Asian Journal of Current Research

Volume 9, Issue 4, Page 51-59, 2024; Article no.AJOCR.12402
ISSN: 2456-804X

Assessment of Radio Frequency Electromagnetic Field Exposure from Wi-Fi Routers in LAUTECH Campus, Ogbomoso, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.56557/ajocr/2024/v9i48871

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.ikprress.org/review-history/12402

Original Research Article

Received: 20/07/2024
Accepted: 23/09/2024
Published: 28/09/2024

ABSTRACT

Wi-Fi routers play a crucial role in enabling internet connectivity within the academic environment. However, there are concerns that radiofrequency electromagnetic field exposure from Wi-Fi routers may be hazardous to human health. The main objective of the research is to assess the safety of

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Cite as: *O. O., Oladapo, Oni E. A., Aremu A. A., Olive-Adelodun A. O., Lawal M. K., Ayanlola P. S., and Lawal S. T. 2024. "Assessment of Radio Frequency Electromagnetic Field Exposure from Wi-Fi Routers in LAUTECH Campus, Ogbomoso, Nigeria". Asian Journal of Current Research 9 (4):51-59. https://doi.org/10.56557/ajocr/2024/v9i48871.*

RF-EMF exposure in educational environments. A total of 14 Wi-Fi routers were randomly selected and investigated across LAUTECH campus using stratified random sampling method. Measurement of the power density and the electric field strength from these routers were taken using a hand-held electrosmog, TES-593, radiofrequency meter. Measurement points were selected at various distances of 1.0, 2.0, 3.0, 4.0 and 5.0 m from the Wi-Fi routers, representing typical distances between users and routers. At each measurement point, the TES-593 meter was held 1 m above the ground at a fixed position for 30 seconds to record the E-field strength and the power density. The measured power density and the electric field strength, varied from routers to routers depending on their location and the distance of measurement from the routers. The power density recorded for all the Wi-Fi routers investigated ranged from 0.001 to 3.302 W/m^2 with a mean of 0.390 W/m^2. For all the Wi-Fi routers investigated. The overall exposure levels for the power density decreases with distances for all the routers. The measured electric field strength also decreases with distance ranging from 0.106 to 3.528 V/m with a mean of 0.981 V/m. The measured power densities and the electric field strengths in this research work were comparable and similar with reports from other research work from different environments including educational, residential, and urban settings. The power densities and the electric field strengths recorded were below the 10 W/m^2 and 5 V/m recommended by various regulatory agencies respectively. All the Wi-Fi routers considered in this research work were within safety guidelines set by regulatory agencies for the power density and the electric field strength, thus emitting radiations at a level that are considered safe for human exposure within the academic communities. The operation of RF-EMF exposure from Wi-Fi routers in the academic environment of LAUTECH will no pose any potential health risks on staff and students of the institution. The evidence-based insights into potential health risks associated with prolonged exposure to electromagnetic fields from Wi-Fi routers in this research can guide policymakers in establishing safety regulations that will limit exposure levels. It can also inform guidelines on the optimal placement of routers, frequency of usage, and the implementation of periodic monitoring to ensure compliance with international safety standards.

Keywords: EMF radiofrequency; Wi-Fi routers; power density; electric field strength; LAUTECH.

1. INTRODUCTION

Wireless Fidelity (Wi-Fi) routers are the unnoticed heroes of our connected world, serving as the central hub that brings together a vast array of devices and facilitates seamless communication between them. These marvels of technology convert data from our devices into radio waves, transmitting them through integrated antennas to create a robust and reliable network. To minimize interference, Wi-Fi routers operate on specific channels within designated frequency bands, such as 2.4 GHz and 5 GHz. Devices connect to the router by identifying its unique Service Set Identifier (SSID), and can be secured with robust encryption methods like Wi-Fi Protected Access 2 (WPA2) or Wi-Fi Protected Access 3 (WPA3). As the nerve center of our digital lives, routers expertly manage data traffic, assign IP addresses to connected devices, and provide Quality of Service (QoS) to ensure that critical applications receive the priority they need, making them an indispensable component of our modern connectivity landscape.

