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Quantitative Estimation of Electromagnetic Radiation Exposure in the Vicinity of Base Transceiver Stations via in-situ Measurements Approach

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ABSTRACT

There is a concern that exposure to radio frequency electromagnetic fields (EMF) from mobile phone base transceiver stations (BTS) might lead to adverse health effects. In order to assess the potential health risks, reliable exposure assessment is necessary. In-situ measurement based exposure assessment is an enhanced approach to quantify ambient exposure to EMF in the vicinity of deployed BTS or other communication devices. In this paper, using in-situ measurement approach, the human exposure level to electromagnetic fields radiated from the base stations in residential areas is studied with a broadband field strength meter. It was observed that values of the electric field strength and magnetic field strength are in the range of 0.07 V/m to 0.96 V/m and from 0.00020 A/m to 0.0025 A/m respectively, both which are quite lower than the maximum safety standard limits ((41V/m for electric field strength and 0.8 A/m for magnetic field strength) set by the International Commission on Non-ionizing Radiation Protection (ICNIRP) and other regulatory agencies. To further validate the electric and magnetic field strength data results, the EM radiation exposure ratio (ER) of each BTS was further calculated and the highest ER of 1.42 E-4 and 8.86E-5 ware recorded in BTS 2, both which *is less than 1. Therefore, we may conclude that the vicinity of each assessed BTS is in compliance with the ICNIRP reference levels used for public health safety.*

Key words: Electromagnetic field radiation, Base transceiver station, in-situ measurement, Exposure rati

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INTRODUCTION

In recent years, personal mobile telephony has become one of the most successful and widely uses of radio communications. The rapid growth and spread of the mobile phone telephony has resulted in the installation of numerous base stations both in urban and suburban or rural areas by different radio network operators. This is done to relay calls between mobile phone users and the telephone system. Also, to provide adequate signal strength coverage throughout the entire service area, many base stations are located or proposed to be sited near residential areas or on school properties. These base stations are either mounted on free standing towers or attached to rooftops or the sides of buildings.

According to the Nigerian National Communications Commission (NCC), the number of deployed BTS or cell sites by the four operators (i.e Airtel, Etisalat, Globacom, and MTN) grew from zero in 2001 to about 44,000 in May 2014. As of May 2014, the GSM operators collectively have a subscriber base of approximately 178 million lines out of which131 million lines were active as. This astronomical growth of GSM deployment suggests a proportionate increase in the amount of radio frequency radiation emitted into the country's air space, a trend that deserves regular monitoring through appropriate measurements of the RF power given out by the base stations (Ekata, Gand Kostanic, 2014)[1].

In parallel with the increase and installation of these BTS, there has been an increase in community concern about possible health effects from the radio frequency (RF) radiation emissions from the stations. This concern has thus pushed the research toward the necessity of finding a reliable means of analyzing radiation exposure pattern from the mobile phone base stations to address the safety dread.

Aim and Objectives

This study is aimed at investigating the potential risk of electromagnetic radiation from BTS, otherwise known as communication masts on human health.

The specific objectives of this study are to:

- Identify possible areas at risk to electromagnetic radiation from BTS.
- Measure the amount of electromagnetic radiation of BTS using electric field and magnetic field strength.
- determine the spatial average value and exposure ratio of measured field data within the space occupied by a human body
- Compare results with international standards or guidelines.

Justification of the study

There is concern that exposure to radio frequency electromagnetic fields (EMF) from mobile phone base transceiver stations might lead to adverse health effects. In order to assess potential health risks, reliable exposure assessment is necessary. However, in Nigeria where this study is carried out, several scientific research gaps in knowledge related to dosimetry and exposure assessment of radiation from mobile phones base are identified, among which are:

- Lack of procedures and test modes for testing EMF radiation from mobile communication devices employing novel communication standards with safety limits
- Limited or lack of precise information on the subject of the level of EMF radiation exposure from mobile telephone base stations under normal use conditions
- Lack of robust in-situ measurement procedures based on absorption characteristics of incident E- and H-field limits with respect to the basic restrictions
- Absence of robust assessment of the magnitude and rate of exposure of an individual or a group to an environmental agent. The agents of interest in this case are the electric and magnetic field strengths

Previous studies on potential health effects from radio frequency EMF from mobile phone base stations have applied several methods to assess exposure. Performing in-situ measurements as employed in research paper could be perceived as a superior approach to obtain precise exposure estimates.

