{\rho} /E/^2 \qquad (17)$$

where:

σ is the electrical conductivity (S m-1) and ϱ is the concentration of the skin (kg m-3). It has been observed that the electric field E (V/m) is the r.m.s. value. As we define SAR as the proportional power received in the tissue and the thickness of that tissue, [10], the averaged SAR is obtained by integrating the following expression:

$$SAR_{av} = \frac{1}{v}\int SAR\, dv = \frac{1}{v}\int \frac{\delta}{\rho} /E/^2 dv \qquad (18)$$

2.0 Materials and Methods

2.1 Materials

The materials that were used are; a broadband RF meter (TM-195,9V DC); a spectrum analyzer (NA-773, 144/430 MHz); a meter rule; and selected mobile transceivers used in Nigeria. These mobile transceivers can accommodate up to three network providers at the same time. Ten (10) of these transceivers base on their brands and models, were sampled and collected from mobile network users. Using different mobile transceiver brands increases expenses due to higher cost of materials, time, and personnel involved, but it enhances the reliability of the detected results and increases the statistical power of the research.

2.2 Method

The different brands of portable transceivers that function on the MTN, GLO, Airtel, and 9Mobile GSM network operators were placed along the antenna direction in an ultra-dense network in 5G networks at 5cm measurement intervals, starting from 5cm until it reached a distance of 30cm. Single measurements were taken for all the mobile transceivers used for the work. Prior to the taking of the actual reading using the Radiofrequency Meter, points of 5cm spacing were marked using a meter rule. The performance of EMR was analyzed after taking the reading when the mobile transceiver was seeking a call connection, establishing a call, and call conversation, all at both ends. The examinations were observed in a similar geographical environment in Ado-Ekiti, Nigeria, to protection that all the ten (10) mobile transceivers used were under the same environmental influence. The quantities measured were used to evaluate the quantities of radiation from mobile transceivers during five (5) different operational techniques such as routing, dialing, ringing, dialer, and receiver. The performance of EMR was examined and analyzed in relation to the radiation quantities engrossed by the mobile network users using power density (PD) radiation. The quantities of radiation absorbed at a specific location from mobile transceivers, using average of 5cm distance and speaker phones at an average distance of 15 cm, are more efficiently measured in the form of power density (PD) at a definite area.

3.0 Results and Discussion

3.1 Results

This shows the reduction in radiation quantities obtained from diverse portable transceivers under assessment with changes in distance between the transceiver and the user.

In the study, quantity of RF emission from designated transceiver stations were measured amidst three major and five minor operational techniques: seeking for connection (routing technique); call establishment (dialing and ringing techniques) and call conversation (dialer and receiver techniques) and with different distance such as 5cm, 10 cm, 15 cm, 20 cm, 25 cm and 30 cm for the selected Ten (10) mobile transceivers of different brands and models to determine the reduction rate of EMR absorption by the mobile network users. The results show the performance analysis of EMR levels of mobile transceiver base on the mobile transceiver's distance from the mobile transceiver user and different operational techniques. Figures 1 to 10 reveal the results obtained using the Excel package in analyzing the data inform of line graphs and the line graphical expressions from the data obtained.

