KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY
COLLEGE OF ENGINEERING

MEASUREMENT AND EVALUATION OF ELECTROMAGNETIC RADIATION EXPOSURE FROM ANTENNAS IN CELLULAR NETWORKS

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DECLARATION

I hereby declare that this submission is my own work towards the award of the MPhil degree and that, to the best of our knowledge, it contains no material previously published by another person or material which has been accepted for the award of any other degree of the university, except where due acknowledgment has been made in the thesis.

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DEDICATION

This work is dedicated to the Lord God Almighty, most Gracious, most benevolent for his priceless gift of life and health and to family and special friends for their prayers, financial support and encouragement.

ABSTRACT

Wireless Technology including that of cellular systems uses radio and microwave energy which is nonionizing in nature, generated at base stations for its transmission via cellular antennas and microwave links to accessible areas for subscribers. The nonionizing radiation (NIR) energy is absorbable by living tissues including human skin and thus, becomes harmful when it exceeds certain thresholds.

The health risks associated with exposure from base transceiver stations has gained attention as the demand for cellular services increases. This has led to an increase in communication infrastructures (Base Transceiver Stations), ushering some in human inhabitance to improve quality of service, as these services become a vital part of modern lifestyle. An increase in base transceiver stations, leads to increased cellular radiation pollution which is of public concern. It is therefore necessary to investigate the levels of cellular radiation to ensure that it public health safety limits are not violated.

In this thesis, NIR level in power density at forty locations involving residential, commercial and University campuses, considering indoor and outdoor scenarios were measured and estimated with a radio frequency (RF) Explorer 6G Combo Spectrum Analyzer. The results were compared with the minimum safety limits of 4.055 W/m^2 for cellular systems in Ghana, formulated by the International Commission and Non-ionizing Radiation Protection (ICNIRP) and enforced by the National Communication Authority of Ghana (NCA).

The maximum total level of radiation consisting of a cumulative of all deployed systems was found to be 862.9 (nW/m^2) for residence near base stations during evening hours and 242.6 (nW/m^2) at day time. The maximum and minimum levels recorded for other locations are 3.96 (nw/m^2) and 0.10 (nw/m^2) at residence away from base stations, 118.5 (nW/m^2) and 0.422 (nW/m^2) for commercial areas and 38.92 (nW/m^2) and 4.97 (nW/m^2) at the campuses. A standard deviation of 49.9 at three different sectors of a single base station was achieved. A highest radiation level of 305.6 (nw/m^2) was recorded at 7 pm of the 24-hour indoor measurement, while the cumulative average of 160.5 (nw/m^2) was recorded at the 24th hour.

A percentage of the highest 862.9 (nW/m^2) radiation level recorded is less than 1% of 4.055(w/m^2) minimum safety limits recommended by the International Commission on Nonionizing Protection (ICNIRP). Thus, cellular system radiation emissions of the selected locations do not pose any health threat to the general public in their current capacity.

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LIST OF ABBREVIATIONS

IARC	-	International Agency for Research on Cancer
NIR	-	Non Ionizing Radiation
ICNIRP	-	International Commission on Nonionizing Radiation Protection
IEEE	-	Institute of Electrical and Electronic Engineers
IEC	-	International Electro Technical Commission
ITU	-	International Telecommunication Union
WHO	-	World Health Organization
ANSI	-	American National Standard Institute
NCA	-	National Communication Authority
RFE	-	Radio Frequency Radiation
QoS	-	Quality of Service
EMF	-	Electromagnetic Field
RNBS	-	Residence Near Base Stations
RABS	-	Residence Away from Base Station
BA	-	Business Area
SAR	-	Specific Absorption Rate
S	-	Power Density
UGHP	-	University of Ghana High Population
KNUSTHP	-	Kwame Nkrumah University of Science and Technology High Population
KNUSTLP	-	Kwame Nkrumah University of Science and Technology Low Population
KTUHP	-	Koforidua Technical University High Population
KTULP	-	Koforidua Technical University Low Population
CR	-	Campus Residence
WLL	-	Wireless Local Loop
GSM	-	Global System for Mobile Communication
WCDMA	-	Wideband Code Division Multiple Access
3G	-	Third Generation
4G	-	Fourth Generation
OCAM	-	Outdoor Commercial Area Market

OCAO	-	Outdoor Commercial Area Offices
ICAO	-	Indoor Commercial Area Offices
OCAI	-	Outdoor Commercial Area Industrial

CHAPTER ONE
INTRODUCTION

1.1 Background of Study

The Universe is made up of a spectrum consisting of magnetic and electrical waves on which certain life processes depends. The current of the ocean and wind that sustain life is driven by sunlight. Technological advancement to enrich human lives in many fields such as medical, communication and entertainment depends on natural and artificial transmission of energy (radiation) through free space, materials and tissues, and is categorized as Ionizing and Nonionizing as shown in Figure 1.1, depending on its effect[1].

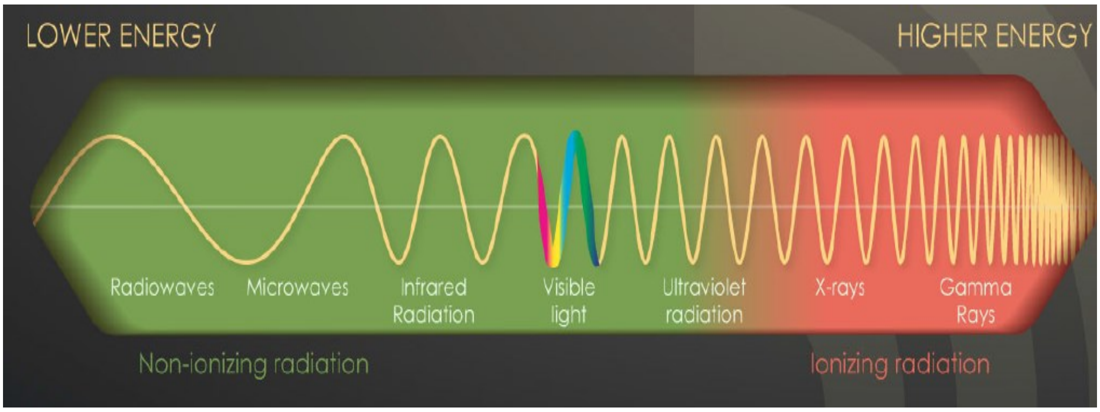

Figure 1.1 Categories of Radiation Energy [2]

Electromagnetic radiation can either be absorbed, transmitted, reflected or a combination of all when it encounters materials. [1]. The ionizing category of radiation has high energy capacity to add or remove electrons (ionize) from atoms or molecules of materials. When it come into contact with living tissues, significant damage can be caused at the level of Cell, Organ or Organism and change the DNA. Non-ionizing radiation on the other hand has less energy which lack the capacity to remove electrons or molecules. That is not to say this category is harmless but the harm is bounded to thermal burns. The minimum Energy per electron volts (ev) needed for ionization to occur is 12.6 ev and the radiation energy below that scale is classified as nonionizing (NIR)[2][3].

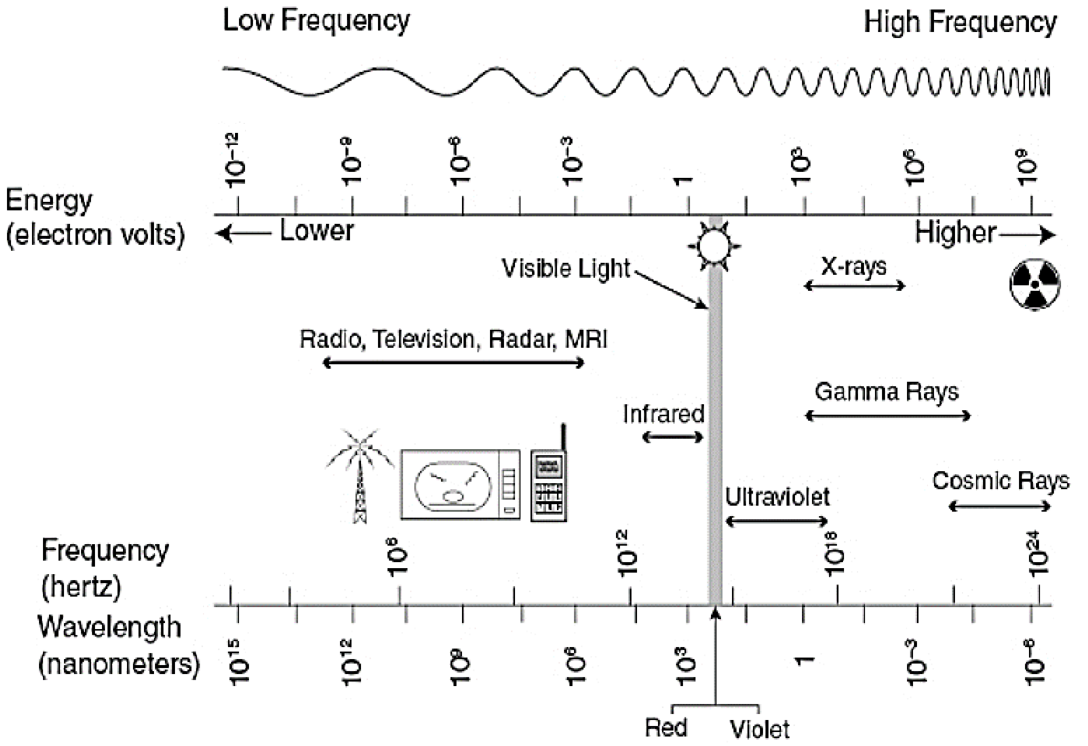

Figure 1.2 Electromagnetic Spectrum with various Energy level [3]

Wireless technology including that of cellular systems uses radio and microwave energy which is nonionizing in nature as shown in Figure 1.1 for its operation. Cellular voice and data services uses antennas and microwave links to transmit the energy generated at the base station to accessible areas for subscribers. Mobile phones including smart phones, emit RF non-ionizing radiation and the part of the body nearest to the antenna can absorb this energy and convert it to heat. Other digital wireless systems such as data communication networks also produce similar non-ionizing radiation. The demand for wireless information, data and mobility is on the rise as cellular technology become a vital part of modern lifestyle. According to the international Communication union (ITU), the rate of internet connectivity has increased from seventeen (17) percent as at 2005 to 53 percent in 2019, accounting for 4.1 billion of the world's population and a ten percent average growth of internet users yearly. Mobile cellular telephone and mobile broadband subscriptions continue to grow as fixed telephone and fixed broadband subscriptions declines[4].

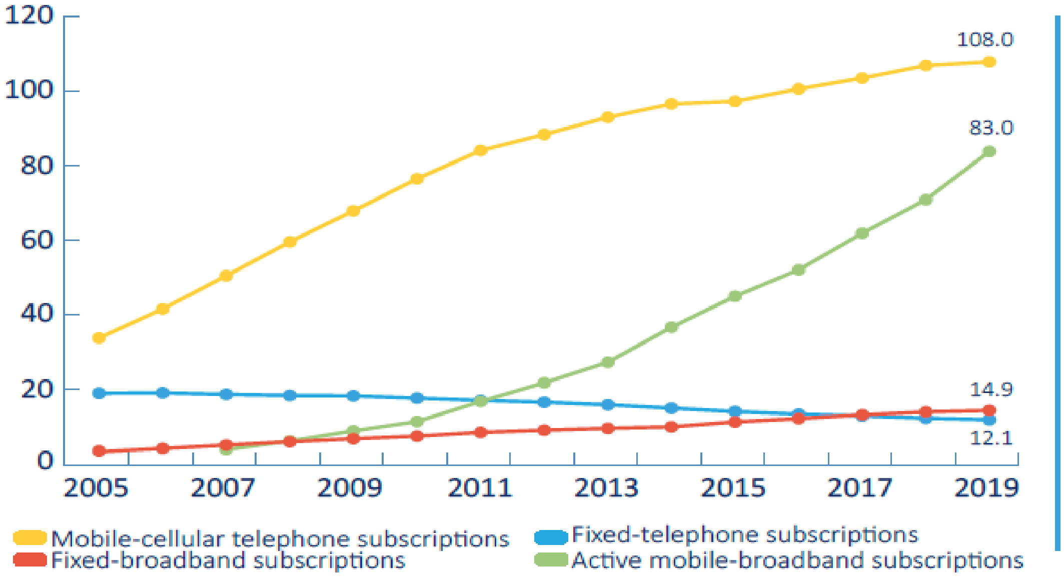

Figure 1.3 Evolution of Fixed and Mobile Services worldwide[4]

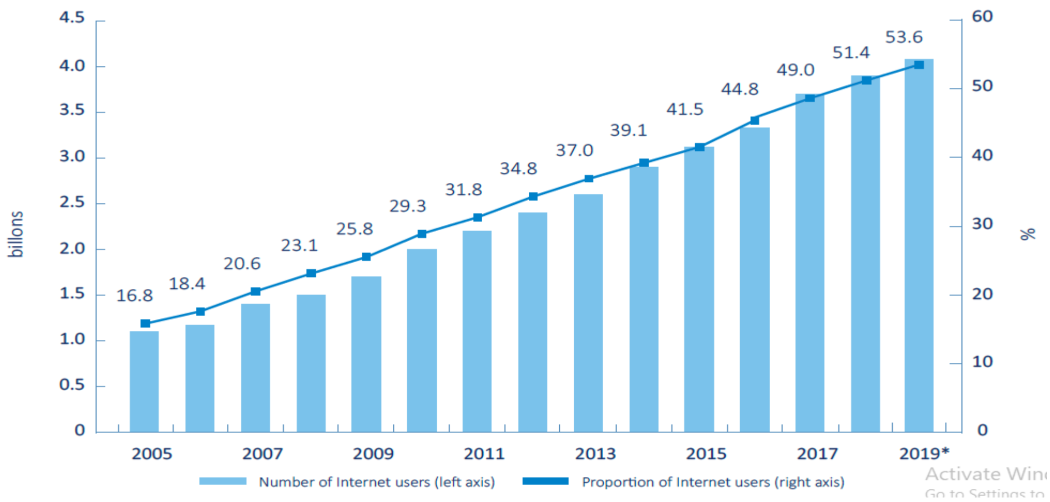

Figure 1.4 Evolution of Internet Users worldwide [4]

Data and voice subscription in Ghana increased from 10.3 million to 28 million and 28,026,482 to 41,959,298 from 2013 to 2019 respectively with 17,372,290 and 23, 945,672 for the leading provider of mobile Telecommunications Services (MTN), reflecting a market share of 67.78% and 57.07% respectively[5].

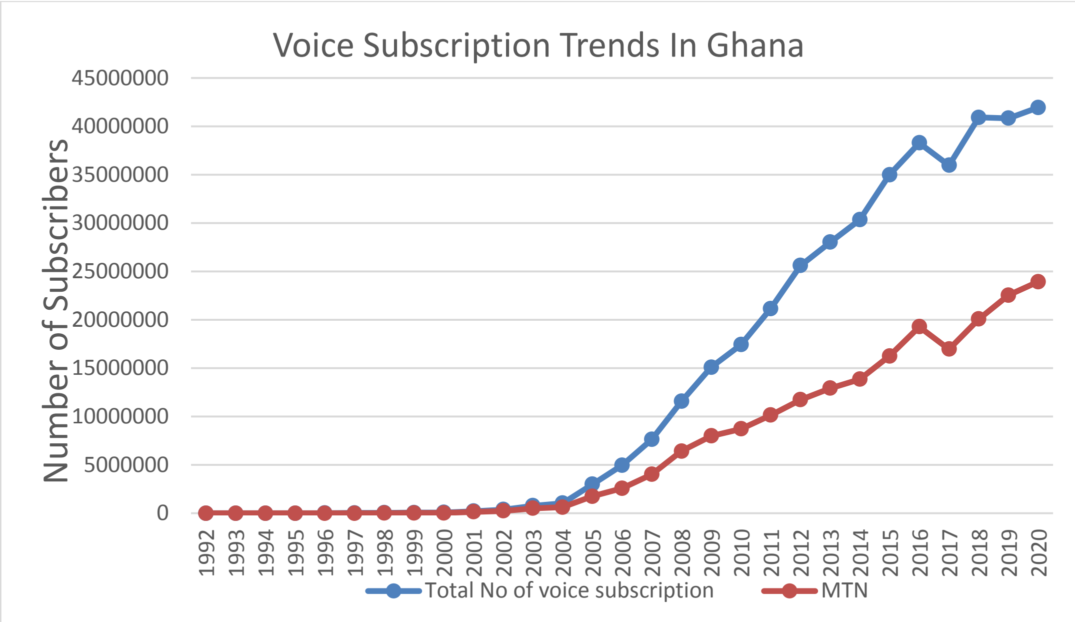

Figure 1.5 Evolution of Voice Subscription in Ghana[5][6]

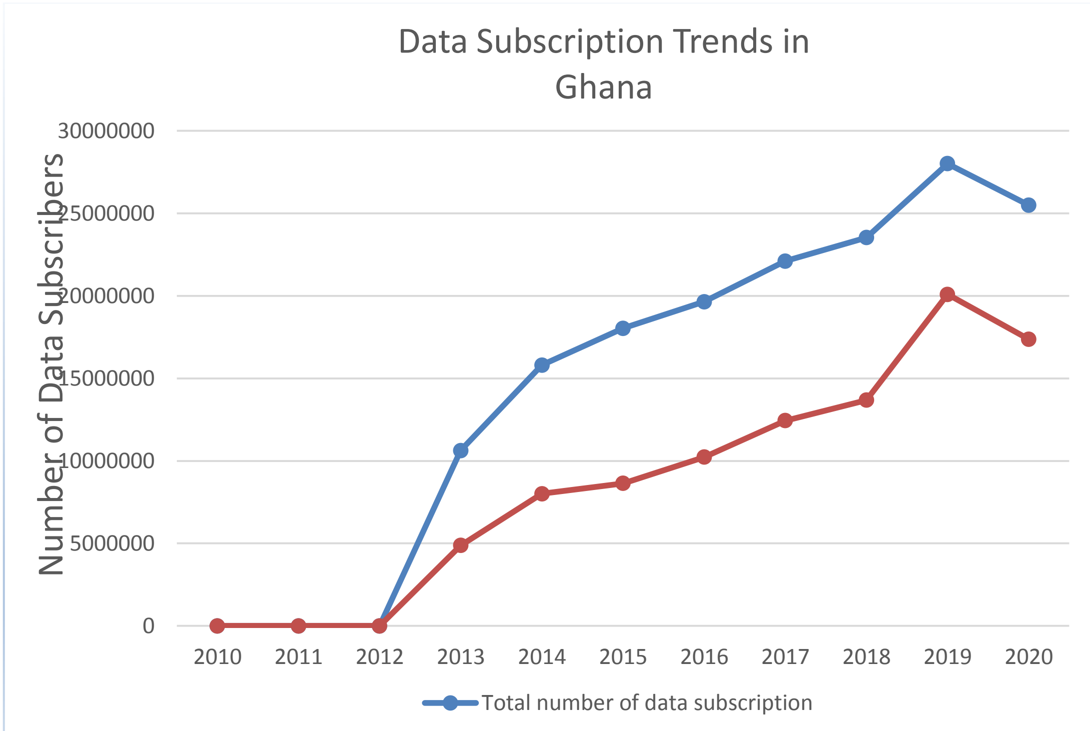

Figure 1.6 Evolution of Data Subscription in Ghana [6] [7]

Though there is lack of evidence connecting NIR to Cancer, the international agency for research on Cancer (IARC) in 2011 categorized radio frequency radiation (RFR) as a possible (Group 2B) human carcinogen[8]. A wide range of health effects has been linked to RFR by research groups and individuals. Biological effects of decrease in spatial working memory and attention in adolescent, impaired cognitive functioning, negative effects on mental health, stress and anxiety, diminished capacity to grow and develop normal neurologic, immune and metabolic functions in children, issues associated with fertility, reduction in melatonin production in humans and animals, depression, Neuropsychiatric effects, decreased in quality of sperm and many more are reported in[9][10][11][12][13][14].