In this modern era of widespread connectivity, wireless networks have become an indispensable part of our daily lives. The proliferation of Wi-Fi routers in homes, offices, and public spaces has enabled seamless internet access and transformed the way we communicate, work, and interact [1]. However, this convenience comes with a hidden cost - the exposure to radio frequency electromagnetic radiation (RF-EMR). As the world grapples with the increasing demand for wireless connectivity, concerns about the potential health risks associated with RF-EMR from Wi-Fi routers have grown. The scientific community has long debated the impact of RF-EMR on human health, with some studies suggesting possible links to cancer, neurological damage, and reproductive issues [2,3]. Since Wi-Fi emits radiofrequency electromagnetic fields, which can be absorbed by the body, several scientist have carried out researches to see whether there are links between radiofrequency electromagnetic fields from Wi-Fi enabled devices and the incidence of cancer, neurological effects, reproductive issues and cardiac issues among others [4-6].

Regulatory agencies like the Federal Communications Commission (FCC), Institute of Electrical and Electronics Engineers (IEEE), and International Commission on Non-Ionizing Radiation Protection (ICNIRP) play a crucial role in ensuring the safe operation of Wi-Fi technology and protecting public health. These agencies establish and enforce safety regulations and standards for exposure to radiofrequency (RF) radiation, which is emitted by Wi-Fi devices. The FCC, for example, sets safety limits for RF exposure in the United States, based on extensive scientific research and consideration of potential health risks. These limits are outlined in the FCC's guidelines for human exposure to RF energy, which cover various frequency ranges, including those used by Wi-Fi devices. Similarly, IEEE develops standards for RF safety, including the IEEE C95.1 standard for RF exposure limits. ICNIRP also provides guidelines for RF exposure limits, which are widely adopted by regulatory agencies around the world. These three regulatory agencies have set a reference power density level of 50 W/m^2 and 10 W/m^2 for occupational and general public exposure scenario respectively [7-9].

Compliance with these regulations and standards is mandatory for manufacturers of Wi-Fi equipment. To legally sell and operate their products, manufacturers must ensure that their devices meet the established safety limits and guidelines. This includes conducting tests and measurements to determine the specific absorption rate (SAR) of their devices, which measures the amount of RF energy absorbed by the body when using the device. Regulatory agencies also provide guidelines for safe installation and operation of Wi-Fi devices, such as recommending minimum distances between devices and the human body. Additionally, they may require manufacturers to provide warning labels or instructions for safe use. By enforcing safety regulations and standards, regulatory agencies like the FCC, IEEE, and ICNIRP help ensure that Wi-Fi technology is used safely and without harm to public health.

In Nigeria, the rapid expansion of wireless networks has outpaced efforts to assess and mitigate the potential risks associated with RF-EMR exposure. Universities, in particular, have become hubs for wireless connectivity, with multiple Wi-Fi routers installed across campuses to support academic and research activities. Against this backdrop, this study aims to investigate the levels of RF-EMR emitted by Wi-Fi routers on the LAUTECH campus in Ogbomoso, Nigeria. Using measurement and simulation technique, this research seeks to assess the exposure levels of students and staff of the university to RF-EMR from Wi-Fi routers and evaluate the potential health risks associated with prolonged exposure.

By exploring the RF-EMR emissions from Wi-Fi routers in a real-world setting, this study contributes to the ongoing debate about the safety of wireless networks and provides valuable insights for policymakers, regulators, and the general public. This research contributes to achievement of Sustainable Development Goal of Good Health and Well-being (SDG 3) by exploring the health effect of EMF radiation from Wi-Fi routers within LAUTECH campus. The findings of this research will help inform evidence-based decisions about the installation and use of Wi-Fi routers in academic environments, ultimately promoting a safer and healthier learning and working environment for all.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is the Ladoke Akintola University of Technology (LAUTECH), located in Ogbomoso, Oyo State, Nigeria. LAUTECH is situated in the heart of Ogbomoso, approximately 10 kilometers north of the city center. The university lies between longitude 4°15'E and 4°20'E, and latitude 8°10'N and 8°15'N. The university campus spans over 400 hectares of land, with a mix of academic, administrative, and residential buildings. The campus is surrounded by a residential area to the north, a forest reserve to the east, and agricultural land to the west and south.

LAUTECH has a comprehensive Wi-Fi network that covers the entire campus, providing internet access to students, staff, and faculties. The network consists of multiple Wi-Fi routers and access points installed in various locations, including offices, libraries and departments. LAUTECH is an ideal study area for this research due to the university's reliance on Wi-Fi for academic and administrative purposes which ensures a high level of exposure to radiofrequency electromagnetic radiation (RF-EMR). Also, the campus hosts a diverse population of students and staff of the university from various age groups, genders, and backgrounds, providing a representative sample

for the study. Furthermore, the university campus offers a controlled environment to assess the levels of RF-EMR from Wi-Fi routers, minimizing external interference. LAUTECH Ogbomoso, allows for proximity to Wi-Fi routers, enabling accurate measurements of RF-EMR levels. LAUTECH provides an ideal setting for this research, offering a unique opportunity to investigate RF-EMR levels from Wi-Fi routers in a real-world academic environment.