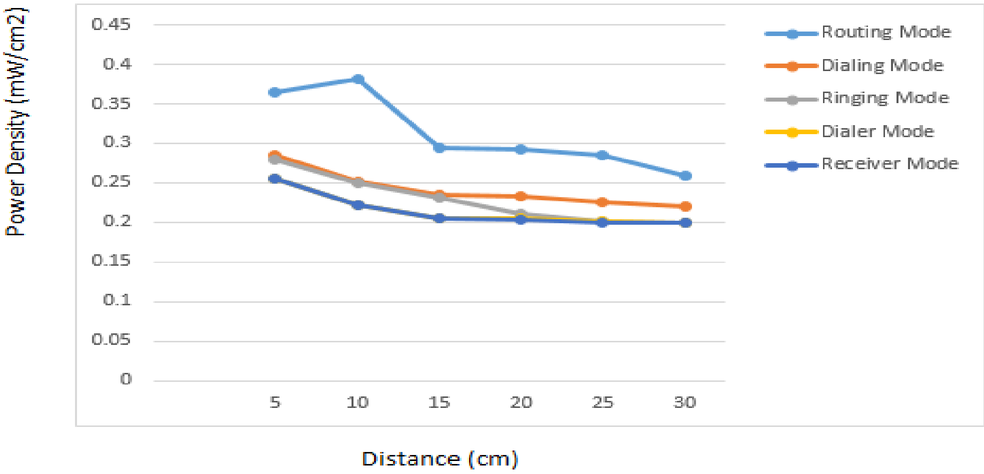

Figure 1. The radiation level of Nokia X20 during different operational techniques (modes)

During routing mode, the EM radiation was very high with the mobile brand, as shown in Figure 1. The radiation levels of Nokia X20 during all operational techniques decrease with an increase in distance and tend to be at the same level with an increase in distance.

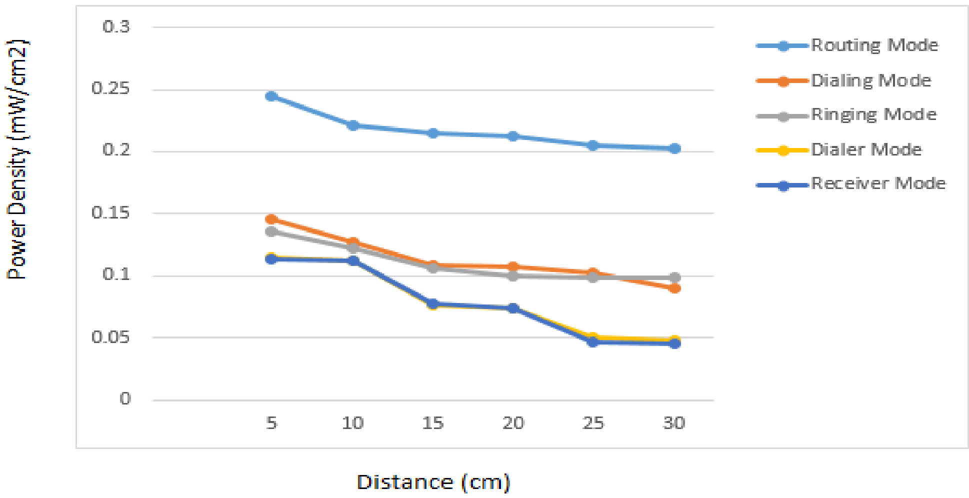

Figure 2. The radiation level of Techno X2 during different operational techniques (modes)

It shows in Figure 2 that during routing mode, the EM radiation was very high. With an increase in distance, the radiation from Techno X2 decreases, but the radiation level during routing techniques is greater than that of other operational techniques as the distance between the mobile brand and the user increases.

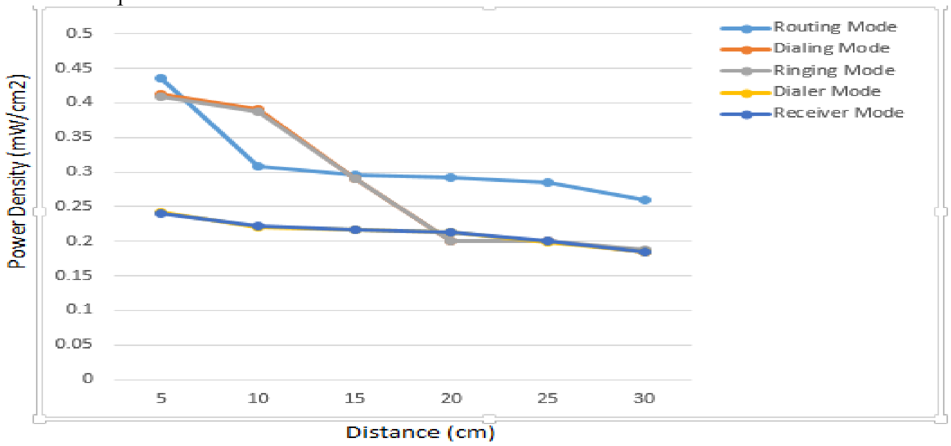

Figure 3. The radiation level of Samsung A14 during different operational techniques (modes)

In Figure 3, during routing for connection, the EM radiation was at a high level, and with an increase in distance, it was very low. With further increase in distance, all operational techniques (modes) were maintaining the same level of radiation except routing mode.

