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QUANTITATIVE ASSESSMENT OF HARVESTABLE AMBIENT ELECTROMAGNETIC ENERGY: A CASE STUDY OF ABEOKUTA, SOUTH-WESTERN NIGERIA

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Abstract

Devices like wireless LAN, routers, TV and radio sets, and mobile phones used for the exchange of information are all sources of electromagnetic energy. This paper provides an insight into the level of power that is harvestable from the environment where these devices are located. Within the study area, measurement of available daily electromagnetic energy was randomly performed in selected locations at about 0-30 cm distance from the devices for a period of six months, covering both wet and dry seasons. Since mobile phone usage, requirements, and strength of electromagnetic field vary with location, the resultant ambient energy arising from electromagnetic sources is expected to be time and location dependent. To achieve a fair comparison, measurements were taken between 9 am and 5 pm at different points in the selected areas. The ambient electromagnetic energy was measured using a Wave control SMP2 Field meter with a WPF8 isotropic electromagnetic field probe in the 100 kHz–8 GHz range. The results of the field measurements revealed that all the selected devices are potential sources of electromagnetic energy, with the telecoms base station antenna being the most viable source of free electromagnetic energy that could be harnessed for various applications.

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1. INTRODUCTION

In 1820, Hans Christian Oersted discovered that electricity generates magnetism, and in 1831, Michael Faraday discovered that magnetism generates electricity [1]. Several years later, James Clerk Maxwell unified these discoveries into four formidable, self-consistent differential equations, which laid the foundation for the existence of electromagnetic waves by introducing displacement current and consequently, wireless communication. Technological advancements in wireless communication technology have increased the number of wireless devices: smart meters, Wi-Fi routers, radio and TV transmitters, and cell phones, all of which radiate free electromagnetic energy into the air space [2, 3]. These wireless devices that radiate electromagnetic energy can be categorized based on the intended application namely: intentional electromagnetic (EM) sources and non-intentional / ambient sources. Intentional EM sources occur when a wireless device is deployed primarily to radiate an EM signal for energy transfer to a specified network [4].

The EM energy produced is controllable and can be predicted based on the manufacturer's specifications. For instance, several transmitters have been deployed by the Power caster Company for this purpose. At short distance ranges, a small amount of energy (microwatts range) is harvestable from a conventional Wi-Fi router transmitting at 50-100 mW [5]. The limitation is that the amount of EM energy from such devices must be within the absorption rate for human consumption and must conform to the Federal Communication Commission (FCC) standards for health and safety reasons, thereby limiting the amount of energy harvestable from such devices [6]. Ambient EM sources are ubiquitous, uncontrolled free EM energy emitted by different wireless devices. Mobile devices, telecommunication base stations, TV and radio broadcasting masts, and power transmission lines are typical examples [7, 8]. Based on the expected amount of energy harvestable from such devices, this can be further sub-classified into two groups: static and dynamic sources. Static type devices produce relatively predictable amounts of EM energy over a period of time, for example; radio and TV transmitters. Wireless devices that are used periodically and freely radiate unlimited amounts of EM energy into the environment are dynamic devices. Examples include wireless mobile phones, Bluetooth devices, and routers.

Based on these classifications, it is evident that the ambient environment houses a large quantum of EM energy that could be harvested and used for various applications [9]. To estimate the available EM energy in the ambient environment, several efforts have been made by various investigators, including the use of spectrum analysers and personal explosimeters [10, 11] under general conditions. The exact location where measurements were taken was not indicated, and the time of measurement was absent in the report, thereby making the result unsuitable for some applications. For health-related use, a health and risk assessment of exposure to EM radiation in the Terrassa region of Spain has been carried out [12] for available RF signals within the broadband frequency of up to 18 GHz. Since the focus of the study is the characterization of the public exposure level to electric field, the effect of the distance between the signal sources and the location of measurement was not considered.

In [13], an RF survey in about 270 underground stations in London for signals within 0.3-3 GHz frequency range was conducted. The work reveals that Digital Television (DTV), GSM 900, GSM 1800, and 3G are all viable sources of EM energy and are location and time dependent. However, with the recent spike in the use of digital technology during and after the COVID-19 pandemic giving rise to the use of wireless equipment and devices and more energy requirements for 4G, 5G (and 6G in some countries) networks, it is imperative to investigate and quantify the available EM energy in the ambient environment. This includes adequate consideration of the distance from the energy source to the measurement location, as postulated in the Friis transmission equation. As such, the effects of path loss, fading, and shadowing would be drastically reduced in the measured RF value.

2. MATERIALS AND METHODS

This section describes the study area and the method adopted in conducting the study.

2.1. Overview of the Study Area

The study area is located in Abeokuta, Ogun State in the southwestern part of Nigeria. It is an urban area with a population of over 500,000 people and a land size of 879 km2. The test points are carefully chosen within the study area and are classified into three groups:

i. University environment.

ii. A hub of the base transceiver station (BTS) site.

iii. Commercial (market) area.