Due to these adverse effects, there are international agencies such as international commission on non-ionizing radiation protection(ICNIRP) recommended by the world Health organization (WHO**),** Institute of Electrical and Electronic Engineers (IEEE) recommended by American National Standards Institute (ANSI), International Telecommunication Union (ITU) and International Electro-technical Commission (IEC**)** that set safety guidelines that limit human exposure to radio frequency non-ionizing radiation. The National Communications Authority (NCA), a regulatory agency for Ghana recommends ICNIRP limits for communication operations in Ghana.

1.2 Problem Statement

The exploit of the Electromagnetic spectrum has enormously enriched human lives in many applications such as domestic and industrial, transport, medical and communication systems. However, these exploitation contribute to environmental radiation pollution, of which communication equipment plays a major role. The extensive increase in the demand for cellular services has necessitated an increase in communications infrastructure such as towers; which are needed to ensure adequate network coverage and access that guarantee minimum quality of service (QoS) ushering base stations in locations close to human habitation[15]. Guidelines and exposure limits are enforced by international and local regulatory agencies to ensure the radiation pollution is within safety health levels but modern communication technology has humans often glued to cellular services resulting in an increased radiation pollution depending on the traffic volume and the time spent[16][17] which may exceed the exposure limits and thus, impair the health of users which is a public concern. It is therefore necessary to investigate whether there is an excess of electromagnetic radiation which can potentially violate the public health safety of general public.

Agencies and scholars has conducted research to access the effects and compliance of radiation limits especially in public places and one of the major finding is that the length of connectivity is a determinant of the generated radiation and recommend that it should be reduced. The question is, what hours or estimated range of connectivity time is a user safe? Investigating a definite period within which the minimum compliance limit is achieved during connectivity in a 24 hour continues measurement and 30 locations in residential, business and campus areas will provide an awareness and cautiousness of radiation pollution to users in relation to their connectivity time than the usual method of caution to reduce usage. Therefore, it is imperative to carry out this research so as to unburden users of fear of radiation pollution or be cautious of the active times of connectivity.

1.3 Justification of Research

Cellular devices and Information Communication technology (ICT) has completely changed the face of businesses, entertainment, Education, social development as well as gatherings, which has greatly influenced the life style of today's generation. On a daily basis, subscribers spend time engaging in voice services, data services or both and depending on the individual life style and career, the connectivity time will vary. Mobile phones are usually in constant communication with the base station using the control channels and Wi-Fi or data connectivity are mostly on even when the service is not in use. Meanwhile, the length of time that a wireless device is connected is an essential determinant in the overall exposure[17].

The extensive use of cell phones has led to cell phone towers (base stations) being positioned in lots of communities and I have personally witnessed instances where concerned citizens question field engineers of Telecommunication networks for the citing of their towers in fear of possible radiation effects. The outcome of this research will determine whether compliance set by the international commission on non-ionizing radiation and the National Communications Authority (NCA) are being followed and whether the concerns of the general public are justified or not.

Also, subscribers especially the internet lovers that spend a reasonable amount of time for business or educational purposes can estimate the hours of screen time necessary to generate the minimum radiation that can put them in danger.

1.4 Research Objectives

1.4.1 General Objective

To measure non-ionizing radiation (NIR) levels of cellular base station antennas in unrestricted environment and assess its effects in selected urban areas in Ghana

1.4.2 Specific Objectives

1. To estimate the NIR exposure levels at residential, commercial and University campuses.
2. To determine the deviation in exposure levels at three different sectors of a single base station.
3. To evaluate the cumulative NIR average exposure level in an indoor measurement for 24 hours.

1.5 Research Contributions

Measurement of NIR exposure limits are considered for six (6) and thirty (30) minutes in the safety reference exposure levels laid down by international and local regulatory agencies. This research seeks to undertake a 24 hour measurement to estimate the daily cumulative average of cellular NIR exposures in a particular area, analyze the percentage cellular radiation contributions of the various network providers in Ghana at the selected university campuses and investigate the deviation in measured exposure levels from different angles at the same base station.

1.6 Organization of Thesis

The rest of this thesis is ordered as follows:

- Chapter two has a general overview of radiation restriction levels, concepts in relation to cellular transmission and review of related work concerning radiation measurements.
- Chapter three demonstrate the method used in radiation measurements and concepts of processing measured data to achieve the results.
- Chapter four discusses and analyses the results obtained from the measured and processed data.
- Chapter five draws conclusions and determines findings from the research. It also recommends a setup of measurement and future work that can be done on this research.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Radiation pollution is a sensitive issue that must be handled with uttermost care. The health of living things, technological innovations in many aspect of life and businesses depends on it. The radiation pollution measurement follow specific laydown procedures to ensure accurate results for proper interpretations of its pollution status and thus, its effect. This chapter presents the standards of non-ionizing radiation pollution measurement for the public as well as review of related works.

2.2 NIR Regulatory Agencies

On the Electromagnetic spectrum shown on Figure1.1 frequency and energy radiation such as radio waves, microwave, ultraviolet, light and infrared which do not have enough energy to ionize atoms and molecules are referred to as non-ionizing radiation (NIR). Studies have been done on NIR limits and requirements through experimental testing methods by international standardization and research organizations and put together the limits of NIR exposure. Government institutions establish safety supervision requirement to guide industries in their corresponding nations to keep to the formulated exposure limits.

2.2.1 International Commission on Non-ionizing Radiation Protection (ICNIRP).

This organization consist of expert of different disciplines and countries that develop and disseminates guidance on limiting exposure to non-ionizing radiation based on scientific findings on biological effects and action mechanisms of radiation for the entire NIR frequency range (0Hz – 300 GHz) which is adopted for global implementation by the World Health Organization (WHO), to protect living things in the environment from the unfavorable consequences of NIR.

The NIR limits formulated by ICNIRP adopts distinct basic limits at different frequencies and are reviewed from time to time[18]. Some referenced guidelines issued by ICNIRP are as listed below[19].

- Guideline static fields -1994 (ICNIRP – 1994)

- EMF Guidelines – 1998 (ICNIRP 1998) is a NIR protection guideline for frequency 0 Hz to 300 GHz. Other guidelines issued thereafter replace partial conclusion of ICNIRP 1998.
- Static Magnetic Fields Guidelines – 2009 is the magnetic flux density and replaces guideline static fields.
- For 1 Hz to 100 kHz, LF Guidelines - 2010 replaces ICNIRP 1998: the basic limit in ICNIRP 1998 is current density; however, LF Guidelines - 2010 regards the induced electric field as the physical quantity to decide the biological effect.
- For 100 kHz to 10 MHz, the basic limits are SAR recommended in ICNIRP 1998 and the induced electric fields in LF Guidelines – 2010.

2.2.2 Institute of Electrical and Electronic Engineers (IEEE)

It is a professional organization whose objective is to cultivate technological innovation and ethics for the benefit of humanity. The NIR standards formulated by IEEE are approved by the American National Standard Institute (ANSI) and used as the USA national standards[20]. The NIR standards formulated by IEEE are as follows:

- IEEE C95 series (IEEE C95.1 – 2005/C95.1a – 2010/C95.6 – 2002) and (IEEE C95.2 – 1999/C95.3 – 2002/C95.3.1 – 2010) assessment methods of electric, magnetic and electromagnetic fields recommends the NIR limits for 0 Hz to 300 GHz.
- (IEE C95.4 – 2002/C95.7 – 2014), guidelines for protection applications.
- IEEE 1528 series (IEEE 1528 – 2013/1528a – 2005) recommends testing technologies of Specific Absorption Rate (SAR) in the human head from wireless devices.

2.2.3 International Telecommunication Union (ITU)

Unlike other agencies the priority of this organization is not to establish NIR limits. Nonetheless, guidance on NIR hazard assessment, protection and mitigation measures from engineering application point of view in ITU-T Series K[21].

- K.52 + K.Sup2 for the protection against interference.
- K.91+K.Sup1 basic assessment guidance.
- K.61, K.93, K.83, K.90 and K.100 for the assessment, site monitoring and mitigation[22]

2.2.4 International Electro - technical Commission (IEC)

IEC develops and publishes a wide range of international standards that ensures safety, reliability and interoperability of all electrical and electronic product and related services put together by government, industries, Research laboratories, Academic and Consumer groups[23]. With regards to NIR emitted by cellular devices, the IEC has formulated:

- Radio Communication Base Station: IEC 62232 dictates the RF fields and Specific Absorption Rate (SAR) exposure in the locality of base stations.
- Hand-held and body mounted wireless communication devices: IEC 62209-1 and IEC 62209-2 for the evaluation of SAR for Hand-held wireless communication devices used in close proximity to the Ear and Human body respectively[22].

2.3 Electromagnetic Field exposure Limits

The frequency scope of emanation of most hand-held radiotelephone frameworks involving the communication between portable handsets and fixed base transmitters that provide coverage of explicit territories (cells) is from around 800 MHz to 2 GHz for current innovations. Limiting exposure guideline to EMFs are established to provide high level protection for both occupational individuals and the general public against substantiated adverse health effects from exposures to radio frequency EMFs. There are basic restrictions which relates to physical quantities involved with radio frequency induced adverse health effects inside an exposed body, which cannot be easily measured and an easily evaluated Reference levels derived from the basic restrictions to provide a more practical means of demonstrating compliance with the guidelines. Reference levels provide an equivalent degree of protection to the basic restrictions and thus, an exposure is taken to be complaint with the guidelines if it is shown to be below either the relevant basic restrictions or the relevant reference levels[24].

The interaction of 800 MHz to 2 GHz with biological tissues are related to the rate of energy deposition per unit mass commonly measured with a Specific Absorption Rate (SAR) dosimetric quantity expressed in unit watts per kilogram (W/Kg) for basic restrictions since it results in localized RF exposure for hand- radio Telephones. Compliance demonstration of the basic restriction or limits which are formulated in SAR are achieved experimentally through measurement in anatomical phantoms. However, base station radiating transmitters within the same frequency range results in whole body exposure of occupational workers and the general public. A practical assessment of which is obtained using reference levels formulated in Electric Field strength (E-Field), Magnetic Field strength (H-Field) and Power Density expressed in V/m, A/m and W/m^2 respectively[25]. The exposure limit in Table 2.1 represent the General Public Reference levels for exposure, averaged over 30 min and the whole body, to electromagnetic fields from 100 kHz to 300 GHz (unperturbed RMS values) for ICNIR and IEEE.

Table 2.1 General Public Reference Levels of Exposure [24][26]

Agency	Exposure scenario	Frequency range (MHz)	Electric field strength (E) (V/m)	Magnetic field strength (H) (A/m)	Incident power density; Sinc (W m−2)	Power density (S) (W/m2) SE
ICNIR	General Public	0.1 -30 >30 -400 >400 - 2000 >2 – 300,000	300/Fm^0.7 27.7 1.375Fm^0.5 NA	2.2/fM 0.073 0.0037fM^0.5 NA	NA 2 FM/200 10	
IEEE	Unrestricted	0.1 -1.34 1.34 – 30 30 -100 100 -400 400 -2000 2000 - 300,000	614 823.8/FM 27.5 27.5 NA NA	16.3/FM 16.3/FM 158.3/FM^1.668 0.0729 NA NA		1000 1800/FM^2 2 2 FM/200 10

2.4 The Cellular System

The cellular system consist of a radio network distributed over a specific area (cell) with the aim of providing coverage and mobility, capacity and quality services using transmitters and antennas that forms base transceiver stations to provide access to users. The backbone of the system is a switching center (mobile switch center) consisting of a Home and Visitor Location Registers (HLR, VLR) that establish connection between elements of the cellular system, the Public Switch Telephone Network (PSTN) and the cellular Mobile Subscribers (MS)[27].

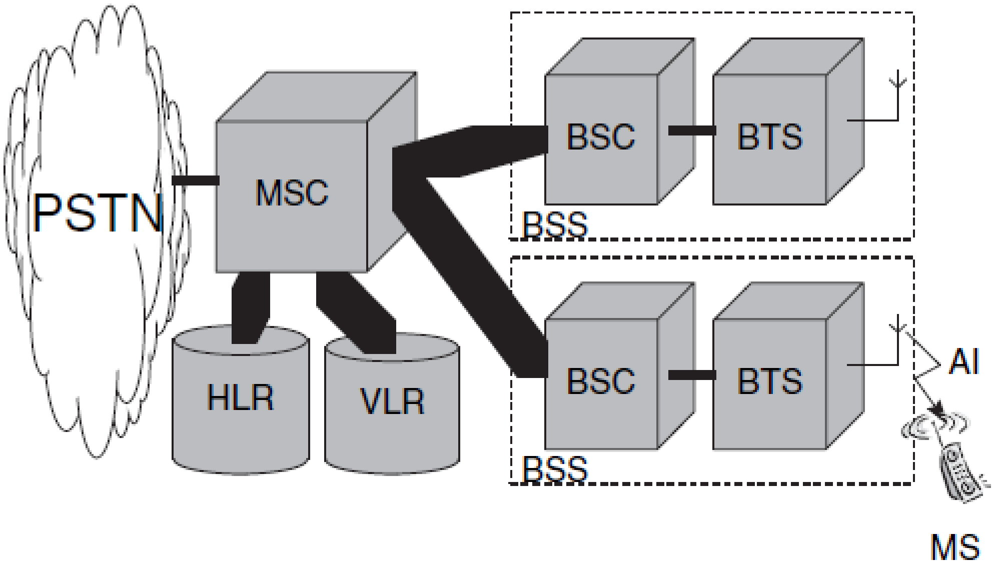

Figure 2.1 Elements of Cellular System with GSM Terminology[27]

The cellular idea replaces single high power transmitter with many low power transmitters consisting of BTS, each providing coverage to only a small portion of the service area (cell) as shown in Figure 2.2.

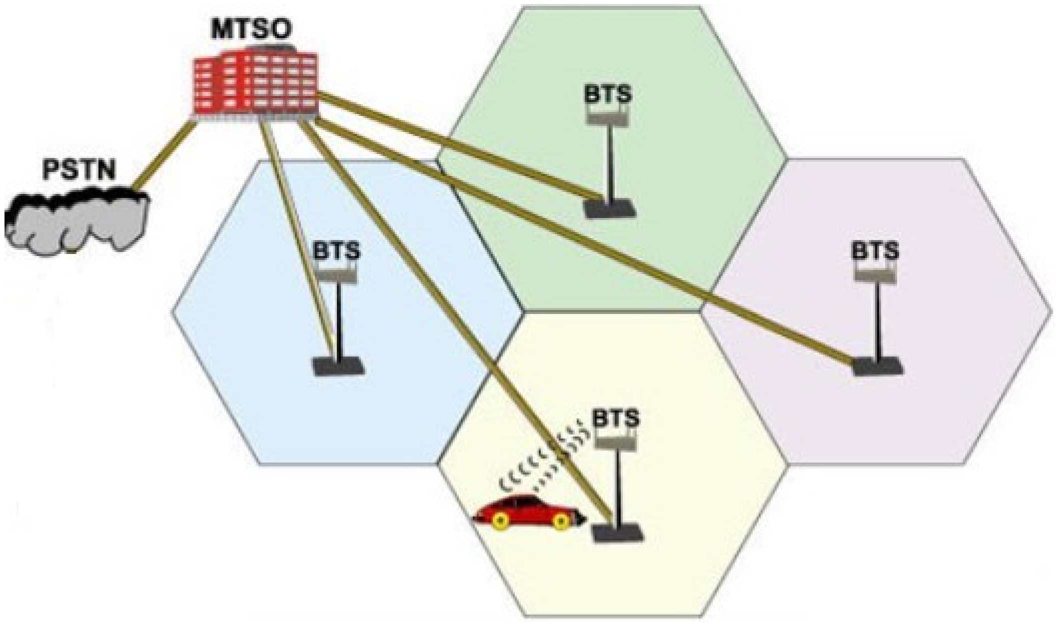

Figure 2.2 Topology of the Cell System[28]

2.5 Base Station Antennas

An antenna is a resonant device consisting of metal rods or dish that convert electrical signals translated from signal sources into electromagnetic waves for transmission or converts electromagnetic waves to electrical signals for reception. The electromagnetic wave is created by the vibration of electrons of the translated electrical signal producing a wave which travel through space at the speed of light. At the reception, the electromagnetic wave flows through the antenna for reception and causes electrons to wiggle back and forth recreating the translated electrical signal and thus, the source signal. Antennas are a key element in any radio communication. They are used in systems such as cellular, radio broadcasting, broadcast television, two-way radio, radar, satellite and many more. Other devices such as wireless microphones, baby monitors, blue-tooth enabled devices, wireless computer networks, garage door openers etc. For communication, the antenna is electrically connected to the transmitter or receiver.

A radio frequency (RF) electromagnetic wave (EMW) has both an electric and magnetic fields. Different forms of electromagnetic energy are categorized by their wavelengths and frequencies. The RF part of the electromagnetic spectrum is generally defined as that part of the spectrum where EMW have frequencies in the range of about 3 kilohertz (3 KHz) to 300 GHz. microwaves are specific categories of radio waves that can be loosely defined as RF energy at frequencies ranging from about 1 GHz and above.