Theoretical Background

In wireless communications, the information that is transmitted from the transmitter to receiver propagates in the form of electromagnetic (EM) wave. The whole range of different EM-waves is described in the electromagnetic spectrum (Figure 1).These waves have diverse energy levels transmitted from a source is generally known as EM radiation. According to Nasa (2010) [2], EM radiation is a particle and wave phenomenon that occurs when an electric field and a magnetic field oscillate perpendicularly and in phase to each other. In other words, EM field waves are fields of perpendicular electric and magnetic forces together create an EM field that propagates in space or a vacuum; both self-induced electric and magnetic fields oscillate perpendicularly to the direction of the EM energy propagation. EM radiation can also be seen as a wave that moves through a medium and transfers energy from point to point. Humans are exposed to EM radiation from natural and anthropogenic sources (Health Canada, 2010) [3].

Generally, EM radiation is part of everyday life, emitted by different sources like the Sun, the Earth and the ionosphere. EMR is also emitted by artificial sources such as presented in table 1

Table 1: Some key sources of EM radiation

S/N	EM Source	Operation Frequency	Transmission Power
1	AM/FM Tower	540 KHz-108 MHz	1kw-30kw
2	TV Tower	48 MHz- 814 MHz	10- 500W
3	Wi-fi	2.4-5GHz	10-100 mW
4	Base Station or Tower	800, 900, 1800, 2100, 2300MHz	20W
5	Mobile Phones	GSM-1800/CDMA GSM-900	1W 2W

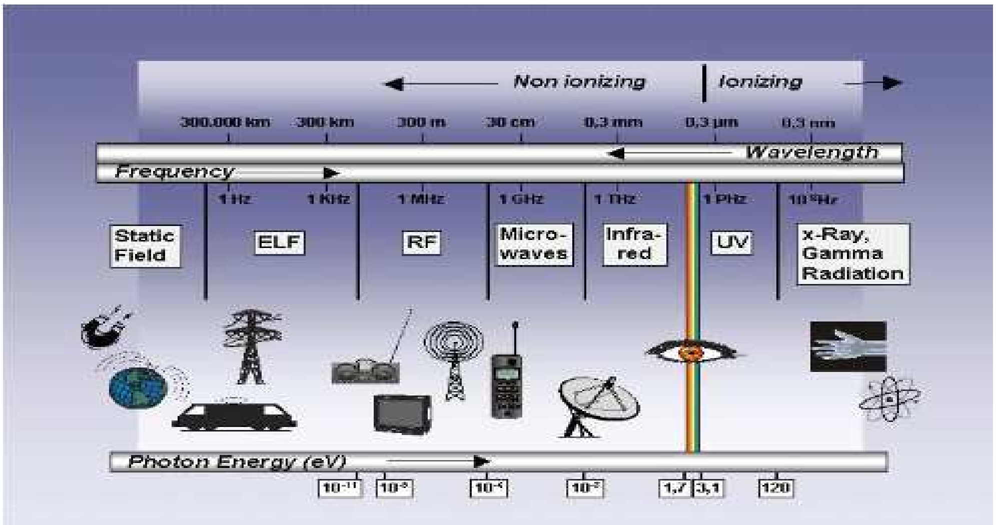

Figure1: The electromagnetic Spectrum

As can been seen in figure 1 above, EM radiation is non-ionising radiation. This means that it is not able to directly impart enough energy to a molecule or atom to break chemical bonds or remove electrons. In contrast, ionising radiation (such as X-rays) can strip electrons from atoms and molecules. This process produces molecular changes that can lead to damage in biological tissue.

It has been known for many years that exposure to sufficiently high levels of radio frequency EM radiation can heat biological tissue and potentially cause tissue damage. This is because the human body is unable to cope with the excessive heat generated during exposure to very high levels.

However, some studies have shown that environmental levels of radio frequency EM radiation routinely encountered by the public are far below the levels needed to produce significant heating and increased body temperature.
At relatively low level of exposure to EM radiation (that is, field intensities lower than those that would produce measurable heating), the evidence for production of harmful biological effects is ambiguous and unproven. Although there have been studies reporting a range of biological effects at low levels, there has been no determination that such effects might indicate a human health hazard, even with regard to long-term exposure