The first category, a university environment, is the Federal University of Agriculture, Abeokuta, Nigeria. It is situated on 10,000 hectares of land within rural communities with about 20,000 population, comprising both students and staff. What informed our choice of the test points, labelled P1-P6 in Figure 1, is the presence of enormous wireless devices and users at this location, which houses three University faculties, a library with good internet facilities, several Wi-Fi transmission devices, and nearness to four telecommunication base transceiver station sites.

The second class of test points marked T1-T3 in Figure 1 are the transceiver antennas located on the BTS sites of three major mobile telecommunication service providers in Nigeria (MTN, Airtel and Globacom). Measurements were taken on the multi-sectoral antennas used for Global System for Mobile Telecommunication (GSM), Worldwide Interoperability for Microwave access (WiMAX), Universal Mobile Telecommunication System (UMTS), 4G and 5G (where available), and microwave links (diameter range of 0.6 - 1.5 m) at about 2-30 cm from their positions on the towers, as depicted in Figure 2. T1 are antennas used for 3G and 4G networks, T2 are dishes for microwave links, and T3 are antennas for 5G networks.

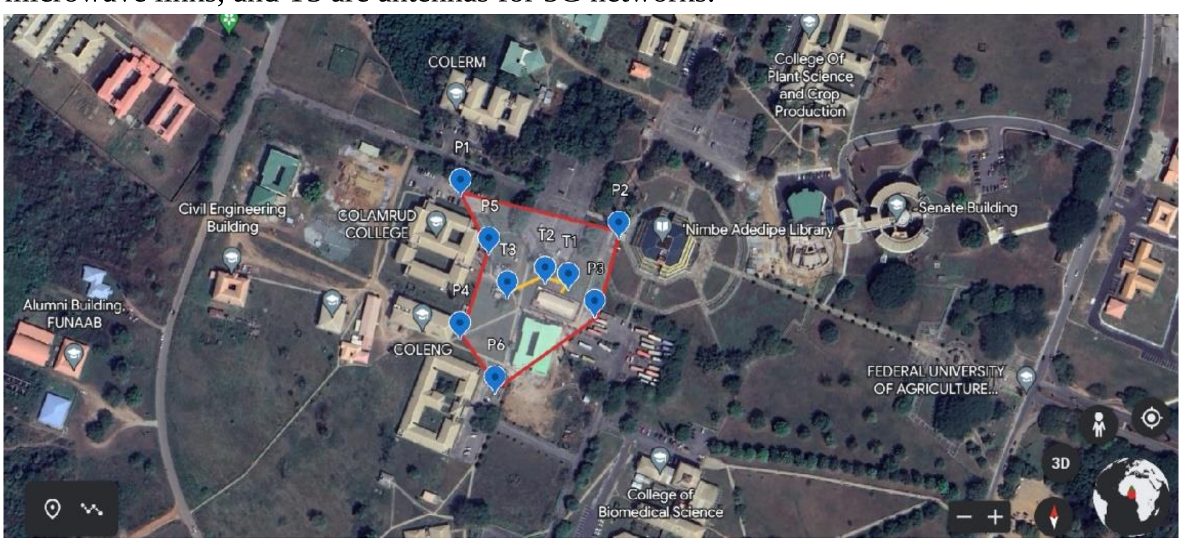

Figure 1. A view of the academic environment for EM energy harvesting (Google Earth, 2023)

The third category is a hub of commercial activities comprising banks, restaurants, mobile phone retailers and users, international hotels, and public offices, all equipped with private and public Wi-Fi transmission, several radio transmitters, and digital terrestrial television labelled M1-M3 in Figure 2.

Figure 2. Map showing the commercial areas of the study areas (Google Earth, 2023)

2.2. Equipment Setup and Data Collection

Figure 3 shows a photographic representation of the equipment setup in the research areas.

Figure 3. Photograph of the RF meter mounted on a tripod stand

In areas where the ground level is smooth, the RF meter was fixed to a tripod stand, as shown in Figure 3, while it was used in handheld mode where there was no possibility of mounting it, and measurements were taken for a maximum of 30 min per test location. To assess the pattern of EM energy radiated by various devices and antennas (at the telecommunication sites) in use by three major telecommunication service providers in the study area, namely, MTN Nigeria, Globacom Nigeria, and Airtel Nigeria, measurements were taken randomly around the site environment during both the wet and dry seasons for a period of six months between 9:00 am and 5:00 pm daily. For the dry season, measurements were performed in the month of November-January while readings were taken during March-May for the wet season. The average EM energy obtained from the actual field measurements at the test points is presented as follows.

3. RESULTS AND DISCUSSION

Displayed in Figure 4 are samples of the readings obtained from the field measurements.