During transmission, the flow of oscillating electrons and the charge of electrons creates an oscillating magnetic and electric fields respectively around the element of the antenna which radiate from the antenna into space as a moving transverse wave. At reception, this time varying fields of the radio wave exert force on the electrons of the receiver antenna elements causing them to vibrate, creating the original source. They are designed to transmits or receive signals omnidirectional (all directions) or directionally (particular direction).

Antennas can be used as both transmits and receive (transceiver) due to their reciprocity properties. The theorem states that, if a voltage is applied to the terminals of antenna A and the current measured at the terminal of another antenna B then, an equal current will be obtained at the terminals of antenna A if the same voltage is applied to the terminal of B. In other words regardless of whether it is transmitting or receiving, it will maintain the same characteristics as long as its parameters (gain) are unchanged[29].

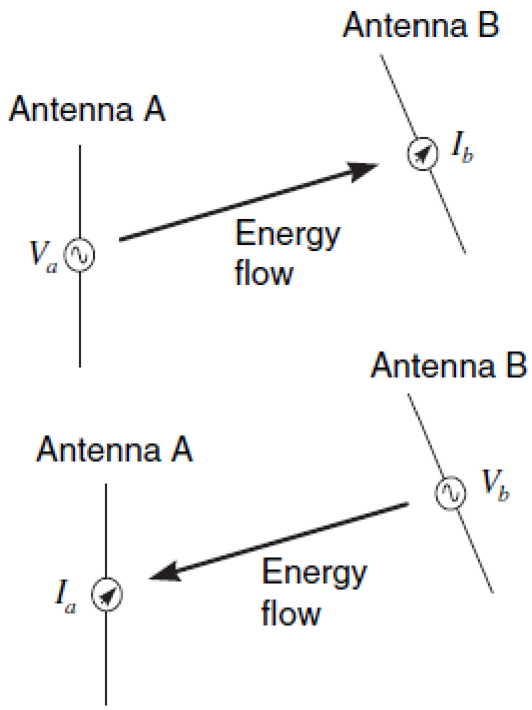

Figure 2.3 The Reciprocity theorem[27]

That is, if $V_a = V_b$ then, reciprocity theorem states that

$$I_a = I_b$$

$$\text{Therefore, } \frac{V_a}{I_a} = \frac{V_b}{I_b} \qquad (2.1)$$

For efficient transmission and reception of signals, the antenna must be tuned to the frequency band of the radio system to which it is connected. Cellular network operators design the system coverage area such that, each hexagonal cell containing a base station is divided in three sectors each covering 120 degrees in a horizontal direction. The antennas of the base stations are mounted on a roof top of building or on a mast, electrically or mechanically tilted downwards to direct the signal towards ground level. The transmitted power of the base station should be sufficient to provide quality cellular services at mobile stations a few kilometers away and therefore, most of the mast or towers are usually close to human habitations being it business or residential areas. The closer you are to the base station, the higher the radiated power, the better the signal reception but that will also mean the stronger the effects of radiation[30].

2.5.1 The Antenna Radiation Pattern

When a signal is fed into an antenna, it will emit its energy in space in a certain pattern. A graphical representation of the relative distribution of the radiated power per unit solid angle or its radiation intensity (U) in the far field into space is called a radiation pattern.

The radiation intensity

$$U = Sr^2 \qquad (2.2)$$

Where S is the power density in watt per square meter at a given distance given by the magnitude of the time averaged pointing vector and r is the distance of point of power density measurement from the antenna.

Assuming that an isotropic antenna that radiates power equally in all directions is used and the total power radiated by the antenna is P and spread over a radius r, the power density at this distance and any direction is

$$S = \frac{P}{Area} = \frac{P}{4\pi r^2} \qquad (2.3)$$

The radiation intensity

$$U = Sr^2 = \frac{P}{4\pi} \tag{2.4}$$

Which is independent of the distance r [27].

2.5.2 Far and Near Field Regions of an Antenna

Base station transmitting antennas are a source of whole body exposure of people close to them. The far field is the region of the antenna where the exposure distance from the transmitting antenna is greater than $\frac{2L^2}{\lambda}$ where L is the largest dimension of the antenna and λ is the wavelength of the field and thus, the electric and magnetic field components vary inversely with distance from the antenna and the power density varies inversely as the square of the distance. Compliance of exposure levels are determined by comparing the measured power densities, electric or magnetic fields to the stipulated reference levels by internal agencies. On the other hand, exposure in the near field is closer to the antenna where the exposure distance is less than $\frac{2L^2}{\lambda}$. The electric and magnetic field component of the radiated signal contains a substantial reactive component that interact with objects. Compliance is demonstrated with basic limits in SAR and achieved through coupled head antennas calculations of the spatial deposition of energy in the head[25]

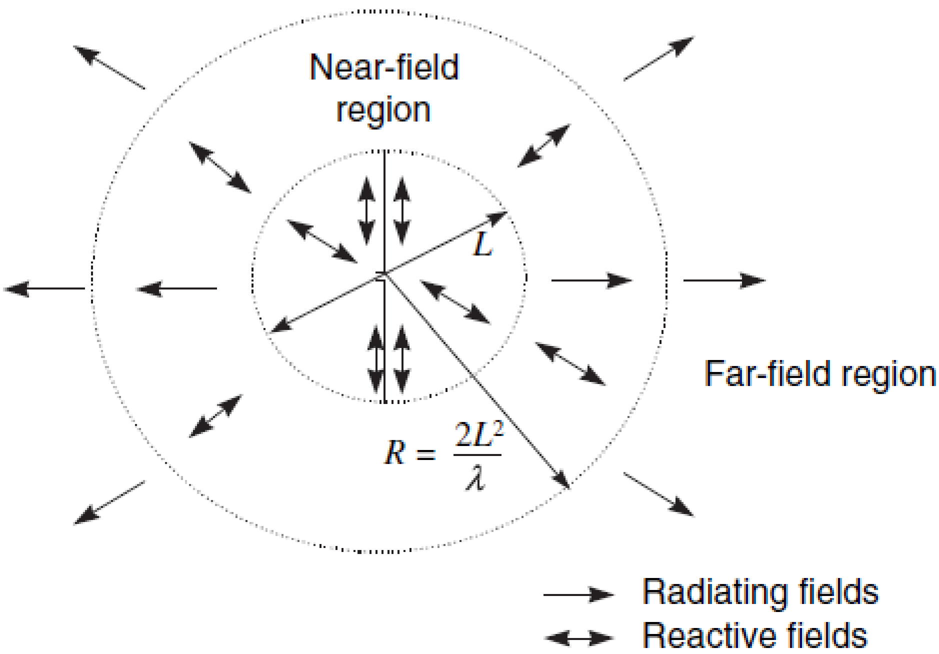

Figure 2.4 Near and Far-field Regions of an Antenna[27]

2.5.3 Types of Antennas

The types of antennas used for communication are classified based on their functionality with carefully designed parameters such as the pattern of its radiation, directivity, gain, reciprocity, bandwidth, radiation resistance and Efficiency, the beam-width, Polarization matching and aperture of reception that ensures its proper functioning. They are named as Wire, Log periodic, array, aperture, Micro-strip, reflector, and lens and travelling-wave antennas[31]. For cellular base stations, GSM and microwave antennas are used. Examples of such antennas are parabolic, hub/sector (array of dipoles), panel and log periodic antennas.

Table 2.2 Types and applications of antennas [31]

Type of Antenna	Example	Application
Wire	Short dipole, dipole, loop, mono dipole	Ships ,aircraft, automobile
Log periodic	Bow tie, log periodic, log periodic long array	Used in applications where variable bandwidth, gain and directivity is required
Array	Linear, phase, Two-element array	Used for very high gain applications, mostly when needs to control the radiation pattern
Travelling wave	Long wire, Yagi-Uda, Helical, Spiral	Satellite communication applications
Lens	Natural and Artificial dielectric, Constrained, Luneburg, Fresnel zone lens	Used for very high frequency applications
Reflector	Flat-plate, corner, parabolic reflector	Microwave communication, satellite tracking, radio astronomy
Micro-strip	Rectangular micro-strip patch, quarter-wave patch	Aircraft, satellites, missiles, cars and even mobile telephones.
Aperture	Slot, horn	Flush-mounted applications, air-craft, space craft

2.6 Communication Systems Evolution

As long as humans have existed, invention of different forms of communication have been used to exchange information, from smoke signals and messenger pigeons to the Telephone and Email. The invention of Telegraph was the biggest communication breakthrough in 1831, then came the telephone and now taken over by digital systems. In 2007, Steve Jobs revealed the first iPhone and apple paved the way for modern smart phones however, flip phones and phones with split keyboards were the norm before the iPhone.

The invention of the internet has also contributed it bit in the revolution of communication. It has made communication easier and faster regardless of location accelerating the pace of businesses and widening the space of enterprises and has provided the platform for technologies such as instant messaging, voice over Internet Protocol (VoIP) telephone calls, Two-way interactive video calls, Blogs, Social networking and discussion forums. Wearable technology that allows calls to be answered on the go most importantly while driving from devices such as smart-watches and audio sunglasses as well as virtual Reality (VR) that ensures connections in the same time space even on different continents without the time sink, nonverbal communication such as voice tones, head and hand movement, hesitations transcribed in VR that improves the understanding of participants are as a results of the internet[32].

2.6.1 Cellular Technology Evolution

Cellular Communication systems have generations in the quest to improving its benefits. The evolution has led to an increase in capacity, efficiency and flexibility for users, reduced cost and cables systems.

Table 2.3 Brief Description of Generations of Cellular Technology[33]

Generation	Period deployed	Technology	Speed	Features
1G	1970-1980	AMPS,MNT, TACS	14.4 kbps	Wireless phones were used for only voice services.
2G	1990-2000	TDMA,CDMA	9.6/14.4 kbps	Data and voice services. Multiple users on single channel are allowed through multiplexing.
2.5G	2001-2004	GPRS	171.2 kbps 20-40 kbps	Growth in streaming and multimedia services, internet usage, Web browsing on some phones.
3G	2004-2005	CDMA200 (1xRTT,EVDO) UMTS,EDGE	3.1 Mbps 500-700 kbps	Popular in multimedia services with steaming, general access and portability via different devices (PDA'S ,Telephones, etc.
3.5G	2006-2010	HSPA	14.4 Mbps 1-3 Mbps	Higher speed and throughput for higher data services.
4G	2017-2020	WiMax, LTE, Wi-Fi	1-3Mbps 100-300 Mbps 3-5 Mbps 100 Mbps (Wi-Fi)	Increased speed to support to higher data demand services Roaming, further portability increase and high definition streaming.
5G	2020	OFDM with millimeter wave	Estimated 20 Gbps peak data rate.	Will provide an even higher speed in gigabits to consumers and ensure efficient use of bandwidth when deployed.

2.7 Cellular Operators in Ghana

Over the last two decades, Ghana's telecommunication sector has gone through phases of growth and diversification. It is presently characterized by vibrant competition and innovative product and services. There are two classifications of the Telephony licenses, the Fixed and the Mobile. There are four (4) Telephony companies currently in operation in Ghana. The table below indicates the operators, their platform used and the spectrum of operation[34]

Table 2.4 Cellular Networks in Ghana, platform and Spectrum of Operation[35]

Operators	Platform	Spectrum
Airtel-Tigo	WLL, GSM/WCDMA, Fiber	900/1800/2100/800 MHz
Ghana Telecom (Vodafone)	Copper, Fiber, WLL, GSM/WCDMA, Fiber	900/1800/2100/800 MHz
Scancom Ghana (MTN)	GSM/WCDMA, Fiber	900/1800/2100/800 MHz
Glo Ghana	GSM/WCDMA, Fiber	900/1800/2100/800 MHz

Table 2.5 Downlink Spectrum Allocation for cellular systems in Ghana[36]

Cellular Service/Technology	Frequency Band (MHz)
2G mobile	921 -925, 925 - 960 1805 - 1880, 1880 - 1900
3G mobile	2110 - 2170
4G mobile	791 -821, 821 - 880 2620 -2690, 2690 - 3000

2.8 Related Work on Radio Frequency Radiation Measurement and Assessments

Several research work has been done in relation to radio frequency Electric, Magnetic and Power density of cellular systems in many countries to ascertain safety limits of NIR emitted by these systems to ensure compliance and safety of both restricted and unrestricted environments since it forms a core part of human activities and communication. A collection of literature in relation to this research has been reviewed and summarized in the succeeding narrative.

In the research done by Hedendahl et al. 2017, " measurement of radio frequency radiation with a body-borne exposimeter: A broadband measurement was done to assess RF emissions in classrooms by measuring the teachers RF exposure so as to approximate the exposure of the children with a body-borne exposimeter EME-Spy

200. Eighteen (18) teachers from seven (7) schools carried the instrument from 1-4 days of work.

The type of Wi-Fi connectivity and the activities in the classroom and that of the teachers were recorded during the measurement to verify the NIR long term adverse effects of using wireless devices for educational purposes. They observed variations in the level of exposure of different Wired Internet, Wi-Fi systems, GSM/3G/4G, whether there were video lessons and if the students were connected to Wired Internet, Wi-Fi, GSM/3G/4G or both. The measured mean exposure ranged from 1.1 to 61.1 μW $/m^2$.

A mean of 396.6 μW $/m^2$ was recorded when student were allowed to watch a five (5) minutes YouTube video and when students connected to GSM/3G/4G systems with their mobile phones, a mean of 82,857 μW$/m^2$ was recorded and yet, far below ICNIR reference levels. However, they reported that most of the measured mean levels were above the precautionary target level of 3-6 μW $/m^2$ proposed by the Bio-initiative report of Sweden. Their recommendation was that to minimize the level of exposure in schools, mobile phones should be placed on plane mode and Wi-Fi Networks disconnected when not in use because an access point over the teachers head had a higher exposure level when Wi-Fi and GSM/3G/4G were accessed by students compared to the exposure of a school with just Wired Internet.

They concluded that Wired Internet is a better option for internet connectivity in schools and the length of time of wireless device connectivity should be reduced since it is a determinant factor of the exposure level[17].

Mutlu & Kurnaz, 2019, in their work " experimental study in electromagnic field strengh measurement in MRI room: The level of Electromagnetic Field strength exposed to patient and staff of Ordu University Research Hospital in the Magnetic Resonance Imaging (MRI) room in Turkey. MRI is a medical monitoring technique where hydrogen atoms are stimulated and vibrated to resonate in a strong magnetic field, and the obtained signals are converted into an image with high contrast and resolution. To obtain the MRI image of any specified region, patients are taken to a strong static magnetic field for the stimulation of hydrogen atoms. EMF, such as 1.5 Tesla/64 MHz, is applied to the region to be monitored for the protons to absorb the sent energy and to divert from their positions according to the absorbed energy value and during this process, magnetic energy is given. Measurements were made at a sample rate of two-second by placing the MRI device near the patient's foot tips for 20 minutes. Three measurement were carried out.

- Measurement of the static magnetic field used to stimulate hydrogen atoms with "Spectran NF-5035" EMF meter, 0 Hz - 1 MHz is used. The maximum magnetic field strength is recorded as 1104 A /m with a mean of 259.8 A/m and a standard deviation is 319.2 A/m.
- EMF measurements in staff room using EMR-300 with an isotropic probe of 2244/90.21, 100 kHz- 3 GHz. The maximum H value obtained is 0.0151 A/m, mean of 0.0045 A/m and standard deviation is 0.0036.

Patients' exposure measurement for controlled and uncontrolled media with Narda EMR-300" EMF meter and 2244/90.27 magnetic field probe 27 MHz -1 GHz. maximum H value is 0.1729 A/m. Mean of is 0.0586 A/m and the standard deviation is 0.044 A/m.

It is seen from the measurement results that for both controlled medium (0.16 A/m) and uncontrolled medium (0.073 A/m) patient is exposed to a magnetic fields that are above the limits determined by ICNIRP. However, the results obtained for (i) and (ii) are below the ICNIR reference levels[37]. In the work by Pastrav et al., 2018, " evaluating the electromagnetic pollution in the 700 – 1000 MHz frequency range in urban areas: an investigation into the level of NIR pollution levels of cellular systems in 16 locations in the capital city of Romania using the R&S Handheld Spectrum Analyzer, the isotropic antenna and the dedicated software specifically designed for EMF measurements. The strength of the EMF obtained complied with the existing regulations limits however, the highest maximum levels were obtained at 790 MHz-820 MHz and 920 MHz-960 MHz frequency bands, corresponding to transmissions in 2G, 3G and 4G mobile cellular Communication networks in Romania[38].

Przystupa et al., 2019, in the paper " assesment of electromagnetic pullution in towns: it was reported that, base stations of mobile phones are the main source contributing to EMF pollution in the city of Vinnytsya, Ukraine. The average power densities measured 2 m above ground level ranged from 0.008 to 0.018 W/m^2 for mobile base stations was lower than the maximum permissible limits for Ukraine

(0.025 W/m^2) and much lower than the permissible limits in Poland, as well as extremely lower than the permissible limits in most European countries, the USA and Japan, however, at the height of a third floor building and above, permissible levels were exceeded.

Measurement was carried out in four different cases. Measurement of 50 Hz frequency electromagnetic field (industrial frequencies) from energy transmission lines, cables, industrial equipment, transformers, office equipment using the electromagnetic field detector BE-50, Measurement of electromagnetic field intensity from office equipment, computers, video- and other displays in the range of 5 Hz–400 kHz in residential buildings and offices, Measurement of electromagnetic field intensity in the radio and microwave range frequency range of 30 kHz– 300 MHz with the electromagnetic radiation detector PZ-41 and Measurement of geomagnetic field intensity (induction). Permissible levels for computers in office buildings (0.06-0.07 W/m^2) at height of 5th floor and overhead energy transmission lines of 330 kV and 110 kV Voltages (170 V/m) were about 10-15% beyond safety limits[39].

In a work by Santana et al., 2017, " measurement campaign on the electromagnetic environment in the central region of the city of Mossoro: a study in the distribution of the electromagnetic pollution by measuring the intensity of the electromagnetic fields in a broad band from 10 MHz to 8 GHz and estimate how these fields are spatially distributed using interpolations techniques with a three Axis Field Strength Meter, TM-196 for 6 minutes at 50 locations. An average results of 28 V/m of electric field, 0.073 A/m of magnetic field, and $2\,w/m^2$ of power density was obtained which is below the exposure limit values established by the ANATEL agency. The spatial distribution showed that the highest intensity of radiation were obtained in areas of about 130 meters from the nearest mobile telephony tower and, three of them, P27, P45 and P25, are located at midpoint between two towers causing a cumulative effect of radiation at those locations[40].