Electric and Magnetic field:
Electromagnetic fields can be sub-divided into two components: the electric field and the magnetic field. Electric field strength is a vector quantity (E) that corresponds to the force exerted on a charged particle regardless of its motion in space. It is expressed in Volt per metre (V/m). Magnetic field strength is a vector quantity (H), which, together with the magnetic flux density, specifies a magnetic field at any point in space. It is expressed in Ampere per metre (A/m). The E-field and the H-field are mathematically interdependent in the far-field, that means only one component has to be measured. For example, in free space if the H-field is measured in this region, it can be used to calculate the magnitude of the E-field and power density P_d
Poynting's theorem defines the relationship between the power density to the E-field and H-field vectors as follows:

$$P_d = E \times H \tag{1}$$

The magnitude of the power density based the sinusoidal nature of the EM wave is expressed by:

$$|P_d| = \frac{|\mathrm{E}|^2}{\eta} = \eta |H|^2 \tag{2}$$

In (2), η is the impedance of the free space defined by:

$$\eta = \sqrt{\frac{\mu_0}{\varepsilon_0}} \tag{3}$$

where

$$\mu_0 = 4\pi \times 10^{-7} \tag{4}$$

$$\varepsilon_0 = \frac{10^{-9}}{36\pi} \tag{5}$$

Then from equation (4) and (5), $\eta = 120\pi = 377\Omega$

Considering (3), (4) and (5) in (2), we have

$$P_d = \frac{E^2}{120\pi} \tag{6}$$

Equation (6) shows that the power density is directly proportional to the square of electric field strength. Also, knowing the radiated power, P_{rad} on the base station antenna, it is possible to estimate the power density P_d on any point around the antenna from a distance, d by dividing the radiated power with surface area of a sphere ($4\pi d^2$) at that distance. That is,

$$P_d = \frac{P_{rad}}{4\pi d^2} \tag{7}$$

Applying G_{rad} as the radiated antenna gain, (7) becomes

$$P_d = \frac{P_{rad} G_{rad}}{4\pi d^2} \tag{8}$$

From the above, we can see that

$$\frac{E^2}{120\pi} = \frac{P_{rad} G_{rad}}{4\pi d^2} \tag{9}$$

Thus, the E-field can be calculated from (9) as:

$$E = \sqrt{\frac{30 P_{rad} G_{rad}}{d^2}}$$

$$E = \frac{\sqrt{30 P_{rad} G_{rad}}}{d} \tag{10}$$

MATERIALS AND METHODS

This part describes adopted procedures for measuring electromagnetic field that aims to evaluate EMF radiation form BTS deployed at public places and to compare the results with recommended levels. All procedures for the method of measurements at different points are made on the basis of the recommendations of international organizations [4, 5].

Depending on the operation state of the base station, the radiated EMF from a radio base station can be evaluated by three methods (Byung, 2009)[6]: certification measurement when a base station gets on to the market, in-situ measurement when a base station is offering a service, and electromagnetic environment measurement when a base station is put into service. According to this author, Certification measurement is the same as a performance verification test carried out in an anechoic chamber, while in -situ measurement is a human exposure assessment focused on human beings. In this paper, we adopt in-situ measurement to obtain our data (electric field strength and magnetic field strength)

Measurement Locations

The measurements were executed in April 2014 at different locations in Benin City, Nigeria, and consist of 8 GSM BTSs. The measurement locations, outdoor were randomly selected across Benin in order to compare BS exposure of various sources. The short-term measurements were executed to characterize in situ exposure of distinct radio frequency sources at different locations

Measurement equipment

The equipment used for data collection consisted GPS, fiber measuring tape, and EMF radiation meter with isotropic field probes. The radiation meter was used to measure the effective values of electric field strength data in each measurement location.

Measurement procedure

The data (electric and magnetic field strength) were collected from the three GSM operators (which are MTN, AIRTEL and GLOBACOM)' base transceiver stations (BTSs). All the BTSs were located in GRA, Benin City, Nigeria. For each of the measurements location, electric field strength data were taken at 5m intervals to 50m from the BTSs. All the BSs are dual band-three sectored antennas; the antennas have an in-build features which enable them radiate at 900/1800MHz. The antennas are sectored 120 and the antennas were installed at different heights ranging from 22m to 40m above the sea level for three network operators respectively. The electromagnetic broadband meter was place at approximately 1.5m to detect the field strength at a given point.