2.2 Sampling and Sample Selection

To ensure a representative sample, 14 Wi-Fi routers were randomly selected and investigated across the campus. A stratified random sampling method was employed to select the 14 Wi-Fi routers. The campus was divided into strata based on the location and type of router. The required number of routers from each stratum was selected randomly based on a sampling frame which consist of a list of all Wi-Fi routers on campus, including their location and type. This list was obtained from the university's ITC center. Upon selection of the 14 Wi-Fi routers, data on the RF-EMR levels emitted were collected for each router.

2.3 Measurement of Power Density and Electric Field Strength

The measurement of RF-EMR levels emitted by Wi-Fi routers was employed using the TES-593 Electrosmog RF meter. The TES-593 meter was set to measure frequencies between 10 MHz and 8 GHz, covering the 2.4 GHz and 5 GHz frequency bands used by Wi-Fi routers. The TES-593 Electrosmog RF meter was calibrated before the measurement process in accordance with the IEC 62209-2 standardized calibration procedure. Since the TES-593 does not have built-in filtering for specific frequency bands, the device was calibrated to focus on the 2.4 GHz and 5 GHz frequencies. The measurement area was cleared of unnecessary electronic devices to minimize interference.

The TES-593, RF meter was set to the “Power Density” mode to measure in unit of Watt per centimeter square (W/cm^2) and later converted to Watt per meter square (W/m^2). For the electric field strength measurement, the TES-593, RF meter was set to “Electric Field” mode to measure in unit of Volt per meter (V/m). Measurement points were selected at various distances (1.0, 2.0, 3.0, 4.0 and 5.0 m) from the Wi-Fi routers, representing typical distances between users and routers. Measurement was taken at a height of 1 m above the ground with the probe facing downward. At each measurement point, the TES-593 meter was held at a fixed position for 30 seconds to record the power density and the electric field strength. Three consecutive readings were taken at each point, and the average value was calculated and recorded.

Plate 1. Picture of an Electrosmog RF meter

3. RESULTS AND DISCUSSION

Table 1. The Measured Power Density and the Measured Electric Field Strength for Varying Distances from the Wi-Fi Routers

Distance (m)	Measured Power density in (W/m^2)	Measured Electric Field Strength (V/m)
ROUTER 1		
1.0	1.267	2.186
2.0	1.142	2.075
3.0	0.470	1.311
4.0	0.308	1.078
5.0	0.414	1.249
ROUTER 2		
1.0	2.756	3.223
2.0	0.770	1.704

Distance (m)	Measured Power density in (W/m²)	Measured Electric Field Strength (V/m)
3.0	0.526	1.408
4.0	0.368	1.179
5.0	0.282	1.031
ROUTER 3		
1.0	1.028	1.969
2.0	0.458	1.314
3.0	0.144	0.37
4.0	0.157	0.769
5.0	0.128	0.695
ROUTER 4		
1.0	1.203	2.13
2.0	0.523	1.404
3.0	0.167	0.794
4.0	0.224	0.919
5.0	0.168	0.796
ROUTER 5		
1.0	1.472	0.745
2.0	0.94	1.882
3.0	0.209	0.887
4.0	0.320	1.098
5.0	0.179	0.821
ROUTER 6		
1.0	0.118	0.667
2.0	0.060	0.476
3.0	0.024	0.300
4.0	0.125	0.687
5.0	0.001	1.942
ROUTER 7		
1.0	0.057	1.797
2.0	0.400	1.228
3.0	0.137	0.791
4.0	0.127	0.692
5.0	0.044	1.288
ROUTER 8		
1.0	3.302	3.528
2.0	2.459	0.963
3.0	0.201	0.870
4.0	0.617	1.525
5.0	0.128	0.695
ROUTER 9		
1.0	0.166	0.791
2.0	0.292	1.049
3.0	0.299	1.062
4.0	0.553	1.444
5.0	0.033	0.353
ROUTER 10		
1.0	0.085	0.566
2.0	0.074	0.528
3.0	0.036	0.368
4.0	0.086	0.569
5.0	0.052	0.443
ROUTER 11		
1.0	0.095	0.598
2.0	0.047	0.421
3.0	0.029	0.331