Teixeira & Hasan, 2016, " assessing electromagnetic radiation in our environment: the radiation levels of mobile Phone transmissions out and inside a dormitory building was examined. Several indoor buildings house femtocells (indoor cellular antennas) to reduce the distance between the transmitting node and the user. While femtocells provide improved performance for the user, they may also expose users to additional radiation. The ISM band was crucial in their research because most of the unlicensed communication activity takes place in that band Bluetooth and Zigbee also make use of that band. The dosimetric measurements were taken inside the dormitory building of the Natural Science Campus of Sungkyunkwan University, South Korea in steps of 1 meter apart using Electro- smog meter TES- 92, 50 MHz – 3.5 GHz for 6 minutes. Average values of 3 v/m and (30 v/m, 24 v/m and 32 v/m) respectively for dosimetric buildings and cellular base stations. It was established that the highest field intensity came from mobile stations even though they were below the maximum allowable thresholds[41].

In a research by Kurnaz et al., 2016, " monitoring of rf/microwave field strengh at schools in a pilot district in Sumsun/Turkey: EMR measurements in 92 schools to assess the level of EMR effects on students and staff were conducted. On the bases that WLAN and wireless devices had become a core components of learning and research and that its installation had increased on campuses.

In Ilkadim district, an investigation was carried out twice in 2016 considering the population. The PMM–8053 with EP-330 isotropic electric field probe was used for broadband while frequency selective (narrowband) was done with Narda SRM–3006 with a 3501/03 isotropic E-field probe. GSM system recorded the highest levels, the mean values recorded for 6 minutes was 1.1124 v/m and 0.5854 v/m for high and reduced population respectively.

The reason of significant decrease in the maximum E may be the less student population (reduce mobile data usage) at the time of second measurement. They recommended that though the levels are below that of ICNIR, to providing a wide margin of protection and evaluating the health risks they may cause, regular control/measurement of exposed EMR levels should be performed[42].

Etem & Abbasov, 2016, in a paper "electric field measurement of a base station at 2G and 3G frequencies: electromagnetic radiation measurement at a base station in two directions were made and the results compared. They analyzed the relation between electromagnetic radiation and mobile phone users and radiation level with distance with SMP2 EMR device 1 Hz -18 GHz that measures in electric field, magnetic field, power density, along WPT Mobile Frequency Probe. For a time interval of 6 minutes, the maximum average was recorded at 3.84 v/m in a classroom and 2.46 v/m in a housing environment and observed that, the radiation decreases with an increasing distance. The results were below the safety limits[43].

Alvarado et al., 2018 in their work " statistical analysis of radiation levels allowed by international standards in conglomerate wireless systems in differnet Urban areas of the city of Guayaquil: The investigated the NIR levels of wireless systems in urban cities with the SPECTRAN HF-2025E 700 MHz to 2.5 GHz for 6 minutes. The highest average recorded was 0. 010172248952 W/m^2 which is below the safety limits. However, they observed that this value is about 49 percent of the safety levels established and that if there is a population growth of equipment the values of the densities to be accumulated would exceed the exposure limit[44].

In a research by Gil & Fernández-García, 2016, " study of exposure to time varying electric fied in the Eseiaat UPC school: the level of exposure to time-varying electric fields up to 18 GHz in the main building of the ESEIAAT School was studied and compared with regard to the Legal regulation by means of the electromagnetic field meter SMP2 and a WPF18 broadband isotropic probe (1 MHz–18 GHz) to assess the radio electric environment and the potential RF sources. The maximum observed electric field corresponded to 2.53 V/m measured at the sound laboratory. Since the reference level for general public exposure to time-varying electric field is ranged from 28–87 V/m in the studied frequency range, they conclude that all the scenarios under analysis comply with the standard regulation[45].

In a paper "measurement and analysis of radio frequency exposure level from different mobile base transceiver station in Ajaokuta and environs, Nigeria by Ushie, The power densities of ten (10) base stations covering four networks (MTN, GLO, Airtel and Etisalat) were measured with a handheld three-axis RF meter (electrosmog meter) 50 MHz to 3.5 GHz from a distance of 0 m to 125 m apart from the base station in steps of 25 m. They determined that, values were found to be below the standard limit (4.5 W/m^2 for 900 MHz and 9 W/m^2 for 18000 MHz) set by the International Commission on Non-ionizing Radiation Protection (ICNIRP) and other regulatory agencies. The highest mean value of 173 μW /m^2 was recorded at an MTN base station at a distance of 75 m away from the base station. They concluded that the increase at certain distances might be as a result of other RF emission from gadgets like radio transmitters, TV antennas etc. [46].

2.9 Summary of Similar Works

Table 2.6 Summary of similar Works

S/N	Reference no of Paper	Method/ Technology	Results	Country Year	Remarks
1	[17]	Broadband/ Wired Internet, Wi-Fi, GSM/3G/4G	Max. mean 61.1 µW $/m^2$ mean 396.6 µW $/m^2$(5m video) 82,857 (gsm/3g/4g)	Sweden, 2018	Total radiation is not as a result of only cellular systems. Absorption rate for children and adult differs.
2	[37]	Narrowband/ Staff room Controlled uncontrolled	Staff room: 0.0045 A/m Controlled: (0.16 A/m) Uncontrolled:(0.073 A/m)	Turkey 2019	Near field approach would have been appropriate since the MRI is a near field device
3	[38]	Broad and Narrowband 2 m above ground, third floor building and above	BTS 2m(0.008- 0.018 W/m^2) BTS/3F(0.023 W/m^2) 330kV ,110kV(170V/m) Computers(0.06-0.07W/ m^2) Note: BTS= 0.025 W/m^2, BTS is main NIR Contributors	Ukraine 2019	Total radiation for third floor buildings and above is not as a result of only cellular systems.
4		10-MHz-8GHz Broadband method	28 V/m 0.073A/m	Brazil,2	The technology is not

	[39]		$2W/m^2$ Spatial distribution	2017	mentioned
5	[40]	Broadband, Indoor, BTS	4^{th} f :(3 v/m) Basement: (2.2 v/m) BTS:(30 v/m, 24 v/m and 32 v/m)	South Korea, 2016	Results of other sources of radiation to the total radiation at base station and indoor are not stated
6	[41]	Narrowband BTS, radio and TV broadcasting	BTS 1.8 μW/cm^2 Radio and TV (0.27518 μW/cm^2)	Spain, 2018	Only GSM systems were measured
7	[42]	Broadband GSM900 GSM1800	1730 μW $/m^2$	Nigeria, 2013	The results includes everything from 50MHz-3.5GHz and thus does not represent the true reflection of BTS radiations.
8	[43]	Broadband Wireless systems	Max: 0.010172248952 W/m^2 49% of limit further increase in device population is dangerous	Ecuador 2018	Wireless systems used and corresponding results are not stated
9		Broadband Narrowband High population	High population 1.1124 v/m Reduced Population 0.5854 v/m	Turkey, 2016	Results obtained from narrowband

	[44]	Reduced population			measurement is not mentioned.
10	[45]	Narrowband Classroom Housing	Class room: 3.84 v/m Housing: 2.46 v/m	Turkey, 2016	The distance of measurement for both scenario was not stated
11	[46]	Broadband Not stated	Max value at sound lab: 2.53 V/m was as results of audio from instrument.	Spain, 2016	Other scenarios of measurement are not stated

In conclusion, different instrument and measurement scenarios has been adopted in a broad and narrowband method in several countries to assess the safety of radiation levels in public areas. Most of the results are below the standards set by both international and local regulatory agencies.

CHAPTER THREE
TOOLS AND METHODOLOGY

3.1 Introduction

This chapter discusses the method and tools used in the measurement of radiation levels and processing of raw data in decibel per meter into power density in watts per square meter in accordance with stated reference levels for far field measurements.

3.2 Tools

The following Tools or materials are used in developing the methodology.

- RF Explorer 6G Combo Spectrum Analyzer
- Global Positioning System
- Table
- Tripod Stand
- Laptop
- Tape Measure

3.3 Methodology/Measurement Scenarios

In developing the method, forty locations in unrestricted environment classified under three study areas as residential, commercial and University campuses were considered. The selected locations are situated in the Greater Accra, Ashanti and Eastern regions of Ghana. To analyze the NIR levels in power density, measurements of radiation levels in decibel meter (dBm) is carried out and the data, processed with mathematical equations to obtain the results which is then analyzed with MATLAB.

3.3.1 Residential Study Area

Measurement in residential areas were done in Koforidua Eastern Region. The locations are chosen so as to analyze the levels of NIR levels in homes. Fourteen residential locations consisting of six which are near base station with the code name (RNBS1 to RNBS6), five residence away from base station (RABS1 to RABS5) and three campus residence (CR1 to CR3) taking from the universities under study. Residence that are five meters away from the reference base station are categorized as residence near the base station and those fifty meters and above, residence away from base station as described in the location Table 3.1. The measurements were done outdoor and lasted for thirty minutes at each location with the exception of RNBS6 which was carried out indoors for 24 hours.

Table 3.1 Description of residential locations

S/N	Name of location	Description	Distance from Reference Base station
1	RNBS1	Slaughter house Koforidua	5 m
2	RNBS2	Opposite Acapoco near KTU junction	5 m
3	RNBS3	Koforidua zongo	5 m
4	RNBS4	Koforidua Ghanas environs	5 m
5	RNBS5	Koforidua Nsukwao Traffic light	5 m
6	RNBS6	Adweso Koforidua	5 m
7	RABS1	Slaughter house Koforidua	50 m
8	RABS2	Adweso	50 m
9	RABS3	Koforidua zongo	50 m
10	RABS4	Ghanas environs	50 m
11	RABS5	Koforidua Old Estate	50 m
12	CR1	Between Katanga and Shaba hostels KNUST	150 m
13	CR2	Get fund Hostel	150 m
14	CR3	Legon hall	65 m

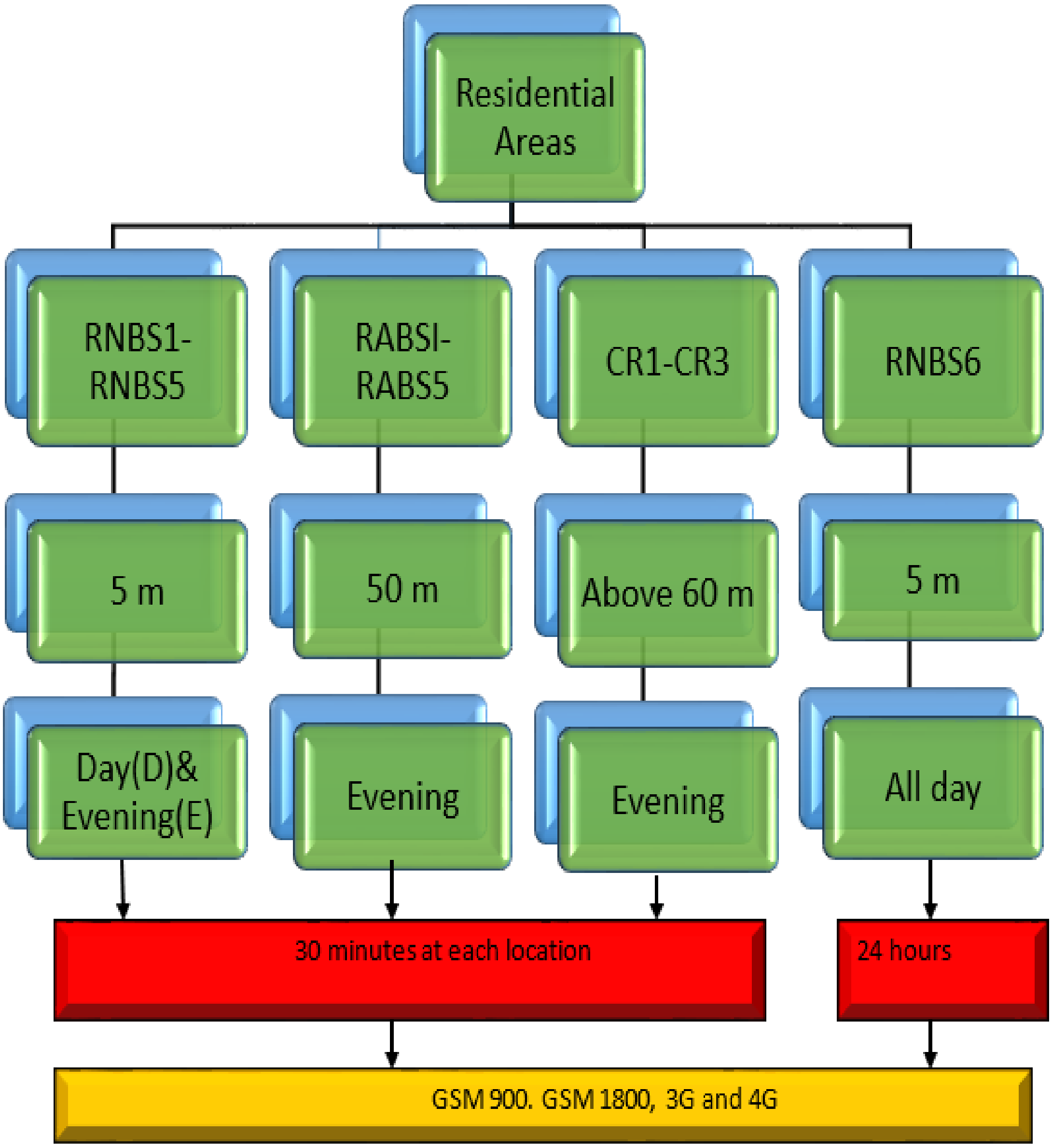

Figure 3.1 Residential measurement structure

3.3.2 Commercial Study Area

Twenty locations categorized as outdoor commercial area market (OCAM), outdoor commercial area offices (OCAO), indoor commercial area offices (ICAO) and outdoor commercial area industrial (OCAI) were studied. The location and distance from their respective reference base stations are described in table 3.2.

Table 3.2 Description of commercial locations

S/N		Location	Description of location	Reference distance
1		OCAM1	Between Vodafone and all nations market/lorry station	30.1 m
2		OCAM2	Madina Zongo junction market	80 m
3		OCAM3	Accra Melcom, post office environs	78 m
4		OCAM4	Adenta market near Total filling station	10 m
5		OCAM5	Koforidua central market	100 m
6		OCAO1	Koforidua post office	41 m
7		OCAO2	Koforidua ministries	193 m
8		OCAO3	Koforidua SNNIT compound	20 m
9		OCAO4	Gallaway Traffic Koforidua	97 m
10		OCAO5	Silver Star Tower Airport	83 m
11		ICAO1	Opportunity bank	5 m
12		ICAO2	Ministries	145.3 m
13		ICAO3	Koforidua Ghana post	50 m
14		ICAO4	Antartic plaza stores	10 m
15		ICAO5	Koforidua SNNIT building	25 m
16		OCAI1	Bethlehem – Unispam company limited	10 m
17		OCAI2	Behind Reroy company	25 m
18		OCAI3	Near Top ten International company	11.3 m
19		OCAI4	Opposite Tasty Tom company	9.8m
20		OCAI5	Moifoods company Ghana limited yard	8.4 m

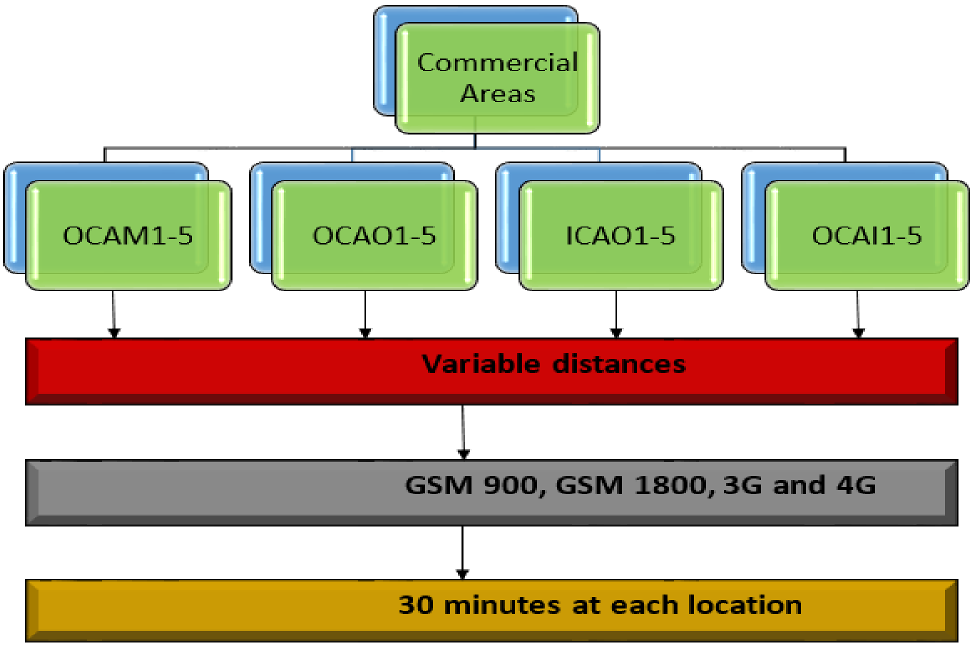

Figure 3.2 Commercial measurement structure

3.3 3 University Campuses Study Area

The campuses under study are Koforidua Technical University (KTU), Kwame Nkrumah University of Science and Technology (KNUST) and the University of Ghana, Legon (UG) in the Eastern, Ashanti and Greater Accra Regions respectively. The measurement takes place when school is in session and during vacations representing high and low populations respectively. The code names for this study area are UGHP, KTUHP, KTULP, KNUSTHP and KNUSTLP for a high and low population (HP and LP) attached to the initials of the universities.