It should be noted here that only electric field strength was measured, since measurements are typically made in the far field. The magnetic field strength was calculated form electric field strength using the intrinsic impedance of free space as in equation (2)

RESULTS AND DISCUSSION

Here, we considered metric such as the electric field strength E (V/m), magnetic field strength H (A /m), and exposure ratios (ER) over the different locations and the corresponding ICNIRP safety standard reference levels in table 2. In this paper, we adopted reference levels of the ICNIRP [7] because it is most commonly used safety standards from among others at the present time due to the following reason as itemised in [8]:

- ICNIRP guides lines were published in 1998.
- Limits are based on all available scientific research and include large safety margins.
- Limits are set to protect all people from established adverse effect from short and long term exposure.
- Specifies limits for both general public and occupational exposure.
- Endorsed by World Health Organisation (WHO).

Table 2: Summary of ICNRIP Reference levels for general Population Exposure

Frequency	E-Field (V/m)	H-Field (A/m)
1MHz - 10 MHz	$87f^{1/2}$	$0.73f^{1/2}$
10MHz - 400 MHz	28	0.73
400MHz - 2GHz	$1.375f^{1/2}$	$0.003f^{1/2}$
2GHz - 300 GHz	61	0.16

Exposure ratio

The exposure ratio (ER) is the ratio of the measured maximum electromagnetic electric field strength (E) or magnetic field strength (H) to the appropriate reference level at a given frequency. A value greater than “1” signifies that levels to which people may be exposed exceed the reference level (CC/REC / (02)04) [9]. It expressed by (ITU-T, 2011) [10]:

$$ER = MAX\left[\left(\frac{E}{EL}\right)^2, \left(\frac{H}{HL}\right)^2\right] \tag{11}$$

where:

ER is the exposure ratio at each operating frequency for the source

EL is the investigation E-field limit at frequency *f*

HL is the investigation H-field limit at frequency *f*

E is the assessed E-field at frequency *f* for the source

H is the assessed H-field at frequency *f* for the source
ER is applicable to limits based on national regulations, or if they are not defined then in ICNIRP principles.
Here, in order to evaluate the human exposure to base station radiation with ICNIRP recommendations or guidelines, the ER value using several data measured within the measurement location is calculated using the expression in equation (11), and then the result is compared with the limits.
Shown in tables 3-4 and figures 2- 7 are the variations of electric field strength and magnetic field strength as a function measurement distance from each assessed BTS. It can be observed in table 3 and table 4, that values of the electric field strength and magnetic field strength are in the range from 0.07 V/m to 0.96 V/m and 0.00020 A/m to 0.0025 A/m respectively, both which are quite lower than the maximum safety standard limits ((41V/m for electric field strength and 0.8 A/m for magnetic field strength) set by the International Commission on Non-ionizing Radiation Protection (ICNIRP) and other regulatory agencies.
We also observed that the electric field strength and magnetic field strength of the EM waves fluctuates and decreases very quickly as the distance between the base station and mobile stations increases. The fluctuations may be presumably due to differences in physical parameters, (e.g. input power of the base station), in measurement protocol, (e.g. position of the measurement antenna in relation to the base station antenna and its main lobe), and in the type and characteristics of the measurement site (e.g. Side lobe effects, attenuation and obstacles like buildings, trees, ground reflections etc).

Table 3: Electric field strength data from assessed base transceiver stations (BTS)

	BTS 1	BTS 2	BTS 3	BTS 4	BTS 5	BTS 6	BTS 7	BTS 8
5	0.65	0.815	0.7132	0.5044	0.0771	0.3722	0.6629	0.341
10	0.558	0.879	0.6723	0.4736	0.2903	0.275	0.4984	0.324
15	0.671	0.888	0.6165	0.4062	0.3167	0.2699	0.4597	0.4
20	0.617	0.768	0.8321	0.3821	0.1982	0.2233	0.4296	0.342
25	0.538	0.962	0.7215	0.4123	0.2746	0.3816	0.5722	0.256
30	0.5	0.909	0.7746	0.8172	0.2384	0.3306	0.7448	0.243
35	0.402	0.926	0.7122	0.5166	0.2046	0.2007	0.8644	0.321
40	0.361	0.598	0.6448	0.3325	0.2209	0.2675	0.886	0.421
45	0.392	0.44	0.4125	0.4142	0.2573	0.2294	0.6509	0.403

Table 4: Magnetic field strength data from assessed base transceiver stations (BTS)