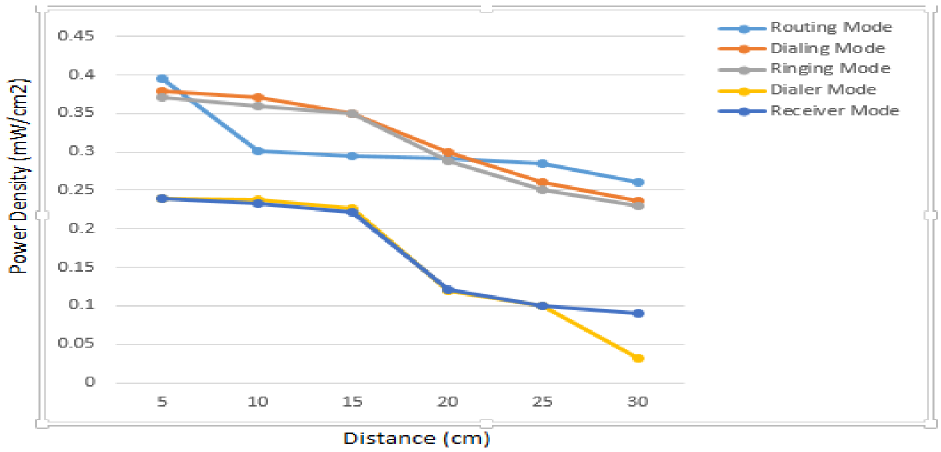

Figure 4. The radiation level of Huawei G8P during different operational techniques (modes)

Throughout routing, ringing, and dialing techniques, the radiation levels were the same and decreased with distance, but during dialer and receiver techniques, the quantities of radiation were at a lower level and rapidly decreased with distance, as shown in Figure 4.

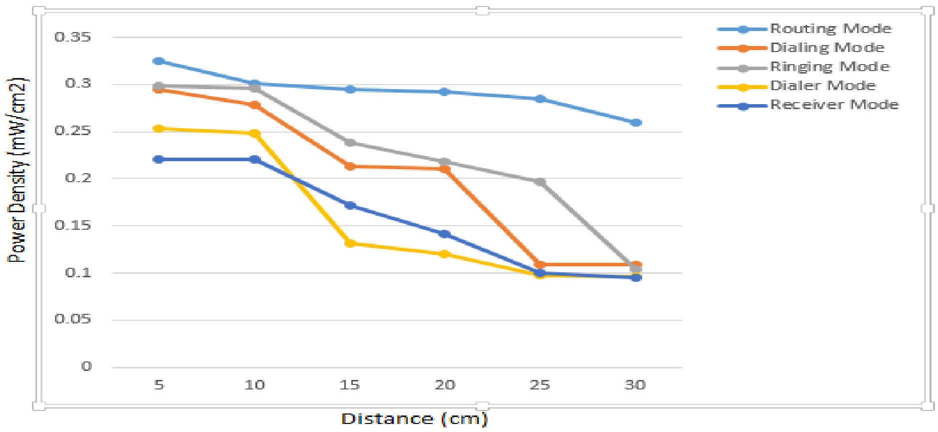

Figure 5. The radiation level of Itel P38 during different operational techniques (modes)

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Referring to the connection routing in Figure 5, the radiation level is high, but during dialing, ringing, dialer, and receiver modes, the radiation levels were low and of different levels up to 25 cm distance from the user, but the same radiation levels when the distance increased to 30 cm.