Table 3.3 Description of University locations

S/N	Location	Description locations	Reference distance
1	UGHP	College of humanities building	20 m
2	KTUHP	Between CCB and admissions block	20 m
3	KTURP	Between CCB and admissions block	20 m
4	KNUSTHP	In front of Petroleum building	20 m
5	KNUSTRP	In front of Petroleum building	20 m

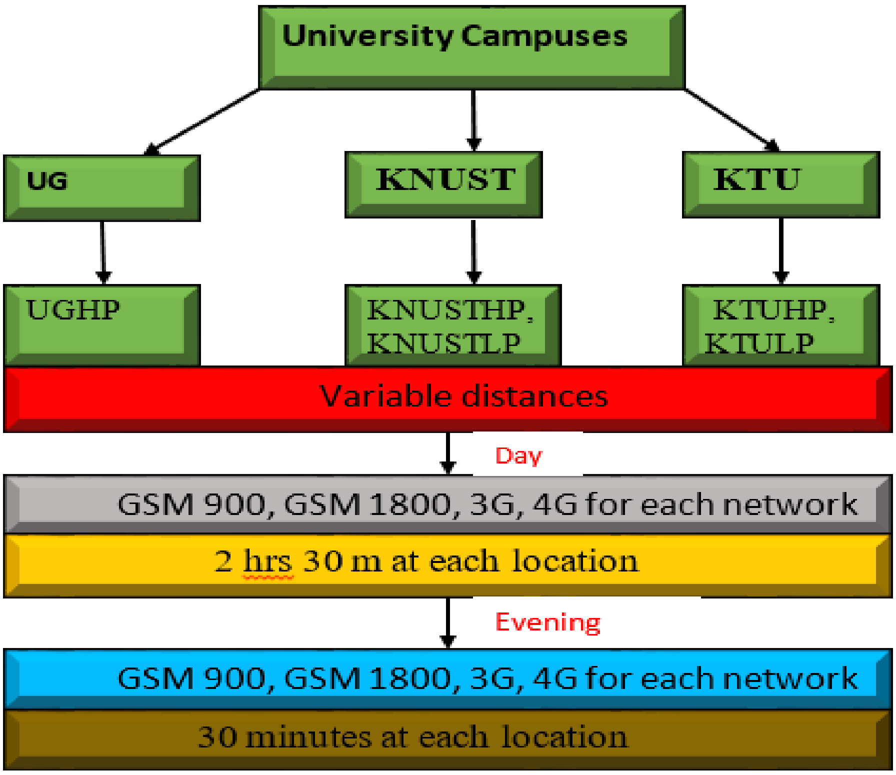

Figure 3.3 University campus measurement structure

3.4 Measurement procedure

Once the area of study is decided, a survey of the area is done to pinpoint the exact location where the measurement will take place by moving around that environment with the Analyzer in the hand of the operator pointed to the sky. There may be more than one base stations around the chosen location and thus, a reference base station which is the nearest to the measuring point is located. The distance between the point of measurement and the reference base station is then estimated and the measuring setup is erected at a height of 1.5 meters above ground as shown in the measurement setup below.

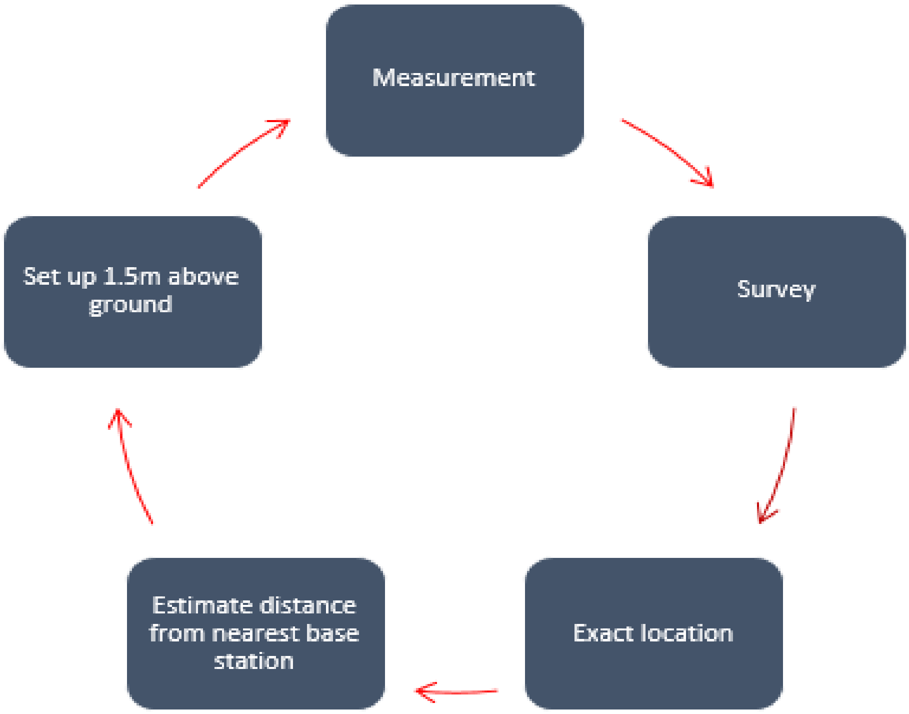

Figure 3.4 Procedure for measurement

Measurement at the residential evening and day, business and Campus evening areas are measured over a period of thirty (30) minutes at each location by scanning the frequency spans of the available Technologies used by the network operator (GSM 900, GSM 1800, 3G and 4G) for six (6) minutes each, while measurements at the campuses day time are obtained over a duration of two (2) hours thirty minutes at each location. For each technology, the spot frequency for each network operator is scanned in order to estimate their percentage contribution to the total radiation measured over the period. In the 24 hour measurement, the deployed systems or technologies are each measured for fifteen minutes within every hour.

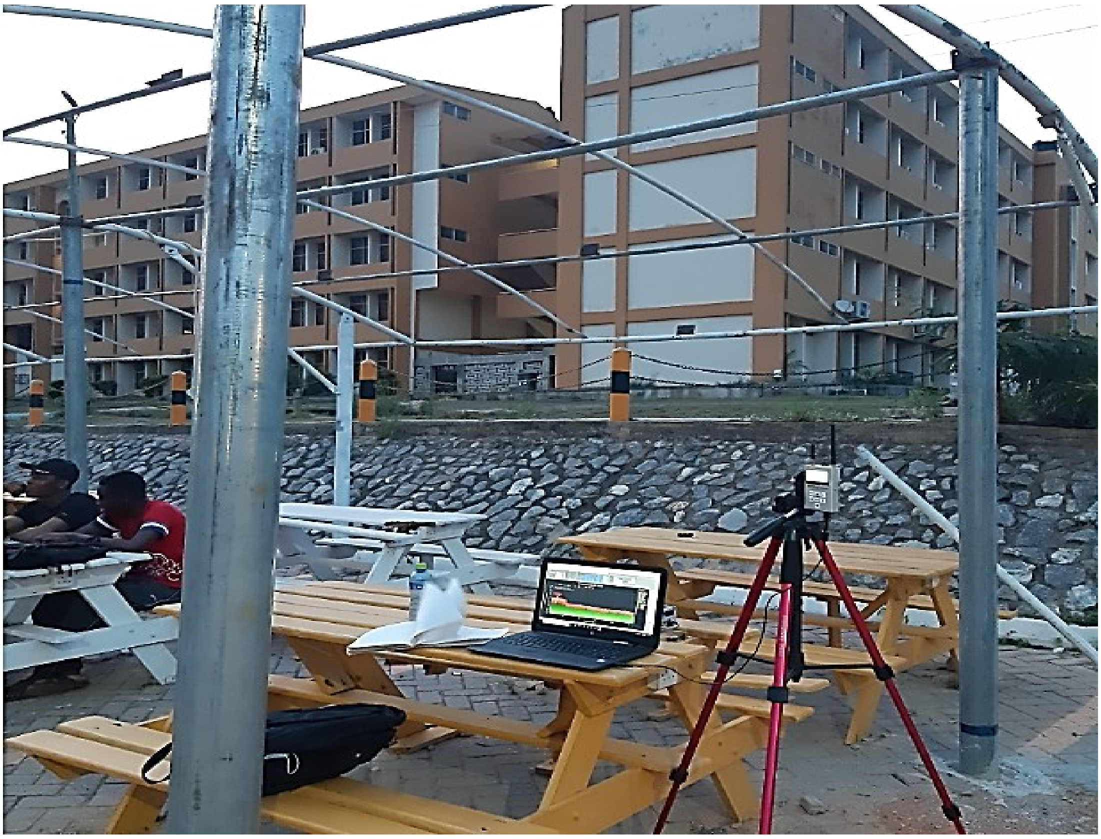

Figure 3.5 Measurement Setup

3.5 Data Processing

The energy or field strength radiated into space by a cellular base station is evaluated by measurement, calculations with equations or a blend of measurement and calculations. The results of this research is obtained by a combination of measurement with an RF Explorer 6G Combo Spectrum Analyzer and calculations using the Friis Free Space propagation equation which establishes a known field strength in free space[47].

The power measured at a far field distance d from a base transmission station with the Spectrum Analyzer is expressed in decibel relative to one milli-watts (dBm).

$$\text{dBm} = 10\log\left(\frac{p(watts)}{1mw}\right) \quad (3.1)$$

$$\text{P (watts)} = 1000 * 10^{\frac{P(dBm)}{10}} \quad (3.2)$$

However, the compliance for NIR radiation is stated in watts per square meter (power density) which an expression of the measured power or field strength in relation to the physical space. The power density (S) received a distance d from the transmitting base station is given by the Friss equation as

$$S = \frac{P_r G}{4\pi d^2} \qquad (3.3)$$

Where, P_r is the power in watts delivered to the receiving antenna of the spectrum Analyzer and G, the effective gain of the antenna which is isotropic, d is the distance from the reference base station where the measurement is conducted. The denominator of the equation represents the surface area of a sphere in this case, the area of measurement. The received power pr and the distance d is obtained in measurement as shown in the table of collected data and location tables respectively. The gain G of the antenna is specified by the instrument manufacturer in its specification.

3.6 Instrumentation

3.6.1 Spectrum Analyzer

A portable handheld digital RF Explorer 6G Combo Spectrum analyzer that weighs 185 grams was utilized in the measurement of electromagnetic field radiation at the selected locations. The module incorporates a 6G units in addition to an RFEMWSUB3G Expansion module. It has two SMA connectors and three antennae. An NA733 Nagoya wideband Telescopic antenna with a gain of 2 dBi for sub-GHz frequencies , 5.8 GHz rubber duck with a gain of 3.5 dBi and a 2.4 GHz whip helical antennas which offer coverage for frequencies used in most modern telecommunication technologies. The range of frequencies that can be monitored by the combined module is 15 MHz to 2.7 GHz and 4.8 GHz to 6.1 GHz. It is isotropic in nature (three axis) and applied in areas such as GSM, Wi-Fi, LTE, GPRS, Wireless audio and video, Satellite DTV, CATV and more. It also comes with a firm wear for windows and MAC and a 2.0 USB for additional analyzing functions[48].

Figure 3.6 RF Spectrum Analyzer with Antennas

3.6.2 Specification

- Frequency band 15 MHz – 2.7 GHz and 4.8 – 6.1 GHz
- Frequency span 112 MHz – 600 MHz
- Graphics LCD 128 x 64 pixels
- PC Window client support windows XP/Vista/Windows 7 both 32 and 64bits
- 4.8 MHz – 6.1 MHz, dynamic range of -105 dBm to -15 dBm
- Right SMA port (WSUB3G) 15 MHz – 2.7 MHz, dynamic range of -110 dBm to -10 dBm
- Absolute maximum power input (without damage)
  - Right SMA port (WSUB3G) +35 dbm
  - Left SMA port (6G) 30 dBm
- Average noise level -115 dBm for (WSUB3G) and -105 for Left SMA port (6G)
- Frequency stability and accuracy -10 ppm and -0.5 ppm for right and left port respectively
- Amplitude stability +-6 and -3 dBm for right and left ports
- Frequency resolution 1 KHz
- Resolution bandwidth (RBW) 58 KHz to 812 KHz
- Size 113 x 70 x 25 mm

3.6.3 Principle of Operation

A digital spectrum Analyzer is a type of radio receiver that utilizes the super heterodyne guidelines or rules as its basic standard of operation. It make use of a local oscillator and a mixer to convert the frequency. The input signal frequency is converted to a lower frequency with the help of high performance low and band pass filters. The input frequency to the analyzer is changed by varying the frequency of the local oscillator[49]. It consist of a screen that displays the level of the received signal. Like a graph, it has a vertical axes which is usually logarithmically scaled to ensure wide display for the amplitude of received signal levels with respect to frequency on a liner adjustable horizontal axes to suit the frequency range of interest. The scale on the vertical axes is calibrated in decibel relative to 1 mill-watt (1 dBm) and thus, has to be converted to watt in order to estimate the radiation in terms of power density.

3.6.4 Configuration

The following steps were taking in configuring the RF Explorer for the measurement of radiation power level at the selected locations.

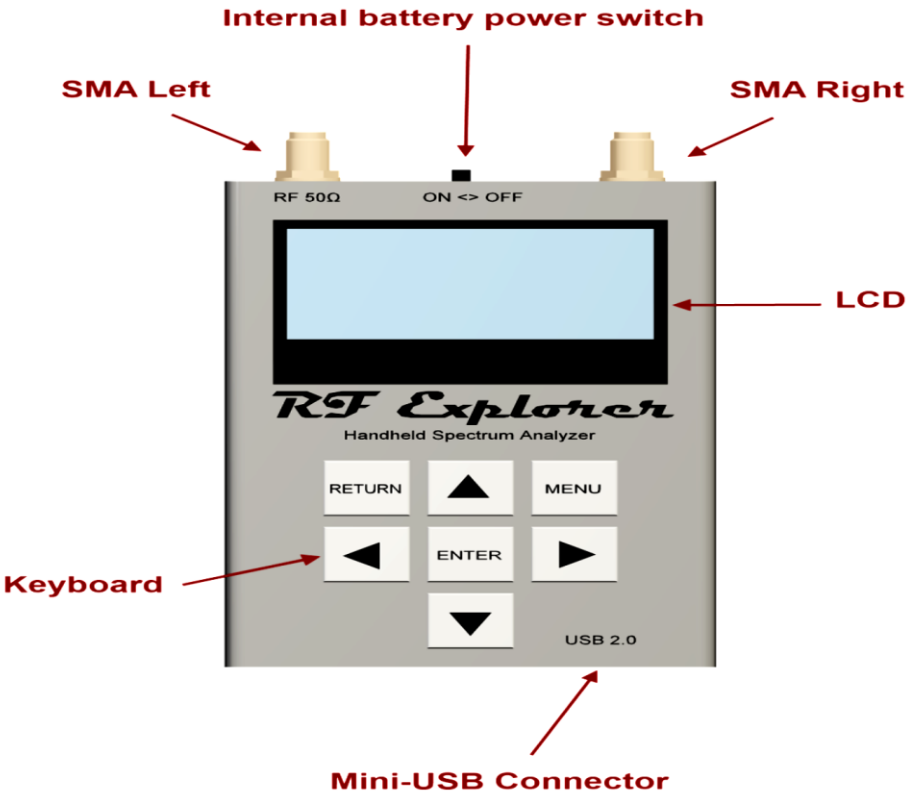

Figure 3.7 RF Explorer 6G Combo

1. Connect antenna 3 on the left SMA and 2 on the right SMA as indicated in figure 3.2 above.
2. Turn the internal battery switch to the ON position
3. Press the menu button on the Analyzer to go into the operational mode
4. Press the menu again to select spectrum analyzer as the mode of operation. The center, Span, Start and Stop frequencies and Module will be displayed with the center frequency already highlighted or selected.
5. Press enter and use the up and down arrows keys to edit the values and press enter to save
6. Use the down arrow key to select the next frequency to be entered and repeat step five for all the frequencies displayed.
7. Activate the module you wish to use by using the down arrow key to select module and press enter.
8. Press menu to display the attenuator menu and select the appropriate functions, values and units in which the measurement will be made till all the fields displayed are taken care of.
9. Press menu to display the CONFIG menu and fill all the fields using down arrow key and enter.
10. Press enter to display the preset menu to fill in the field and press the return key to view Analyzer graph.
11. Connect the USB to the laptop and the analyzer as shown in the measurement setup and open the firm wear installed on the laptop to view additional function and record the measured values.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction

In this section, the NIR effects of cellular systems of selected urban areas in Ghana were analyzed. The radiation levels or power density measured in (n W/m^2) of forty locations were measured and used as the basis of the analysis. The results were then compared with the minimum safety limits of 4.055 W/m^2 for cellular systems in Ghana.

4.2 Results

The results of radiation levels or power density in Nano watt per square meter (nW/m^2) obtained at forty locations under three study areas are shown in this section. The study areas whose NIR levels are analyzed are classified as residential, commercial and University campuses. The total radiation levels at each location represents the addition of the measured and estimated values of GSM 900, GSM1800, 3G and 4G.

4.2.1 Residential Areas

Fourteen residential areas in Koforidua, the Eastern region of Ghana, were randomly selected considering day time (D) and evening (E) measurement for residence near base stations (RNBS) and only evening for residence away from base stations (RABS). A 24-hour hourly measurement at residence near base station six (RNBS6) was also obtained to estimate the cumulative average of NIR exposures in a day.

Table 4.1 to Table 4.4 represent the results in the quest to analyze radiation levels in residential areas. The highest total radiation of 862.9 (nW/m^2) constituting the cumulative effects of the deployed systems that is, GSM900, GSM1800, 3G and 4G was observed during an evening measurement of a residence near base station (RNBS3E) which is five (5) meters away from the base station.

The highest radiation level of 862.9 (nW/m^2) is far below the ICNIRP standards for public exposure of 4.055 W/m^2 obtained by calculation using Table 2.1 and a minimum frequency of 811 MHz of the spectrum allocated for cellular systems in Ghana. The results shows that GSM 900 systems produces the highest radiation levels among the technologies deployed with the exception of locations at campus residences (CR1 and CR3) where 4G levels are higher than GSM . GSM 1800 produces the least radiation among the deployed systems.

An hourly radiation indoor, residential records involving 15 minutes measurement of each of the cellular systems or technology deployed, is shown in Table 4.3 and 4.4. The results shows that 3G systems have the highest radiation levels. The maximum and minimum exposure level of 305.6 $nW/m^2$and 54.9 $nW/m^2$was recorded at 7 pm and 2 pm respectively.