	BTS 1	BTS 2	BTS 3	BTS 4	BTS 5	BTS 6	BTS 7	BTS 8
5	0.0017	0.0021	0.0018	0.0013	0.0002	0.0009	0.0017	0.0009
10	0.0014	0.0023	0.0017	0.0012	0.0007	0.0007	0.0013	0.0008
15	0.0017	0.0023	0.0016	0.0010	0.0008	0.0007	0.0012	0.0010
20	0.0016	0.0020	0.0022	0.0010	0.0005	0.0005	0.0011	0.0009
25	0.0014	0.0025	0.0019	0.0010	0.0007	0.0010	0.0015	0.0006
30	0.0013	0.0024	0.0020	0.0021	0.0006	0.0008	0.0019	0.0006
35	0.0010	0.0024	0.0018	0.0013	0.0005	0.0005	0.0022	0.0008
40	0.0009	0.0015	0.0010	0.0008	0.0005	0.0007	0.0023	0.0011
45	0.0010	0.0011	0.0010	0.0010	0.0006	0.0006	0.0017	0.0010

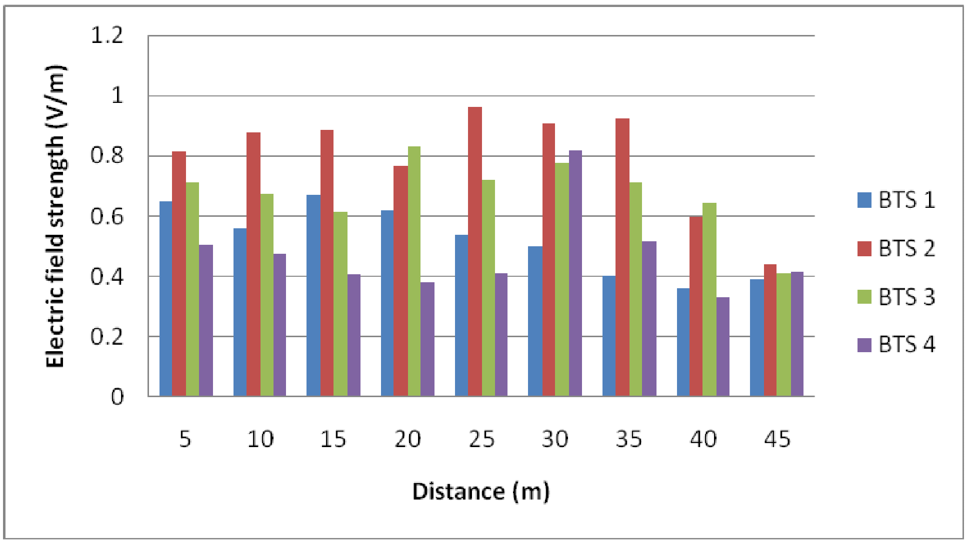

Figure 2: Electric field strength (V/m) versus distance (m) for GLOBACOM