Distance (m)	Measured Power density in (W/m²)	Measured Electric Field Strength (V/m)
4.0	0.010	0.194
5.0	0.073	0.525
ROUTER 12		
1.0	0.049	0.43
2.0	0.033	0.106
3.0	0.041	0.393
4.0	0.053	0.447
5.0	0.027	0.319
ROUTER 13		
1.0	0.197	0.862
2.0	0.174	0.809
3.0	0.057	0.464
4.0	0.085	0.566
5.0	0.020	0.275
ROUTER 14		
1.0	0.498	1.370
2.0	0.159	0.774
3.0	0.131	0.703
4.0	0.056	0.459
5.0	0.345	0.846
Mean	**0.390**	**0.981**

3.1 Power Density

The results of the power density from the 14 Wi-Fi routers within the LAUTECH campus show a consistent trend across all routers. As the distance from the router increases, there is a general decrease in power density. This behavior aligns with the inverse-square law, which predicts that the intensity of electromagnetic waves decreases with the square of the distance from the source. Specifically, the measurements from 14 different Wi-Fi routers, taken at distances of 1 m, 2 m, 3 m, 4 m, and 5 m from the routers, showed a clear reduction in power density as the distance increased. The power density values, measured demonstrate variability depending on the router and the distance measured.

For Router 1**,** the power density is 1.267 W/m² at a distance of 1 meter, which decreases to 0.414 W/m² at 5 meters. This router shows a more consistent decrease in power density with distance compared to others, although the 5-meter value is slightly higher than at 4 meters. Router 8 exhibits the highest initial power density of 3.302 W/m² at 1 meter. The power density decreases sharply to 0.128 W/m² at 5 meters, indicating a significant drop in exposure as one moves away from the router. Router 5 shows an interesting pattern where the power density at 4 meters (0.320 W/m²) is higher than at 3 meter (0.209 W/m²). This anomaly could be due to specific environmental factors such as interference from other EMF devices. Router 12 has the lowest power density values across all distances, with a maximum of 0.049 W/m² at 1 meter. This suggests that the router might be a low-power model or is situated in an environment with significant attenuation. The mean power density across all routers and distances is approximately 0.390 W/m². This averages suggest that while there is variability between different routers and their locations, the overall exposure levels decrease predictably with distance. All the power densities measured for all Wi-Fi Routers at varying distances investigated in this research work all lie below the permissible power density level of 10 mW/m² recommended various agencies [7-9] for the general public. The result of the power density levels from these Wi-Fi routers were all within safety guidelines set by these regulatory agencies and the radiation emanating from these routers are considered safe for human health.

Similar studies conducted in various settings over the last years corroborate these findings. For instance, a study by Alzahrani et al., [10] investigated the power density of Wi-Fi routers in university campuses and found a marked decrease in RF-EMF exposure as the distance from the router increased. The study observed that power density values dropped significantly beyond 2 meters, aligning with the results from this study within LAUTECH campus. This supports the notion that proximity to Wi-Fi routers is a critical factor in determining exposure levels.

Kurnaz et al., [11] focused on residential settings, where RF-EMF exposure from Wi-Fi routers were measured at various distances. The findings indicated that at a distance of 1 meter, the power density was considerably higher than at 4 meters, with a reduction rate that closely matches the pattern observed in this study. This suggests that the trend of decreasing power density with distance is consistent across different environments, whether academic or residential. A more recent investigation by Margaritis et al., [12] extended the analysis to public spaces, such as libraries and cafes, where Wi-Fi routers are often installed. The study noted that at 1 meter from the router, the power density was within safety limits but still higher than the values recorded at 3 and 5 meters. This reinforces the findings at LAUTECH, where the exposure levels decreased progressively with increased distance, suggesting that the general public in these environments is less exposed to potentially harmful RF-EMF levels as they move away from the source. These comparisons with other research works highlight a consistent pattern in RF-EMF exposure levels from Wi-Fi routers across different environments. While the specific values of power density might vary depending on factors like router model, environmental conditions, and the presence of physical obstructions, the underlying trend remains the same.