Table 4.1 Evening (E), Day (D) and total power density at RNBS1 to RNBS5

Techno Logy	Power density (S) in (nW/m^2) Location Codes									
	RNBS 1E	RNBS 1D	RNBS 2E	RNBS 2D	RNBS 3E	RNBS 3D	RNBS 4E	RNBS 4D	RNBS 5E	RNBS 5D
GSM 900	172.4	91.2	270.8	115.4	634.9	109.7	230.4	32.1	148.2	8.55
GSM 1800	9.2	7.84	3.2	0.53	6.41	5.28	2.85	2.1	2.85	0.64
3G	5.8	1.58	54.2	1.38	47.0	38.5	13.5	19.95	44.89	17.8
4G	141.8	43.5	14.96	11.3	174.6	89.1	85.5	54.2	34.2	7.84
Total	329.2	144.1	343.2	128.6	862.9	242.6	332.3	108.4	130.1	34.83

Table 4.2 Power density and total power density at RABS1 to CR3

Techno Logy	Power density (S) in (nW/m^2) Location Codes							
	RABS1	RABS 2	RABS 3	RABS 4	RABS 5	CR1	CR2	CR3
GSM 900	0.278	1.33	2.96	0.53	2.36	0.23	0.055	0.0211
GSM 1800	0.064	0.014	0.05	0.021	0.036	0.0024	0.000158	0.00422
3G	0.41	0.093	0.199	0.27	0.140	0.051	0.00317	0.0126
4G	0.69	0.47	0.74	1.13	0.360	0.580	0.046	0.493
Total	1.442	1.91	3.96	1.88	2.89	0.86	0.10	0.53

Table 4.3 Total, Cumulative average from 6am to 5pm

Systems	Power density S (nW/m^2)											
	6 am	7 am	8 am	9 am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm
GSM 900	32.8	27.1	27.1	38	100	24	47.7	49.9	9.9	9.3	33	28
GSM 1800	2.9	2.9	2.1	0.7	5.7	1.4	7.7	3.6	0.14	0.1	2.1	1.4
3G	122	126.1	96.9	100	36	63	76.2	123.9	31.4	25	85	128
4G	47.7	52.0	38.5	36	68	30	51.3	34.1	13.5	28	33	29
Total	205	208.1	164.6	174	210	118	183	211.5	54.9	62	153	185
Ave	205	206.7	192.7	188	192	180	180.4	184.3	168	159	159	161

Table 4.4 Total, Cumulative average from 6pm to 5am

Systems	Power density S (nW/m^2)											
	6 pm	7 pm	8 pm	9 pm	10pm	11pm	12am	1am	2am	3am	4am	5am
GSM 900	26.4	37.8	27.1	31	31	26	22.1	22.8	7.8	9.3	24.2	25
GSM 1800	0.7	4.9	2.9	0.6	0.6	0.6	0.3	0.01	0.007	0.001	0.01	6.4
3G	94.8	176.7	138	106	88	132	73.4	59.9	56.3	70.5	74.8	76
4G	48.5	86.2	62	34	39	40	24.9	57.7	69.1	49.2	47.0	27
Total	170.4	305.6	130	159	160	199	121	140	133.2	129	146	135
Ave	161.4	171.7	169	168	168	169	167	166	163.9	162.4	162	161

4.2 2 Commercial Areas

Twenty commercial locations were selected from the city of Koforidua and Accra in the Eastern and Greater Accra regions respectively. These locations were sub classified as outdoor commercial area market (OCAM), outdoor commercial area offices (OCAO), indoor commercial area offices (ICAO) and outdoor commercial area industrial (OCAI), five locations each. Locations representing industrial areas were limited to the free zone enclave in Tema.

Table 4.5 Power density at commercial area

Technology	Power density (S) in (nW/m^2) Location Codes									
	OCAO1	OCA02	OCAO3	OCAO4	OCA05	OCAM1	OCAM2	OCAM3	OCAM4	OCAM5
GSM 900	1.16	0.26	3.43	2.68	0.82	4.935	1.564	2.928	104.8	0.239
GSM 1800	0.03	0.00	0.22	0.03	0.01	0.177	0.003	0.023	0.356	0.00
3G	0.52	0.01	11.9	0.08	0.19	1.179	0.053	0.073	11.22	0.073
4G	0.09	0.03	1.56	0.63	0.24	0.427	1.100	0.699	2.137	0.11
Total	1.79	0.30	17.1	3.41	1.26	6.772	2.72	3.72	118.5	0.422

Table 4.6 Power density at commercial areas

Technology	Power density (S) in (nW/m^2) Location Codes									
	ICAO1	ICAO2	ICAO3	ICAO4	ICAO5	OCAI1	OCAI2	OCAI3	OCAI4	OCAI5
GSM 900	16.7	0.02	0.02	5.38	0.67	13.2	0.94	0.68	0.868	12.654
GSM 1800	0.04	0.0000	0.00	0.08	0.03	0.09	0.04	0.0	0.125	0.169
3G	0.68	0.0010	0.10	12.9	1.8	2.57	0.65	0.33	3.222	3.035
4G	1.24	0.0024	0.04	1.95	0.41	21.4	2.92	1.84	11.977	29.664
Total	18.7	0.023	0.16	20.3	2.91	37.3	4.56	2.931	16.192	45.442

4.2.3 University Campuses

On the other hand, the University campuses featured measurement and estimation of NIR level contribution of the four main networks, MTN, Vodafone, Airtel-Tigo and Glo within the deployed technologies. Six locations at the Kwame Nkrumah

University of Science and Technology (KNUST), Koforidua Technical University (KTU) and the University of Ghana (UG) at high population (HP) and low population (LP) attached to the initials of the Universities were considered as shown in Table 4.7 and 4.8, representing when school is in session and during vacation respectively. Measurement at the campuses also involved day time (D) and evening hours (E) as shown in the location codes in the table of result. Table 4.7 shows the radiation of individual deployed technologies that add up to a total at each location for both day and evening measurements, whereas Table 4.8 depicts the measurement for total radiation of each of the networks at the chosen campus locations during the day.

Table 4.7 Power density at campus study areas for Day (D) and Evening (E)

Technology	Power density (S) in (nW/m^2) Location Codes									
	UGH PD	UGHP (E)	KNUSTHPD	KNUSTHPE	KNUSTLPD	KNUSTLPE	KTUHPD	KTUH PE	KTULPD	KTUL PE
GSM 900	24.0	24.94	0.468	10.73	5.745	2.00	5.10	7.62	2.583	3.38
GSM 1800	0.49	0.22	0.106	0.489	0.133	0.223	0.04	0.074	0.045	0.02
3G	1.38	0.76	0.673	1.157	1.100	0.400	0.51	1.425	0.762	0.66
4G	1.47	1.83	11.49	26.544	5.567	2.745	2.63	16.88	2.084	0.95
Total	27.3	27.8	12.74	38.92	12.55	5.37	8.28	25.99	5.47	4.97

Table 4.8 Total radiation of network providers at campus study areas.

Network provider	Power density(S) in (nW/m^2) Location Codes				
	UGHP	KNUSTHP	KNUSTLP	KTUHP	KTULP
MTN	27.30	11.9	11.7	2.8	2.5
Vodafone	0.013	0.06	0.035	0.07	0.01
Airtel-Tigo	0.092	0.57	0.40	5.1	2.24
Glo	0.003	0.25	1.33	0.25	0.77

4.2.4 Three Sectors of a Base Station

The base station at this location has three towers. The tower with the least number of antennas has five sector antennas. Measurement at this location is to estimate the deviation in radiation levels at different sectors of the same base station. Radiation levels vary even at the same location, same reference distance but different zones to the base station due to reflection and absorption by obstacles and also variation in network traffic. Table 4.9 represents the results of total radiation levels measured 7.3 meters away from a base station near KTU campus. The radiation at the same base station is entirely different and shows that exposure depends on the point of location of individuals. The standard deviation of radiation levels at this base station or location is approximately 50.

Table 4.9 Power density of Different angles of a base station

Power density S (nW/m^2)	Angle 1	Angle 2	Angle 3	Standard deviation
	273.1	174.5	210.3	49.9

4.3 Analysis

Visualization of data or results from Table 4.1 to Table 4.4, 4.7 and 4.8 constitutes stacks of radiation values for individual technologies deployed (GSM 900, GSM1800, 3G and 4G) to make up the total radiation at a particular location thus, each bar graph is made up of four data entries. In some locations, the value of a particular technology may be small such that it becomes insignificant and therefore does not appear on the bar.

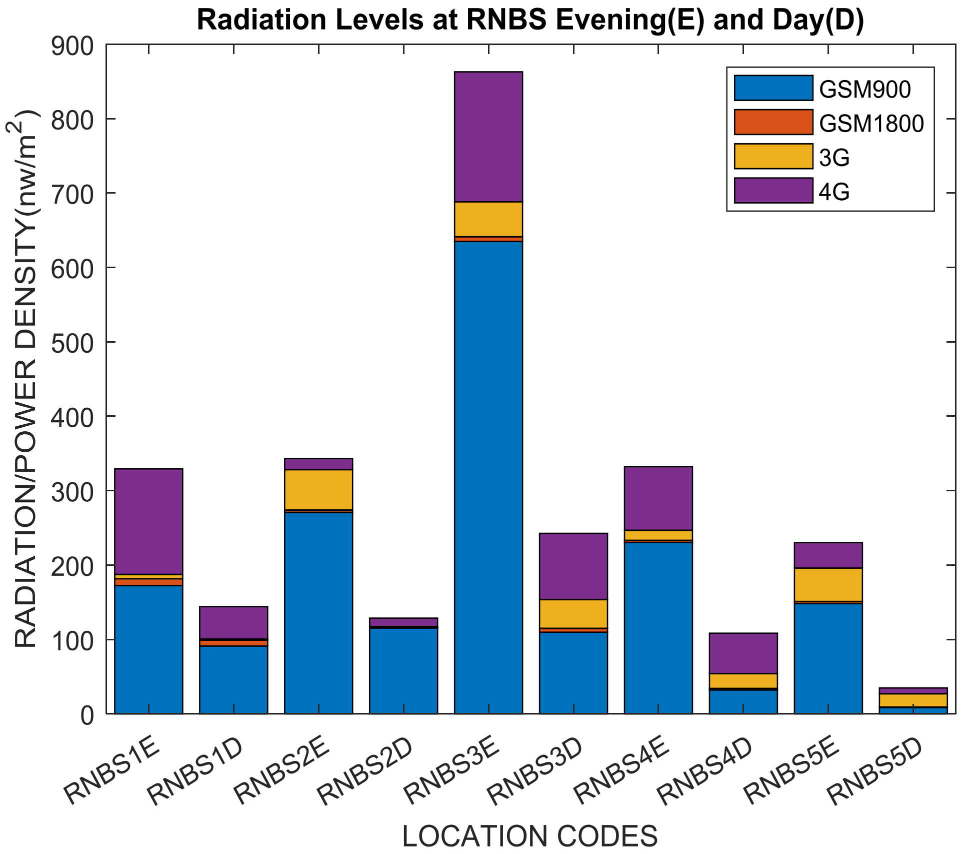

Figure 4.1 Power density at residence near base station, Evening and Day hours.

The Figure 4.1 shows results obtained at a distance of five (5) meters away from base stations, described as RNBS1-5 during evening and day time measurement. Each pair represents results at one particular location for evening and day hours. It is observed that the total radiation during the day is lesser than the radiation levels in the evening, the reason being that, most people leave their residences for work and businesses during the day, hence reducing the number of people or the population being served by the site. This accounts for the reduction in the radiation since the number of connected devices is less. It can also be inferred that GSM 900 is the technology mostly used by the masses followed by 4G.

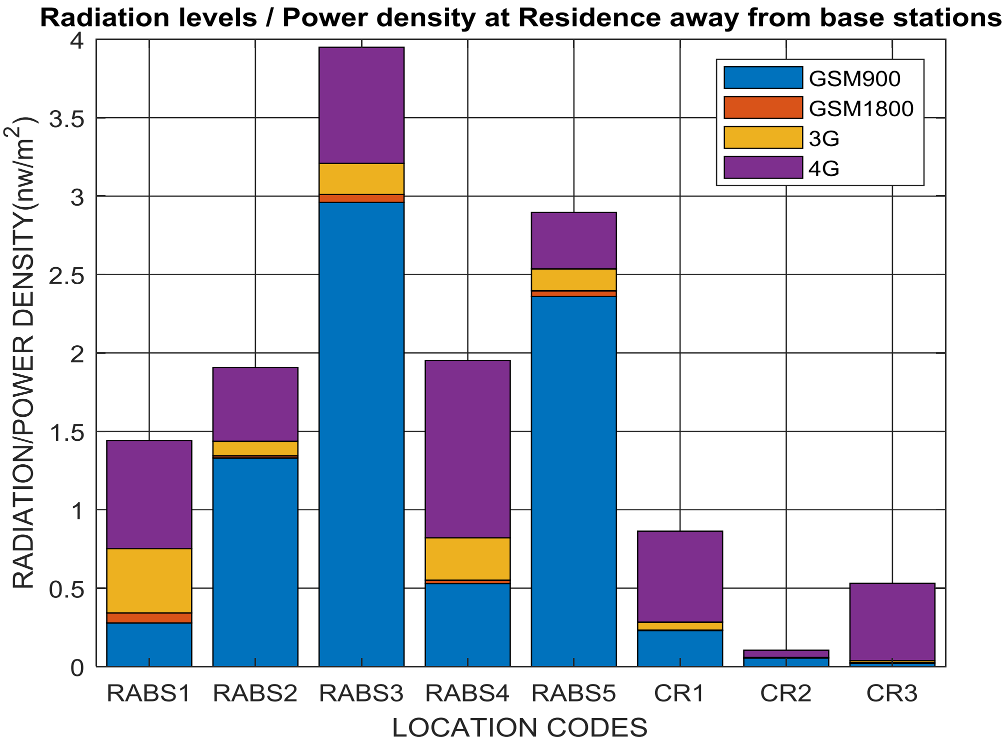

Figure4.2 Power density of RABS and CR.

The results at residences away from base stations (RABS1 to RABS5) obtained fifty (50) meters from the reference base station and campus residences (CR1 to CR3) one hundred and fifty (150) for CR1and CR2 and sixty-five (65) meters for CR3 are visualized in Figure 4.2. GSM 900 produces the highest radiation at residences away from base stations except for RABS4 where 4G is highest. Furthermore, 4G is the highest at campus residences. Exposure at residences near base stations even at day hours is higher than exposure at residence away from base stations in the evening as shown in Figures 4.1 to 4.2. The maximum and minimum RF levels at residences away from base stations are 862.9 in (nw/m^2) and 34.83 in (nW/m^2) respectively and 3.96 in (nW/m^2) and 0.10 in (nW/m^2) respectively. While radiation exposure levels are far below the standards set by ICNIRP, exposure at locations near the base stations are higher compared to those away from stations.

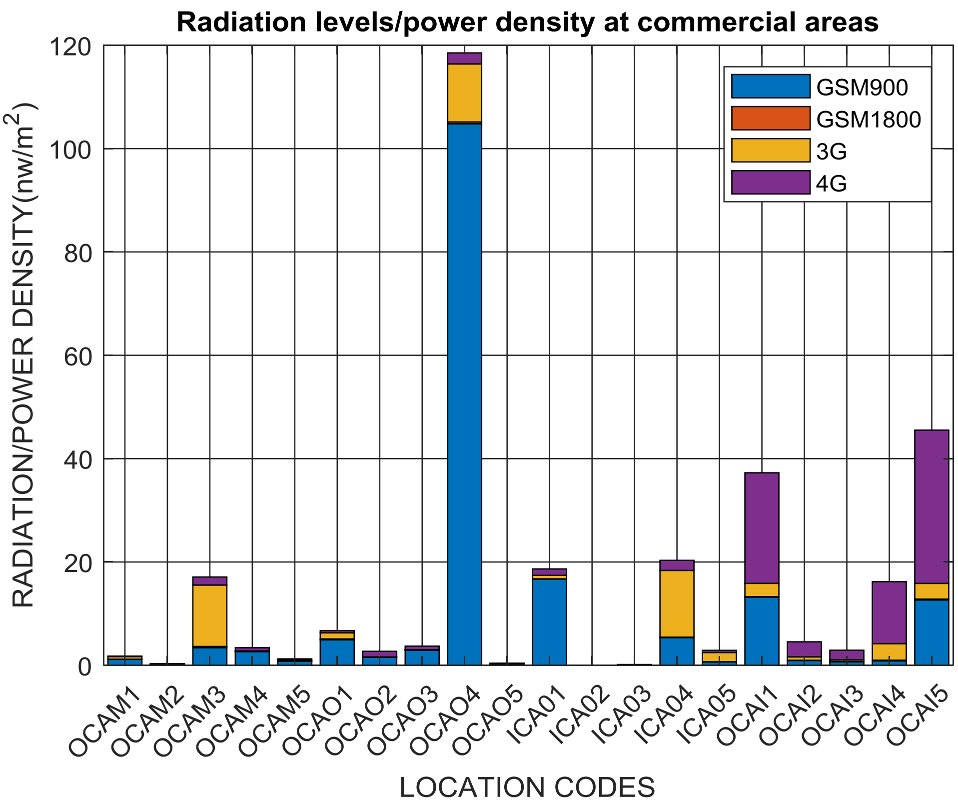

Figure 4.3 Power density at business areas

Radiation exposure at commercial areas as depicted in the Figure 4.3, is higher than residence away from base stations. Nevertheless, its low value is as a results of tall structures obstructing the signals. The low exposure in 4G systems at the office areas may be due to WLAN usage for data services in the various offices instead of the cellular networks. Furthermore, users might also be busily discharging their duties thus, have no time to use personal cell phones. Outdoor industrial areas has high 4G data usage compared to markets and office areas.