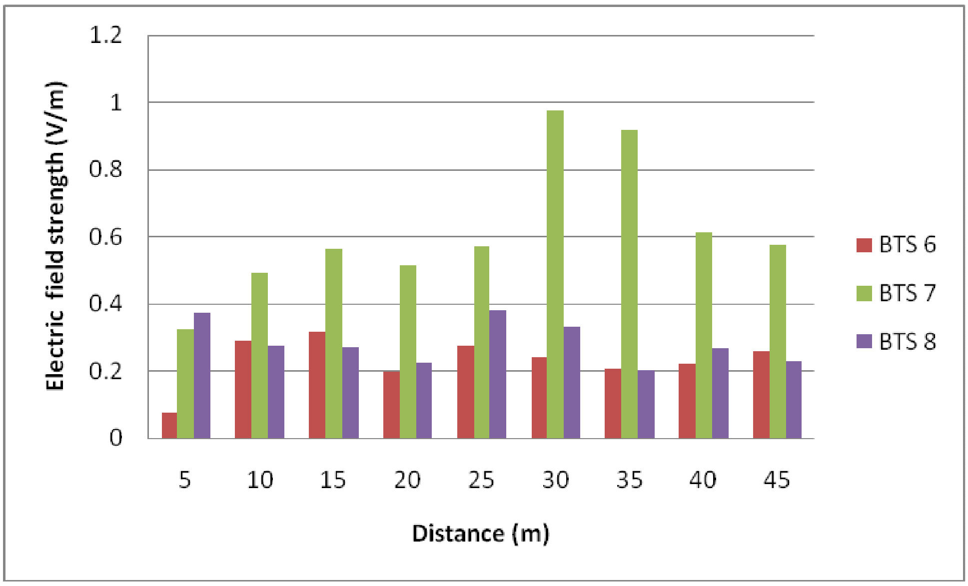

Figure 3: Electric field strength (V/m) versus distance (m) for MTN

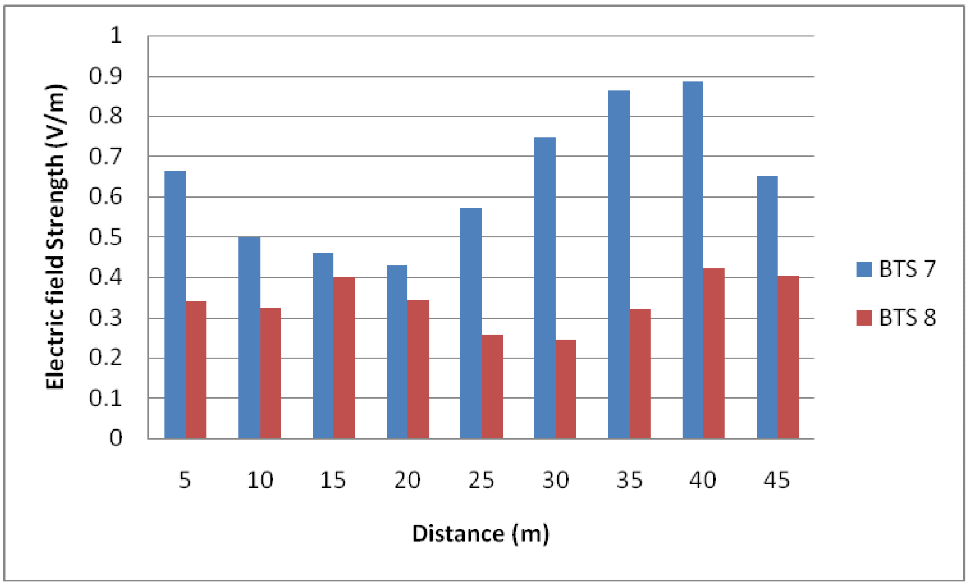

Figure 5: Electric field strength (V/m) versus distance (m) for AIRTEL

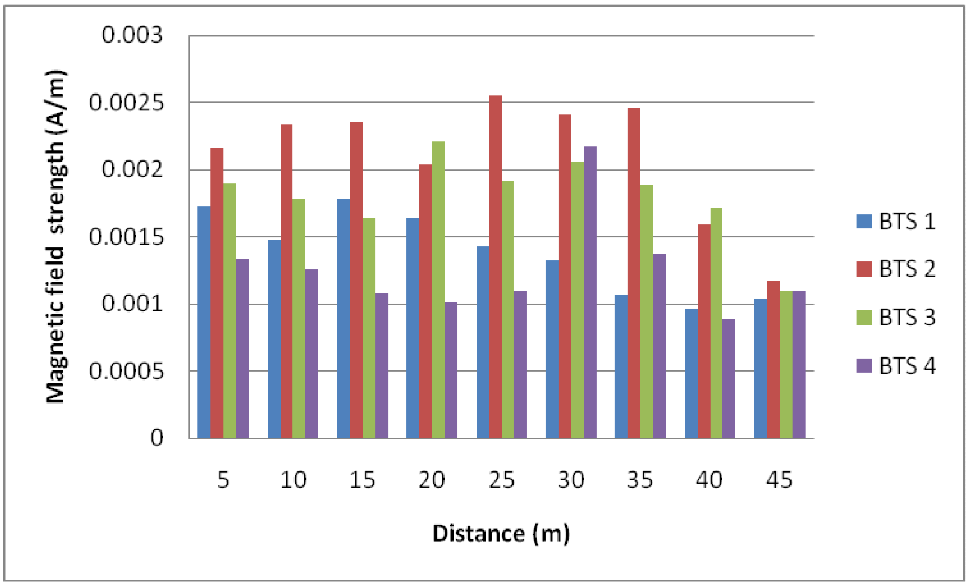

Figure 6: Magnetic field strength (A/m) versus distance (m) for GLOBACOM

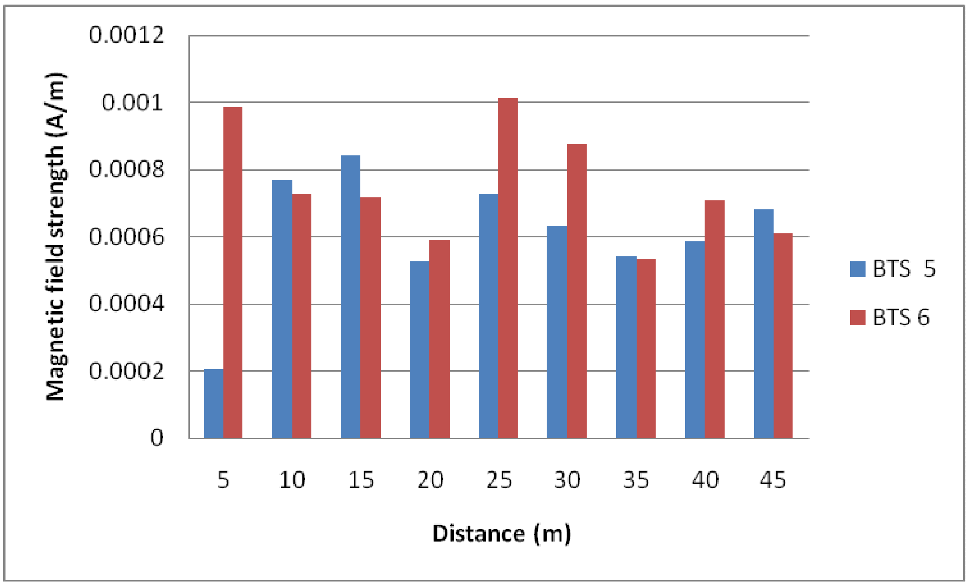

Figure 7: Magnetic field strength (A/m) versus distance (m) for MTN

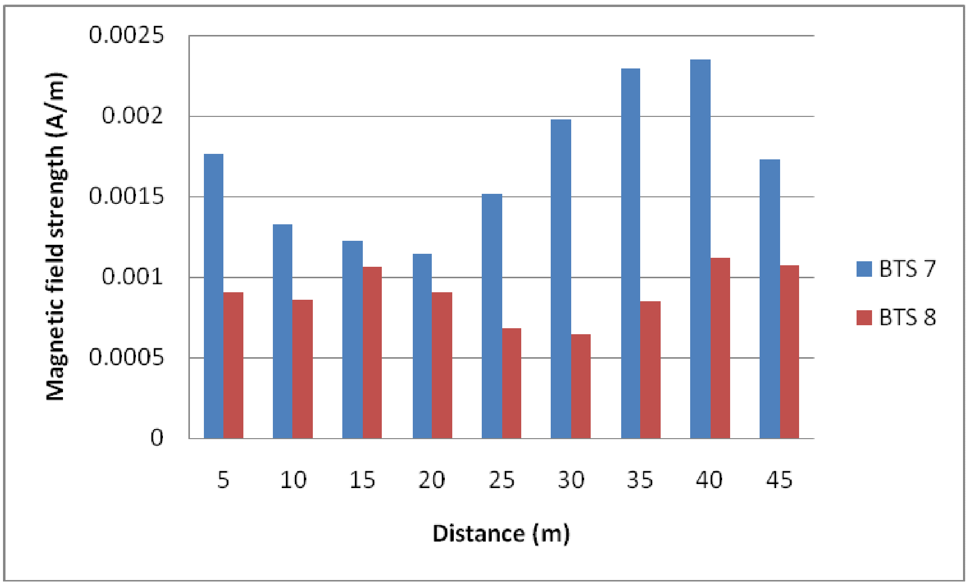

Figure 8: Magnetic field strength (A/m) versus distance (m) for Airtel

To validate previous results using the electric and magnetic field strength data in figures 2-7, the EM radiation exposure ratio of each BTS is further calculated using equation (8) and the results are presented in table 5 and figures 9-10. The highest ER of 1.42 E-4 and 8.86E-5 were observed in BTS 2, both which is less than 1. Therefore, the vicinity of each assessed BTS is in compliance with the reference levels for general public since the ER value is lower than 1.0.

Table 5: EM Radiation Exposure ratio (ER) from the various Base transceiver stations (BTS)

Base Transceiver Station (BTS)	BTS 1	BTS 2	BTS 3	BTS 4	BTS 5	BTS 6	BTS 7	BTS 8
E-field ER	3.48E-5	1.42E-4	7.34E-5	2.69E-5	5.50E-6	7.73E-6	4.57E-5	8.77E-6
H-field ER	1.61E-10	8.86E-10	4.48E-10	1.18E-10	6.68E-12	1.42E-11	3.81E-10	2.82E-11