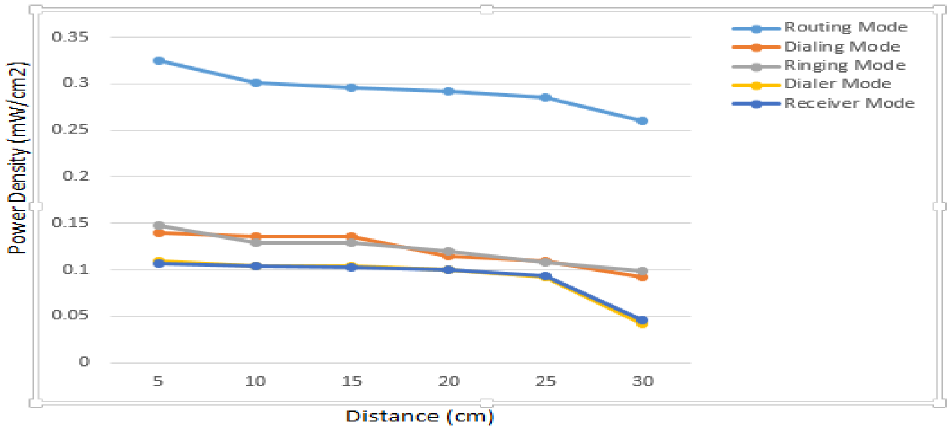

Figure 6. The radiation level of Infinix 6 during different operational techniques (modes)

Figure 6 displays that during routing for connection, the radiation quantities of Infinix 6 were greater than those of other operational techniques, though decrease as the distance increased. Receiver and dialer modes were at the same level, lower than ringing and dialing modes, which were also at the same radiation level.

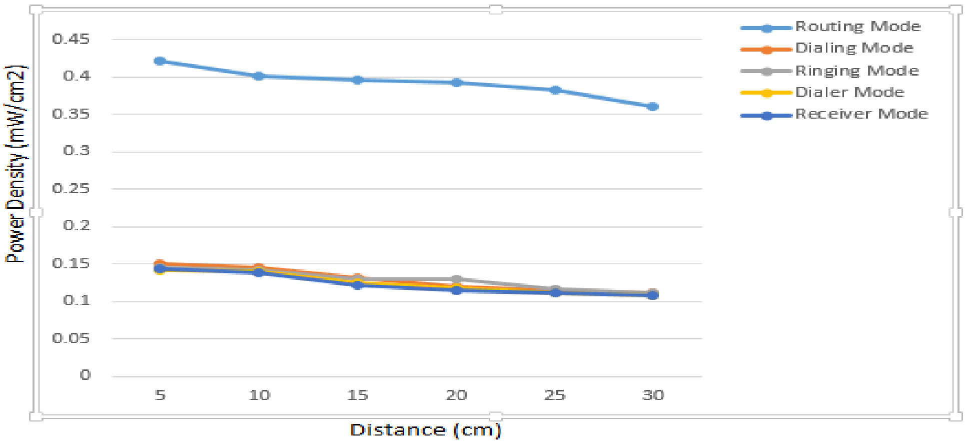

Figure 7. The radiation level of Gionee F20 during different operational techniques (modes)

During routing for connection in Figure 7, the radiation was at a high level compared to other modes of operation at all distances between the mobile brand and the user. With an increase in distance from Gionee F20, the radiation levels were the same in all modes except during routing mode.