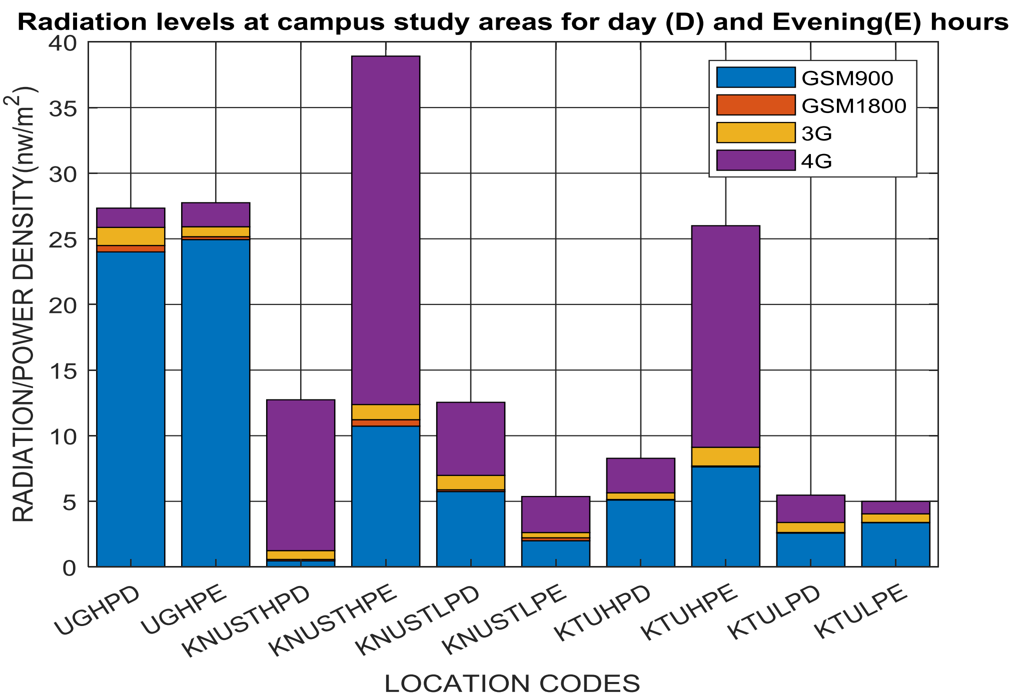

Figure 4.4 Radiation levels at campus study areas for day and evening hours

Radiation levels at three campus study areas were measured. For two Universities, namely KNUST and KTU, measurements were taken when school was in session and also during vacation. For University of Ghana (UG), measurements were taken when school was in session; during the day and evening. The result of the measurement is shown in Figure 4.4. For KNUST and KTU where the measurement was taken during the examination time, it can be observed that radiation during the day time for when school is in session is less than the evening measurement. This observation is due to the fact that during the day, majority of the students were busy writing exams and leave to their hostels afterwards and latter return in the evening to prepare for the next day's exams. Radiation during the vacations is less compared to when school is in session. Day and evening time measurement at UG is almost the same though the evening is a bit high since at the period of measurement even though school was in session, it was not examination and student were not researching. This resulted in GSM 900 having the highest radiation while 4G was the highest for KNUST and KTU. It should be noted that during the measurement at UG, the students' population was reduced since only the second and third years were on campus because of Covid- 19 pandemic.

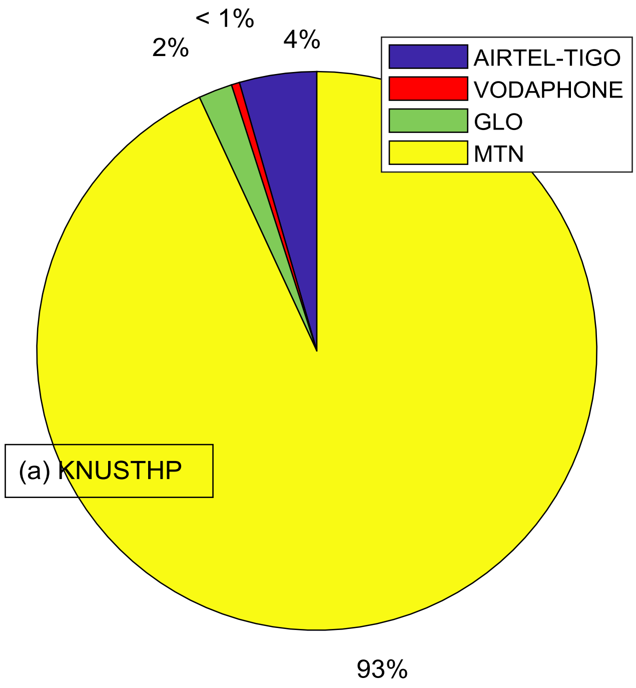

Figure 4.5 KNUSTHP network provider contributions

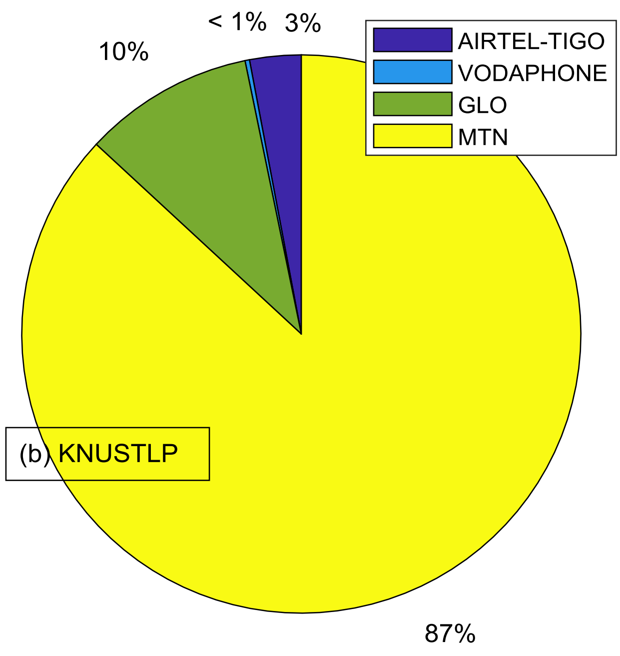

Figure 4.6 KNUSTLP network provider contributions

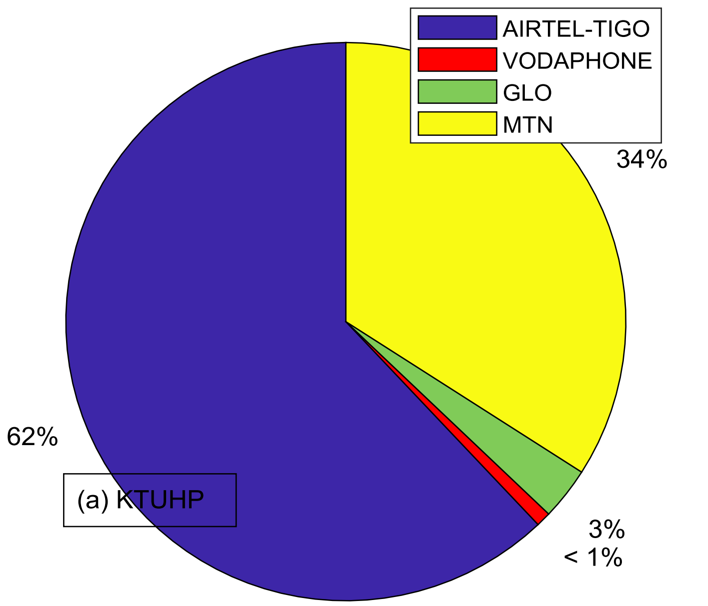

Figure 4.7 KTUHP network provider contributions

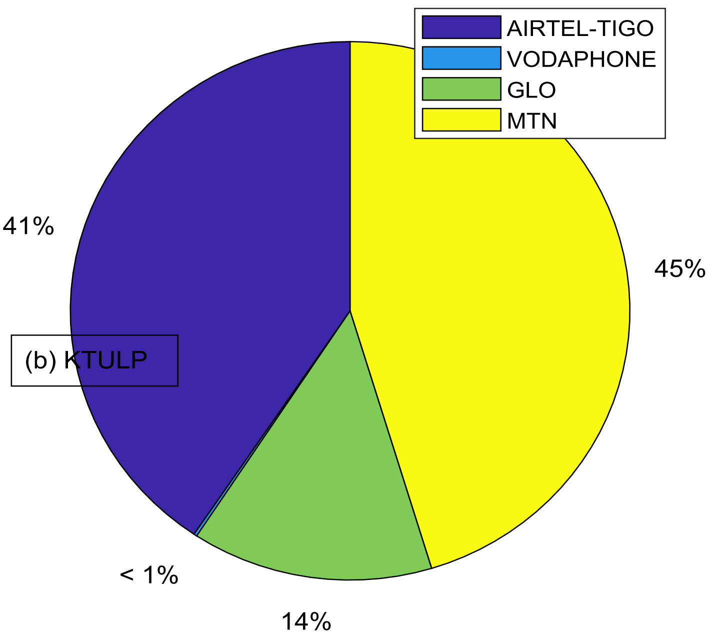

Figure 4.8 KTULP network provider contributions

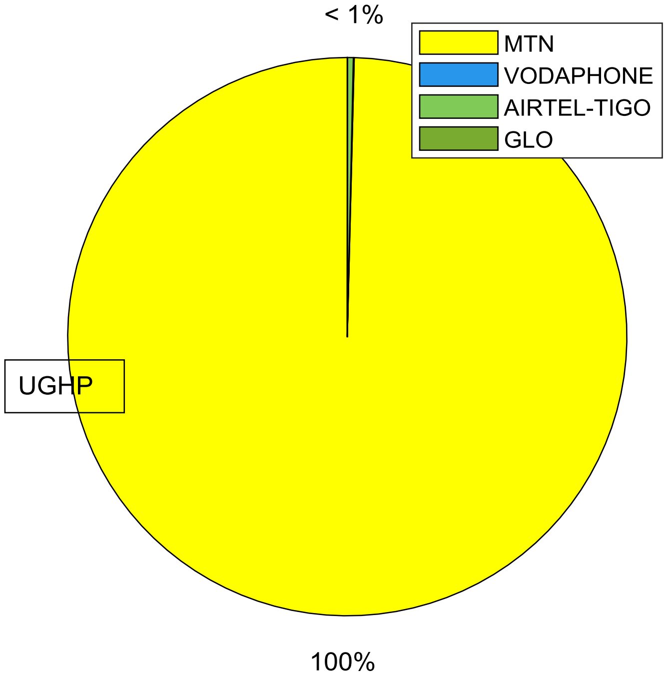

Figure 4.9 UGHP network provider contributions

The percentage contribution of radiation levels at the campuses are shown in Figure 4.5 to Figure 4.9. At the KNUST and UG campuses, MTN occupies about 95 percent of the total radiation generated and about 45 percent at the KTU campus while Airtel – Tigo takes about 51 percent of the total radiation at the KTU campus. The percentage contribution of MTN is no surprise as the voice and data subscription trends in Figure 1.5 and 1.6 suggest they have the highest market share of customers in Ghana. However, that of Airtel-Tigo on the KTU campus came as a surprise and thus, a measurement of three different sectors 7.3 meters from the base station close to KTU campus was done and the results of total radiation obtained shown in Table 4.9. The calculated deviation turned out to be 49.91 and the angle with the highest radiation (Angle1) happened to be from KTU campus. The percentage of Airtel-Tigo at KTU when school is in session is 62% and decreases to 41% during the vacations. It must be noted that Airtel-Tigo though does not have special packages for students, their data packages are cheaper compared to other networks at the time of measurement and might be the reason for its high patronage by the students.

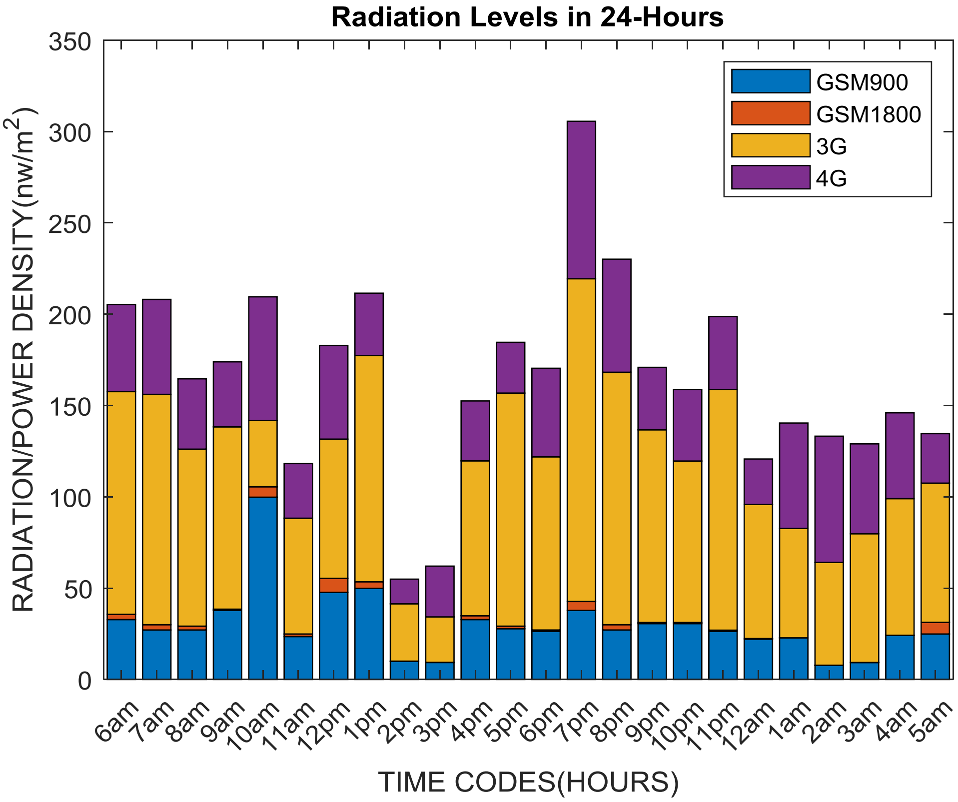

Figure 4.10 24- hour indoor radiation levels

The Figure 4.10 depicts the indoor radiation levels at a residential area (RNBS6). The distance of the reference base stations is about 5 meters from the entrance of the house. The total hourly radiation consisting of a 15 minutes measurement of each of the system deployed is represented as displayed in the legend. The hourly radiation levels show high radiation in the early morning when consumers are up, reduces in the late morning and increases during the hours of 12 and 1pm. The radiation levels reduce drastically after lunch and rises from 4pm. The highest radiation is recorded at 7pm. There is a considerable amount of radiation at late-night which might be as a results of cheaper data bundles at night and free calls as depicted (3G and 4G) in the late night hours. The 3G system contributes a greater portion of the hourly total radiations. The maximum radiation level of 305.6 nW/m^2 recorded at 7pm is also far below the safety limits of ICNIRP and IEEE.

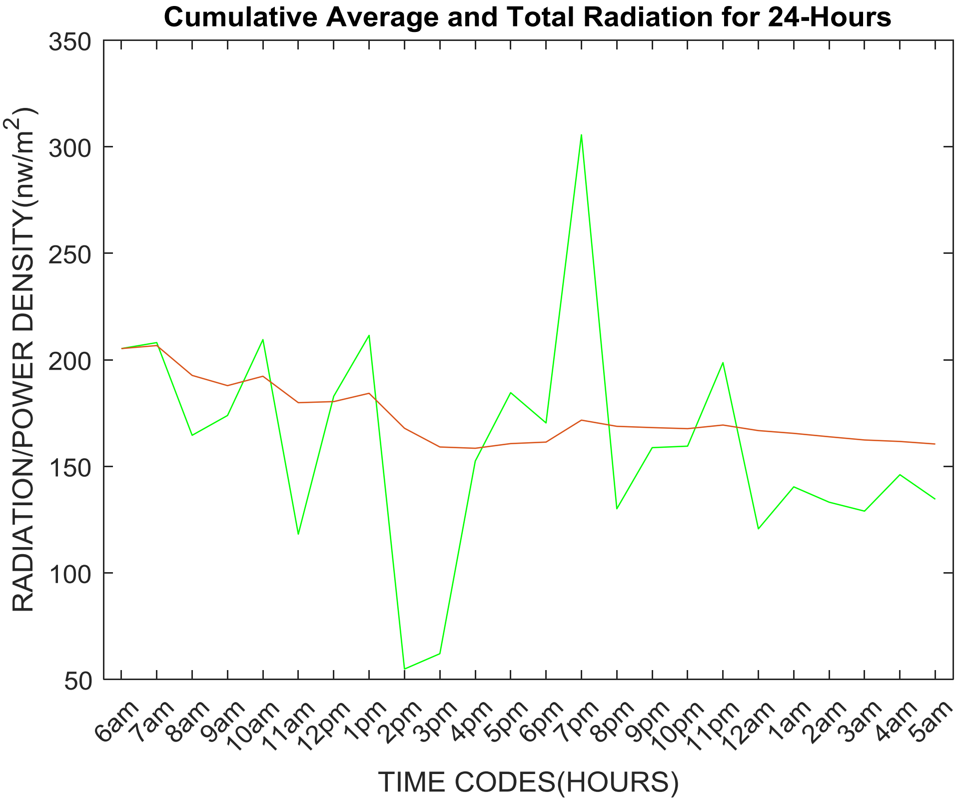

Figure 4.11 Cumulative Average and Total Radiation for a day

Figure 4.11 shows the hourly total (green) and the hourly cumulative average (red) radiation levels in an indoor residential measurement. This represents the amount of cellular radiation that the inhabitants of the residence are exposed to on an hourly bases over 24 hours. At the 24th hour of the day, the cumulative average of radiation that an individual in that residence is exposed to is 160.5 nW/m^2 which is less than 1% of 4.055 W/m^2 minimum safety level for cellular systems.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research analyzed the NIR levels using far-field measurements in unrestricted environment under three objectives considering the issues of the number of increasing devices that are being connected to cellular systems, the close proximity of cellular base stations to human inhabitant in the quest to increase the quality of service and the modernized life style that keep subscribers glued to their devices either for business, education or socialization.

In the first stage, NIR levels at fourteen residential locations sub-classified as RNBS1-6, RABS1-5 and CR1-3 were estimated in an outdoor measurement with the exception of RNBS6 which was taken indoors. The maximum total level of radiation consisting of a cumulative of all deployed systems was found to be 862.9 (nW/m^2) and 242.6 (nW/m^2) achieved at the evening and day hours of residences near base stations respectively. Residences away from base stations had a maximum of 3.96 (nW/m^2) and a minimum 0.10 nW/m^2). Twenty commercial locations involving outdoor market, outdoor offices, indoor offices and outdoor industrial areas recorded 118.5 (nW/m^2) and 0.422 (nW/m^2) as the maximum and minimum radiation level respectively. Also, five university campus locations when school is in session and during vacation at day and evening hours had a maximum and minimum levels of 38.92 (nW/m^2) and 4.97(nW/m^2) at the evening hours of KNUSTHP and KTULP. MTN network provider contributed about 95 % of the radiation levels at UG and KNUST campuses, while Airtel- Tigo had about 50 % at KTU, MTN 45 % and 5 % to other networks.

Meanwhile, a highest radiation level of 305.6 (nW/m^2) was recorded at 7 pm of the 24 hour indoor measurement, while the cumulative average of 160.5 (nW/m^2) was recorded at the 24th hour of the second stage of NIR level measurement and estimation. The standard deviation obtained at the third phase of the research is 49.9 for the measurement of three different sectors of the same base station.