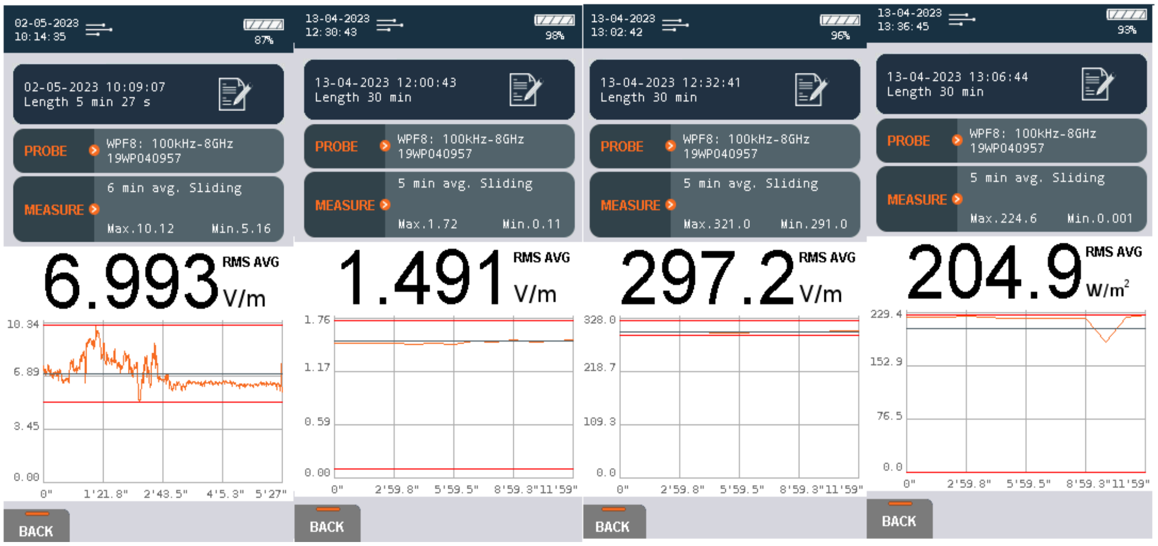

Figure 5. Samples of readings from the SMP2 meter

For the sake of clarity, the measured electric field values during the wet season are summarized and presented in Table 1, while Table 1 contains those taken during the dry season. It should be noted in Tables 1 and 2 that TB stands for the base of the telecommunication tower.

Table 1. Summary of the electric field strength measured during the wet season

Test Point	Time	Electric Field (V/m)		
		Minimum	Maximum	Average
P1	9 am to 4 pm	2.23	4.09	3.12
P2	9 am to 4 pm	4.362	12.84	8.26
P3	9 am to 4 pm	3.13	4.74	3.63
P4	9 am to 4 pm	2.08	2.32	2.12
P5	9 am to 4 pm	2.27	3.12	2.46
P6	9 am to 4 pm	1.84	2.33	1.86
T1	9 am to 5 pm	64.36	99.92	75.43
T2	9 am to 5 pm	84.87	127.9	102.3
T3	9 am to 5 pm	86.69	106.3	91.12
TB	9 am to 5 pm	2.13	2.75	2.32
M1	9 am to 5 pm	1.84	2.56	2.33
M2	9 am to 5 pm	3.79	10.94	8.83
M3	9 am to 5 pm	4.87	5.41	4.2

Table 2. Summary of the electric field strength measured during the dry season

Test Point	Time	Electric Field (V/m)		
		Minimum	Maximum	Average
P1	9 am to 4 pm	2.59	4.7	3.65
P2	9 am to 4 pm	4.67	14.77	9.66
P3	9 am to 4 pm	3.63	5.45	4.25
P4	9 am to 4 pm	2.41	2.67	2.48
P5	9 am to 4 pm	2.63	3.59	2.88
P6	9 am to 4 pm	2.13	2.68	2.18
T1	9 am to 5 pm	65.08	100.92	76.18
T2	9 am to 5 pm	85.72	129.18	103.32
T3	9 am to 5 pm	87.56	107.36	92.03
TB	9 am to 5 pm	2.26	2.97	2.58
M1	9 am to 5 pm	1.95	2.76	2.59
M2	9 am to 5 pm	4.02	11.43	9.8
M3	9 am to 5 pm	5.16	5.84	4.66

Results obtained revealed that the air space is a home for free EM Energy. The measured E-field values presented in Tables 1 and 2 indicate that the ambient environment and wireless devices are potential sources where EM can be harvested, with the telecom's antenna being the most viable source of free EM energy within the study areas, the values of which depend on the distance between the source and the point of measurement, which agrees with some of the previous studies [13, 15]. It is also observed from the results at all the test points P1-P6 and M1 -M3, taken within the ambient environment, that during the dry season when the temperature is higher, more EM Energy is harvestable compared to the dry season when the relative humidity is comparatively higher and consequently weakens the signal strength. However, for measurements at few centimetres (0-5 cm) from the telecommunications antennas, the variation in measured values between the wet and dry seasons is almost negligible. It is also worth mentioning that regardless of the season during which the measurement is taken, more energy is measured along the line of sight of the antennas.

4. CONCLUSION

In this work, we have quantitatively shown that airspace is filled with a large amount of EM energy that can be harvested and used for different applications. It is obvious from the onsite field measurements that the telecom antenna is the most viable source of free EM energy, with more EM energy harvestable at near field along the line of sight of the transmitting antenna.

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Ethical Consideration: This work has no conflict whatsoever with any known ethical standards that require the seeking of permission and approval.

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