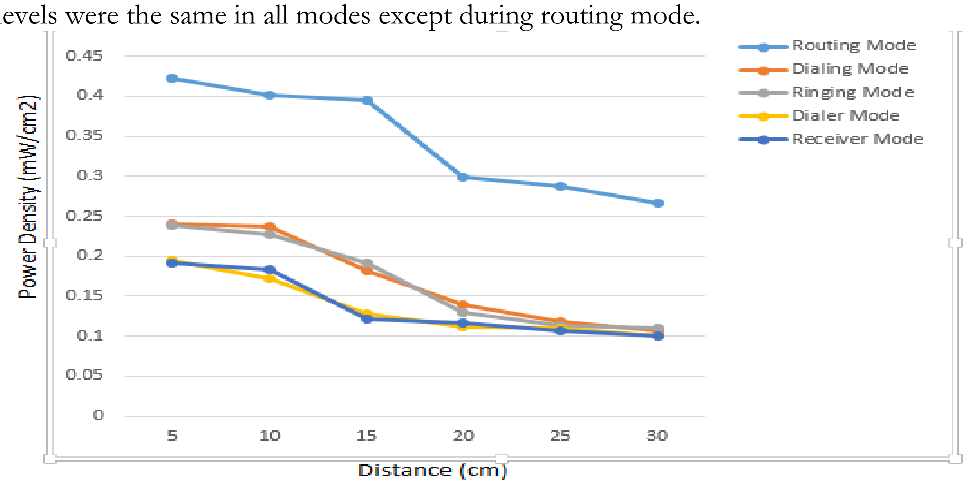

Figure 8. The radiation level of Oppo A77 during different operational techniques (modes)

From Figure 8, routing mode at all distances was greater compared to other operational techniques, though decrease with increasing distance from Oppo A77. The radiation levels for dialing, ringing, dialer, and receiver modes were the same as distance increased from the mobile transceiver brand.

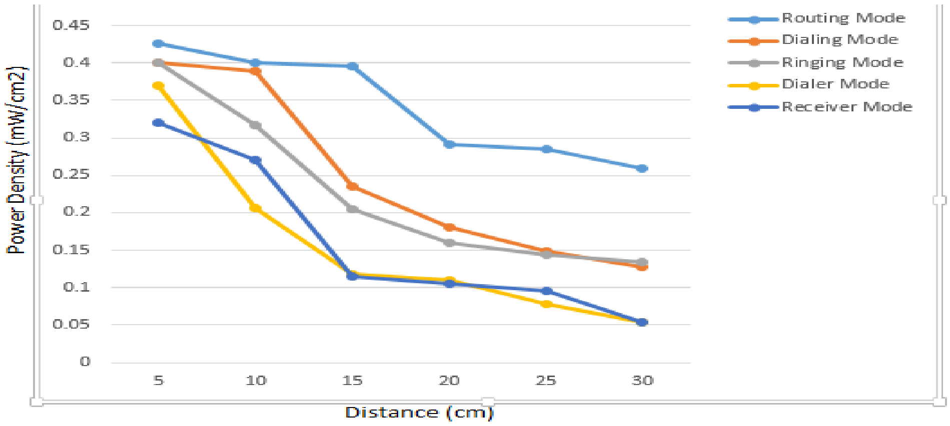

Figure 9. The radiation level of Vivo Y17 during different operational techniques (modes)

It shows in Figure 9 that during routing for connection, the radiation level was high at all distance compare to other operational techniques. As distance increases from Vivo Y17, the radiation levels during dialing and ringing modes were the same, while dialer and receiver modes were also the same, especially at 30 cm intervals.

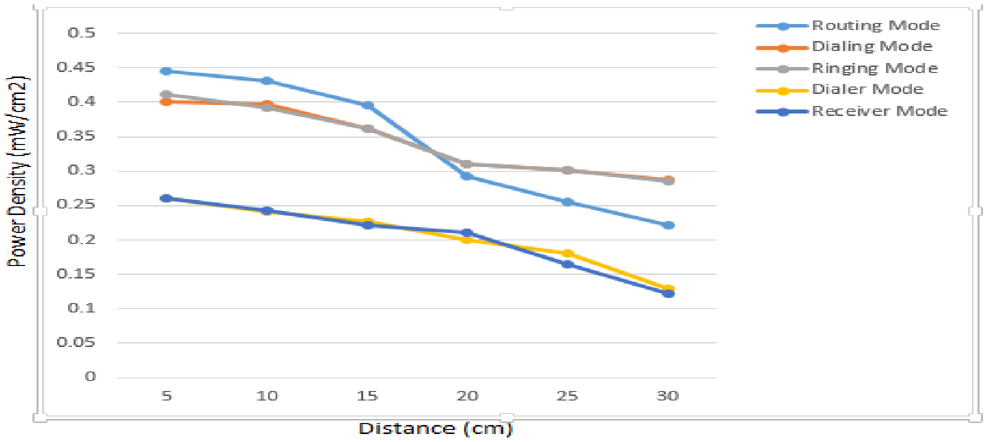

Figure 10. The radiation level of Apple iPhone 12 during different operational techniques (modes)

Figure 10 shows that, as the distance from the mobile transceiver increases, receiver and dialer modes were at equal levels. Routing mode was at a greater level than dialer and receiver modes but lower than dialing mode. During routing for connection, the radiation level was high between intervals of 5 cm up to 15 cm from the iPhone 12 but reduced drastically between 15 cm and 20 cm; from 20 cm upward, the radiation during routing mode was lower than the ringing and dialing techniques. At all distances, the radiation levels during dialer and receiver modes were the same and very low.