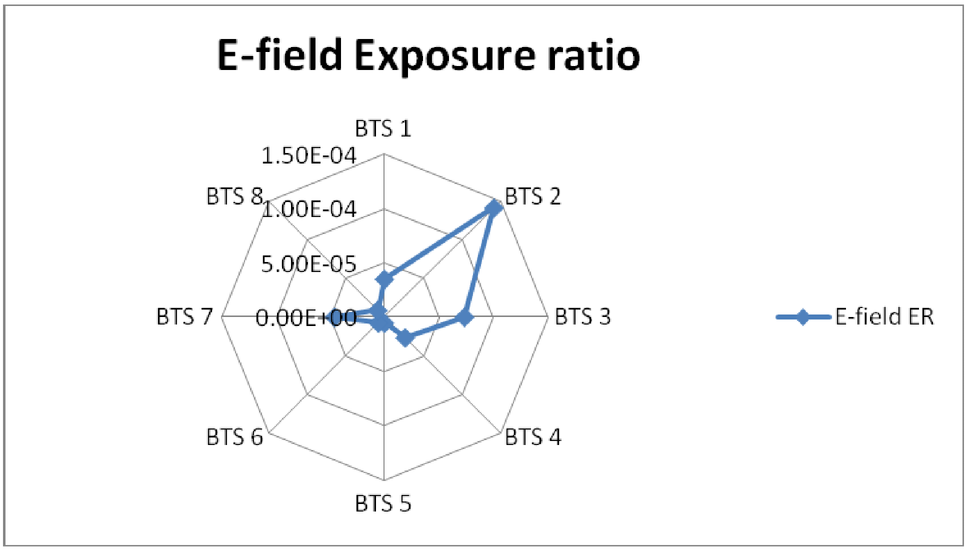

Figure 9: Estimated Electric field strength exposure ratio across the BTS

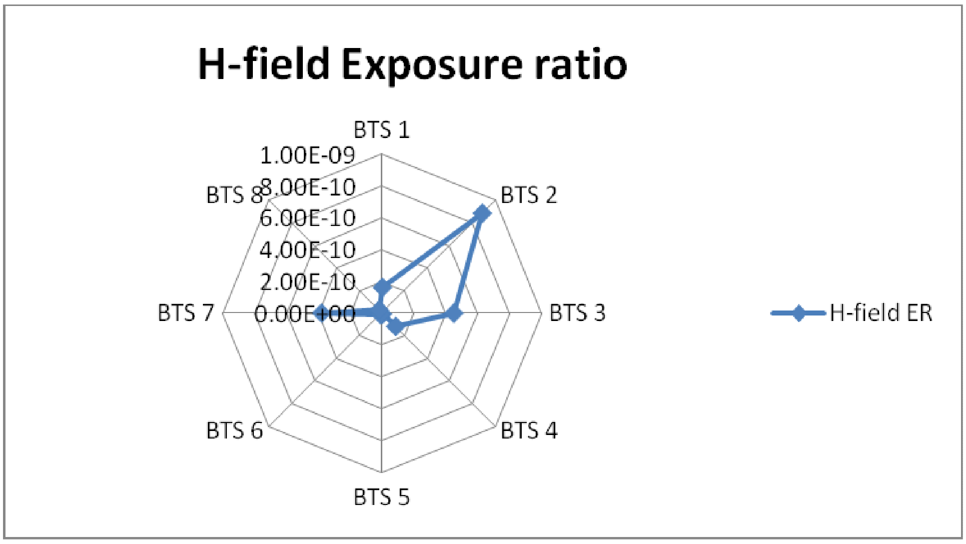

Figure 10: Estimated Magnetic field strength exposure ratio across the BTS

CONCLUSION

The biological effects of EMF radiation exposure are a much studied, albeit not thoroughly mastered subject. Considering increased number of EMF sources, the development of modern systems for EMF monitoring became necessary, as a support for authorities in their efforts to timely inform public on current level of EMF strength in environment and their surroundings.

In this paper, using in-situ measurement approach, the human exposure level to electromagnetic fields radiated from the base stations in residential areas with a broadband field meter. Results show that level of electric and magnetic field strength are in acceptable range and far below allowed limit prescribed by the International Commission on Non–Ionizing Radiation Protection and other organization. To validate previous results using the electric and magnetic field strength data, EM radiation exposure ratio (ER) of each BTS was also calculated and the highest ER of 1.42 E-4 5 and 8.86E-5 were recorded in BTS 2, both which is less than 1, both which are less than 1. Therefore, the vicinity of each assessed BTS is in compliance with the reference levels for general public since the ER value is lower than 1.0.

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