3.2 Electric Field Strength

The electric field strength measured in this work also decreases with distance, though not always as consistently as the power density. The electric field strength (E-field) measured for Wi-Fi routers within LAUTECH campus ranged from 0.106 V/m to 3.528 V/m at varying distances from the routers. For example, Router 10 shows a slight increase in electric field strength from 3 meters (0.368 V/m) to 4 meters (0.569 V/m), which may be due to environmental reflections or other factors. For Router 8 at 1 meter, the electric field strength is 3.528 V/m, the highest recorded among all routers. This value decreases sharply to 0.695 V/m at 5 meters, indicating a significant reduction in potential RF exposure as one moves away from the router. All the electric field strength measured in this work for all the varying distances all lie below the 5 V/m recommended by the Federal Communications Commission, Institute of Electrical and Electronics Engineers and International Commission on Non-Ionizing Radiation Protection [7-9] indicating that the emissions from these routers are within safety guidelines.

In a study conducted by Amoako et al., [13] in a university setting in Ghana which measured electric field strengths around Wi-Fi routers in lecture halls and offices reported E-field strengths ranging from 0.2 V/m to 3.0 V/m at distances of 1 to 5 meters. These values are quite similar to those observed in the current study, with the highest recorded E-field strength of 3.528 V/m falling within the range observed by Amoako *et al.* This indicates comparable levels of RF exposure in similar educational environments. The E-field strengths reported by Tomitsch et al., [14] who assessed RF exposure in public libraries across several European cities ranged from 0.1 V/m to 2.7 V/m, with higher values typically observed closer to the Wi-Fi routers. The results from the LAUTECH campus, particularly the maximum E-field strength of 3.528 V/m, are slightly higher than the maximum observed in the library settings. This could be due to differences in router power, environmental factors, or measurement techniques. In residential and office environments in Malaysia, Ibrahim et al., [15] reported E-field strengths from Wi-Fi routers between 0.05 V/m and 2.5 V/m at similar distances. The slightly lower maximum value compared to the current study might be attributed to the power output of the routers used in the study. Nevertheless, the general trend of decreasing E-field strength with distance observed in the LAUTECH study is consistent with their findings. A study by Wang et al., [16] in an urban environment in China found E-field strengths ranging from 0.3 V/m to 3.8 V/m, with the highest values recorded near high-power routers in densely populated areas. The E-field strengths observed in this current work fall within this range, particularly the peak value of 3.528 V/m, suggesting that the exposure levels at LAUTECH are comparable to those in urban settings with more powerful routers and higher network demands. In a study focused on RF exposure in schools, Martinez-Ballesta et al., [17] recorded E-field strengths between 0.08 V/m and 2.9 V/m, depending on the proximity to Wi-Fi routers and the number of connected devices. The E-field strength in the LAUTECH study, especially at 1 meter from the routers, aligns closely with these findings, reinforcing the notion that educational environments typically exhibit similar RF exposure levels.

3.3 Statistical Analysis

The correlation analysis conducted between the power density readings (W/m^2) and the electric field strength (V/m) resulted in a correlation coefficient (*r*) of 0.77. This indicates a strong positive relationship between the two variables. Specifically, a correlation of 0.77 suggests that as the power density increases, the electric field strength also tends to increase in a fairly consistent manner. While the correlation is not perfect (with 1.0 representing a perfect positive correlation), the result implies a significant association between the two variables, suggesting that variations in power density are strongly related to variations in electric field strength in the context of this study.

4. CONCLUSION

The assessment of power density and electric field strength exposure from 14 Wi-Fi Routers at various distances was carried out within LAUTECH Campus, Ogbomoso using a hand-held electrosmog RF meter. The power density measured for all the Wi-Fi routers investigated ranged from 0.001 to 3.302 W/m^2 with a mean of 0.390 W/m^2. Although the measured power density revealed variability between different routers and their locations, the overall exposure levels decreases predictably with distances. The measured electric field strength also decreases with distance ranging from 0.106 to 3.528 V/m with a mean of 0.981 V/m. The decrease is not as consistence as that of the power density. The measured power densities and the electric field strengths in this research work were comparable and similar with reports in various studies over the years, spanning different environments including educational, residential, and urban settings. The power densities and the electric field strengths recorded were below the 10 W/m^2 and 5 V/m respectively recommended by various regulatory agencies. The study provides valuable insights into the RF-EMF exposure levels from Wi-Fi routers in an academic setting. While the exposure levels are generally within safe limits, the variability between different routers highlights the importance of careful placement and regular monitoring to ensure that exposure remains as low as possible, particularly in densely populated areas of the campus. These findings should inform future policies on the installation and use of Wi-Fi routers in educational institutions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://prh.ikprress.org/review-history/12402