Generally, Figures 1 to 10 present five-line graphs exemplifying the relationship between distance and power density for different operational techniques from all mobile transceivers used. Each line graph represents a distinct mode with power density measured in milliwatts per square centimeter (mW/cm^2), plotted against distance.

Mostly, the results revealed in Figures 1 to 10 discovered the existence of diverse quantities of EMR from all the portable transceivers at different operational techniques. It is evidently seen that the power concentration and the EM radiation engrossed the user reduce with an increase in distance between the transceiver and the users. It is pragmatic that radiation intensity absorption by the mobile network user is very high during routing mode, but very low during dialing, ringing, dialer, and receiver modes.

The concentration of emission from several transceivers during routing mode (call establishment) was higher than when call conversation (dialer and receiver modes) was on at both ends, as made known in Figures 1 to 10. However, the radiation was very high (VH) when seeking a connection (routing mode); the result confirms that there is electromagnetic radiation reduction when mobile transceiver users were making conversation at both ends (dialer and receiver modes). The results also show the radiation levels of mobile transceivers in diverse modes of operation. It was observed that the quantities of EMR were far greater during transceivers' seeking activation

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(before ringing at both ends). It was also shown during conversation that the transceiver users will be exposed to a small amount of electromagnetic radiation.

3.2 Discussion of the Results

The obtained results in Figures 1 to 10 discovered the existence of diverse quantities of EMR from entirely designated transceiver brands with different operational techniques (models) at different intervals between mobile transceivers and the users. The quantities of power emission around the users diminish with the increase in distance between the transceiver and the users. It can also be detected that the quantities of EMR attained in the form of power density decreased as the mobile transceiver kept a distance from the Radiofrequency Meter at every single interval of 5 cm. It was likewise observed that radiation intensity absorption of transceiver users is greater when seeking for call at the sending end (Driving mode), high when establishment of the call at both ends, but low during call conversation at both ends. 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 results also shown the quantities of radiation of portable transceivers at diverse operational techniques were not the same. This demonstrates that when connecting to the tower, the power of the portable transceiver will be high. It was established that the amount of EMR was far higher when the transceivers were seeking connection. It also shows that when a call conversation is on, it exposes mobile network users to small quantities of EMR.

4.0 Conclusion

4.1 Conclusion

Reduction of EMR in ultra-dense network areas using EM radiation emanating from particular portable transceivers used in Nigeria is the major objective of this research. Hundreds of such telephones have been imported into the country and are being used by the generality of the country's population, from young and old, literates and illiterates alike, and have generally exposed mobile network users to EM Radiation. There are international standards stipulated for the highest levels of radiation to avoid too much engrossment of EMR on the user. Two major standards are the Federal Communications Commission (FCC), USA, which stipulates $0.60 mW/cm^2$ and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) that stipulates $0.45 mW/cm^2$. The levels of radiation from portable/mobile transceivers considered were established to be affected by: the distance from the mobile transceiver; the higher the distance from the mobile transceiver, the lower the EMR received by the users; and the operational techniques (mode of operations) of the mobile transceiver. Generally, the attained results revealed that any mobile transceiver users who did not elongate time before picking calls are liable to be opened to greater quantities of electromagnetic radiation levels.

4.2 Recommendations

Power density generated by the transceiver is greater when placing the mobile transceiver at a 5 cm distance from the users than at 30 cm, and it is also high during seeking for call, especially during driving mode; therefore, it is recommended that we keep the mobile transceiver farther away from the ear, especially during call-seeking modes, than during call conversation modes.

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