The maximum radiation levels recorded for all the measurement scenarios are by far lesser than the minimum acceptable level of 4.055 (W/m^2) for the cumulative of all the deployed cellular systems or technologies in Ghana. Thus, cellular systems emissions of the forty selected locations being it campuses, residential or business areas are far below the minimum permissible reference levels for the general public when compared with ICNIRP levels. The percentage of the highest NIR level (862.9 (nW/m^2) is less than 1% of 4.055(W/m^2) minimum safety limits recommended.

The results obtained suggest that;

1. Residences near base stations have the highest radiation levels. Therefore, residence near base stations is at higher long term risk than those far from the base stations.
2. Residences away from base stations have the lowest radiation levels.
3. GSM systems contribute significantly to the highest radiation in residential and business areas while 4G contributes to the highest radiation levels at university campuses.
4. Radiation levels are not constant even at the same location.
5. Radiation levels depends on network traffic and hence, the higher the population or connected devices, the higher the radiation and vice versa.
6. The level of radiation does not depend on the length of time of measurement.
7. MTN network provider occupies a larger percentage of the cellular emissions in Ghana as they have the highest market share of cellular subscribers.

Based on the analysis, it can be concluded that Ghana's radiation levels are however lesser than countries such as Sweden, Turkey, and Spain whose assessments are reviewed in the literature of this research.

5.2 Recommendation and Future Works

The assessment of radiation levels should be done from time to time since the number of connected devices keeps increasing. Collecting real data from the field and processing them takes a significant amount of time and resources. Also radiation is not constant which makes its long term risk assessment difficult. It is recommended that, a predictive algorithm be used in learning the existing systems to predict the radiation levels at any point in time at a given location.

The measurement for this research was made with one setup which required the deployed technologies to be measured one at a time (6 minutes each) and the values summed which may introduce errors since the radiation varies. The number of setups used in gathering the data should be equal to the number of the deployed technologies and networks so as to increase the efficiency of the measurements, reduce the time spent at each location and also reduce the errors that may occur due to varying radiation levels.

REFERENCE

[1] R. Eckhardt, “It ’ s Everywhere !,” Los Alamos Sci., no. 23, 1995.

[2] Y. Health, “Radiation and Your Health The Electromagnetic Spectrum : Non-Ionizing Radiation,” pp. 1–3, 2019.

[3] N. Radiation, “Types of Ionizing Radiation,” pp. 2–4, 2016.

[4] ITU, “Measuring digital development: Facts and figures 2019,” ITU Publ., pp. 1–15, 2019, [Online]. Available: https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2019.pdf.

[5] NCA, “Legend DNA-Data Not Available NIO-Not in Operation,” no. April, pp. 15–17, 2017.

[6] NCA, “Mobile Data Subscriptions from January to March 2020,” Commun. Ind. Stat., no. March, p. 1, 2020.

[7] “Mobile Data Subscriptions in Ghana from 2013 to January 2017,” no. January, p. 2017, 2017.

[8] A. B. Miller et al., “Risks to health and well-being from radio-frequency radiation emitted by cell phones and other wireless devices,” Front. Public Heal., vol. 7, no. AUG, pp. 1–22, 2019, doi: 10.3389/fpubh.2019.00223.

[9] S. A. Meo, M. Almahmoud, Q. Alsultan, N. Alotaibi, I. Alnajashi, and W. M. Hajjar, “Mobile Phone Base Station Tower Settings Adjacent to School Buildings : Impact on Students ’ Cognitive Health,” 2018, doi: 10.1177/1557988318816914.

[10] C. Sage and E. Burgio, “Electromagnetic Fields , Pulsed Radiofrequency Radiation , and Epigenetics : How Wireless Technologies May Affect Childhood Development,” vol. 89, no. 1, pp. 129–136, 2018, doi: 10.1111/cdev.12824.

[11] K. P. Dahal, “Mobile Communication and its Adverse Effects.”

[12] M. L. Pall, “Microwave frequency electromagnetic fields (EMFs) produce widespread neuropsychiatric effects including depression,” J. Chem. Neuroanat., vol. 75, pp. 43–51, 2016, doi: 10.1016/j.jchemneu.2015.08.001.

[13] J. A. Adams, T. S. Galloway, D. Mondal, S. C. Esteves, and F. Mathews, “Effect of mobile telephones on sperm quality : A systematic review and meta-analysis ,” Environ. Int., vol. 70, pp. 106–112, 2014, doi: 10.1016/j.envint.2014.04.015.

[14] B. J. Houston, B. V King, G. N. De Iuliis, and R. J. Aitken, “The effects of

radiofrequency electromagnetic radiation on sperm function,” 2014, doi: 10.1530/REP-16-0126.

[15] “GOVERNMENT OF GHANA GUIDELINES FOR THE DEPLOYMENT OF COMMUNICATIONS.”2010.

[16] A. Ismail, N. Din, Z. Jamaluddin, and N. Balasubramaniam, “Electromagnetic Assessment for Mobile Phone Base Stations at Major Cities in Malaysia,” no. December, pp. 150–153, 2009.

[17] L. K. Hedendahl, M. Carlberg, T. Koppel, and L. Hardell, “Measurements of Radiofrequency Radiation with a Body-Borne Exposimeter in Swedish Schools with Wi-Fi,” Front. Public Heal., vol. 5, 2017, doi: 10.3389/fpubh.2017.00279.

[18] G. On et al., “Icnirp Statement Exposure To Pulsed Fields and Complex Non - ,” 2003.

[19] ICNIR, “Issued guidelines,” publications. https://www.icnirp.org/en/publications/index.html (accessed Sep. 07, 2021).

[20] IEEE, “IEEE at a Glance,” Ieee, pp. 1–7, 2021.

[21] B. A. Member and O. F. Itu, “About International Telecommunication Union (ITU),” pp. 1–3, 2021.

[22] Z. Xinghai, Z. Weimin, and C. Hao, “Analysis of global major standards and regulations for electromagnetic radiation,” 2016 Asia-Pacific Int. Symp. Electromagn. Compat. APEMC 2016, pp. 1160–1163, 2016, doi: 10.1109/APEMC.2016.7522973.

[23] U. N. Sdgs, “IEC everywhere for a safer and more efficient world,” pp. 1–7, 2021.

[24] G. Ziegelberger et al., Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz), vol. 118, no. 5. 2020.

[25] O. N. Health, I. Related, T. O. The, U. S. E. Of, and H. Radiotelephones, “Icnirp statement,” 1996.

[26] W. H. Bailey et al., Synopsis of IEEE Std C95.1™-2019 “IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz,” vol. 7. 2019.

[27] S. . Saunders and A. Zavala, Antenna and Propagation for Wireless Communication Systems. 2007.

[28] O. Ur-Rehman and N. Zivic, Wireless communications. 2018.

[29] Balanis.C.A, “Antenna Theory Analysis and Design.pdf,” Wiley & Sons Inc. p. Second Edition, 1997.

[30] A. R. Mishra, Advanced Cellular Network Planning and Optimisation,1st ed.United Kingdom.John Wiley& Sons, pp. 124- 139 2007.

[31] Y. Huang and K. Boyle, ANTENNAS FROM THEORY TO PRACTICE, 1st ed.United Kingdom.John Wiley& Sons,2008.pp.130-164.

[32] G. Tembrock, “Evolution of communication,” Eur. Arch. Otorhinolaryngol. Suppl., vol. 1, pp. 1–14, 1994.

[33] M. Meraj and S. Kumar, “Evolution of Mobile Wireless Technology from 0G to 5G,” Int. J. Comput. Sci. Inf. Technol., vol. 6, no. 3, pp. 2545–2551, 2015, [Online]. Available: www.ijcsit.com.

[34] NCA, “Industry Information - Telecom subscriptions for March 2016,” no. June, pp. 1–9, 2016.

[35] “NATIONAL COMMUNICATIONS AUTHORITY PUBLIC CONSULTATION ON THE 800MHz BAND (i . e . DIGITAL DIVIDEND) NATIONAL COMMUNICATIONS AUTHORITY,” no. May, 2015.

[36] T. Mobile, “National Communications Authority,” no. November, pp. 498–501, 2013.

[37] M. Mutlu and C. Kurnaz, “Experimental Study of Electromagnetic Field Strength Measurements in MRI Room,” 2019 19th Int. Symp. Electromagn. Fields Mechatronics, Electr. Electron. Eng. ISEF 2019, pp. 1–2, 2019, doi: 10.1109/ISEF45929.2019.9096908.

[38] A. Pastrav, P. Dolea, E. Puschita, C. Codau, and T. Palade, “Evaluating the electromagnetic pollution in the 700-1000MHz frequency range in urban areas,” 2018 IEEE Conf. Antenna Meas. Appl. CAMA 2018, pp. 1–4, 2018, doi: 10.1109/CAMA.2018.8530655.

[39] K. Przystupa, I. Vasylkivskyi, V. Ishchenko, V. Pohrebennyk, and O. Kochan, “Assessment of electromagnetic pollution in towns,” 2019 Appl. Electromagn. Mod. Eng. Med. PTZE 2019, pp. 143–146, 2019, doi: 10.23919/PTZE.2019.8781697.

[40] T. A. A. Santana et al., “Measurement campaign on the electromagnetic environment in the central region of the City of Mossoro,” SBMO/IEEE MTT-S Int. Microw. Optoelectron. Conf. IMOC 2017, vol. 2017-Janua, no. 303, pp. 1–4, 2017, doi: 10.1109/IMOC.2017.8121116.

[41] T. Teixeira and S. F. Hasan, “Assessing Electromagnetic Radiation in our Environment,” IEEE Potentials, vol. 35, no. 2, pp. 22–25, 2016, doi: 10.1109/MPOT.2014.2309704.

[42] C. Kurnaz, B. K. Engiz, and M. C. Bozkurt, “Monitoring of RF/Microwave field strength at schools in a pilot district in Samsun/Turkey,” Mediterr. Microw. Symp., vol. 0, no. May, pp. 1–4, 2016, doi: 10.1109/MMS.2016.7803786.

[43] T. Etem and T. Abbasov, “Electric field measurements of a base station at 2G and 3G frequencies,” Perspect. Technol. Methods MEMS Des. MEMSTECH 2016 - Proc. 12th Int. Conf., pp. 110–113, 2016, doi: 10.1109/MEMSTECH.2016.7507531.

[44] G. Alvarado, R. Mosquera, and J. Cedeno, “Statistical Analysis of Radiation Levels Allowed by International Standards in Conglomerate Wireless Systems in Different Urban Areas of the City of Guayaquil,” Proc. - ANTEM 2018 2018 18th Int. Symp. Antenna Technol. Appl. Electromagn., vol. 2018-Augus, 2018, doi: 10.1109/ANTEM.2018.8573045.

[45] I. Gil and R. Fernández-García, “Study of the exposure to time-varying electric field in the ESEIAAT UPC School,” 2016 Prog. Electromagn. Res. Symp. PIERS 2016 - Proc., pp. 2184–2187, 2016, doi: 10.1109/PIERS.2016.7734903.

[46] U. P. O. Ushie, P. O., “Measurement and Analysis of Radiofrequency Radiation Exposure Level from Different Mobile Base Transceiver Stations in Ajaokuta and Environs, Nigeria,” IOSR J. Appl. Phys., vol. 3, no. 6, pp. 17–21, 2013, doi: 10.9790/4961-0361721.

[47] I. S. C. C. 28, IEEE Standards Coordinating Committee, I. S. C. C. 28, and IEEE Standards Coordinating Committee, IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, vol. 2002. 2003.

[48] Nutsaboutnets, “Rf Explorer,” Nutsaboutnets, p. 1, 2019, [Online]. Available: http://rfexplorer.com/models/.

[49] C. Brown, “Spectrum analysis basics,” Agil. Technol., no. c, pp. 55–61, 1997.

APPENDICES

Appendix A

Measured Radiation Data.

Table 1 Day and Evening data for RNBS1

Day				Evening		
S/N	SYSTEM	P(dBm)	P(microwatt)	P(dBm)	P(microwatt)	LOC
1	GSM 900	-18.9	12.8	-16.2	24.2	
2	GSM 1800	-29.8	1.1	-29.0	1.3	
3	3G	-36.5	0.2219	-31.1	0.8147	RNBS1
4	4G	-22.2	6.1	-17.0	19.9	
5	TOTAL		20.2219		46.2147	

Table 2 Day and Evening data for RNBS2

Day				Evening		
S/N	SYSTEM	P(dBm)	P(microwatt)	P(dBm)	P(microwatt)	LOC
1	GSM 900	-17.9	16.2	-14.2	38	
2	GSM 1800	-41.3	0.0741	-33.5	0.4459	
3	3G	-37.1	0.1948	-21.6	7.6	RNBS2
4	4G	-28.0	1.5848	-26.7	2.1	
5	TOTAL		18.0537		48.1	

Table 3 Day and Evening data for RNBS3

Day				Evening		
S/N	SYSTEM	P(dBm)	P(microwatt)	P(dBm)	P(microwatt)	LOC
1	GSM 900	-18.1	15.4	-10.5	89.1	
2	GSM 1800	-31.3	0.741	-30.4	0.9	
3	3G	-22.7	5.4	-21.8	6.6	RNBS3
4	4G	-19.0	12.5	-16.1	24.5	
5	TOTAL		34		121.1	

Table 4 Day and Evening data for RNBS4

Day				Evening		
S/N	SYSTEM	P(dBm)	P(microwatt)	P(dBm)	P(microwatt)	LOC
1	GSM 900	-23.4	4.5	-14.9	32.3	
2	GSM 1800	-36.0	0.3	-33.9	0.4	
3	3G	-25.5	2.8	-27.0	1.9	RNBS4
4	4G	21.2	7.6	-19.2	12	
5	TOTAL		15.2		46.6	

Table 5 Day and Evening data for RNBS5

Day				Evening		
S/N	SYSTEM	P(dBm)	P(microwatt)	P(dBm)	P(microwatt)	LOC
1	GSM 900	-29.2	1.2	-16.8	20.8	
2	GSM 1800	-40.1	0.09	-33.6	0.4	
3	3G	-26.7	2.5	-22.0	6.3	RNBS5
4	4G	-29.4	1.1	-23.1	4.8	
5	TOTAL		4.89		32.3	

Table 6 Data for RABS1

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-24.0	3.9	
2	GSM 1800	-30.1	0.9	
3	3G	-22.3	5.8	RABS1
4	4G	-20.1	9.7	
5	TOTAL		20.3	

Table 7 Data for RABS2

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-17.3	18.6	
2	GSM 1800	-37.0	0.2	
3	3G	-28.8	1.3	RABS2
4	4G	-21.8	6.6	
5	TOTAL		26.7	

Table 8 Data for RABS3

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-13.8	41.6	
2	GSM 1800	-30.9	0.8	
3	3G	-25.5	2.8	RABS3
4	4G	-19.8	10.4	
5	TOTAL		55.6	

Table 9 Data for RABS4

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-21.3	7.4	
2	GSM 1800	-35.1	0.3	
3	3G	-24.2	3.8	RABS4
4	4G	-18.0	15.8	
5	TOTAL		27.3	

Table 10 Data for RABS5

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-14.8	33.1	
2	GSM 1800	-32.3	0.5	
3	3G	-27.1	1.9	RABS5
4	4G	-23.0	5.0	
5	TOTAL		40.5	

Table 11 RNBS6 6am to 5pm data for 24 hour measurement

Systems	P(μw)											
	6 am	7 am	8 am	9 am	10 am	11 am	12pm	1pm	2pm	3pm	4pm	5pm
GSM 900	4.6	3.8	3.8	5.3	14	3.3	6.7	7	1.4	1.3	4.6	3.9
GSM 1800	0.4	0.4	0.3	0.1	0.8	0.2	1.1	0.5	0.02	0.01	0.3	0.2
3G	17.1	17.7	13.6	14	5.1	8.9	10.7	17.4	4.4	3.5	11.9	17.9
4G	6.7	7.3	5.4	5	9.5	4.2	7.2	4.8	1.9	3.9	4.6	3.9
Total	28.8	29.2	23.1	24.4	29.4	16.6	25.7	29.7	7.7	8.9	21.4	25.9

Table 12 RNBS6 6pm to 5am data for 24 hour measurement

Systems	P(μw)											
	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12am	1am	2am	3am	4am	5am
GSM 900	3.7	5.3	3.8	4.3	4.3	3.7	3.1	3.2	1.1	1.3	3.4	3.5
GSM 1800	0.1	0.7	0.4	0.09	0.07	0.08	0.04	0.002	0.001	0.0001	0.001	0.9
3G	13.3	24.8	19.4	14.8	12.4	18.5	10.3	8.4	7.9	9.9	10.5	10.7
4G	6.8	12.1	8.7	4.8	5.5	5.6	3.5	8.1	9.7	6.9	6.6	3.8
Total	23.9	42.9	32.3	23.9	22.3	27.9	16.9	19.7	18.7	18.1	20.5	18.9

Table 13 Data for CR1

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-15.4	28.5	
2	GSM 1800	-35.1	0.3091	
3	3G	-22.0	6.4	CR1
4	4G	-11.4	73.1	
5	TOTAL		108.3	

Table 14 Data for CR2

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-21.6	6.9	
2	GSM 1800	-46.4	0.02	
3	3G	-33.9	0.4	CR2
4	4G	-22.3	5.8	
5	TOTAL		13.1	

Table 15 Data for CR3

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-33.0	0.5	
2	GSM 1800	-39.9	0.1	
3	3G	-35.1	0.3	CR3
4	4G	-19.3	11.7	
5	TOTAL		12.6	

Table 16 Data for OCAO1

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-19.6	10.9	
2	GSM 1800	-34.6	0.3	
3	3G	-23.1	4.9	OCAO1
4	4G	-31.1	0.8	
5	TOTAL		16.9	

Table 17 Data for OCAO2

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-19.0	12.5	
2	GSM 1800	-44.5	0.03	
3	3G	-31.3	0.7	OCAO2
4	4G	-29.4	1.1	
5	TOTAL		14.33	

Table 18 Data for OCAO3

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-21.1	7.7	
2	GSM 1800	-32.3	0.5	
3	3G	-15.7	26.7	OCAO3
4	4G	-24.5	3.5	
5	TOTAL		38.4	

Table 19 Data for OCAO4

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-8.5	141.3	
2	GSM 1800	-28.3	1.4	
3	3G	-23.5	4.4	OCAO4
4	4G	-14.8	33.1	
5	TOTAL		180.2	

Table 20 Data for OCAO5

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-15.0	31.6	
2	GSM 1800	-33.3	0.4	
3	3G	-21.2	7.5	OCAO5
4	4G	-20.4	9.1	
5	TOTAL		48.6	

Table 21 Data for OCAM1

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-16.0	25.1	
2	GSM 1800	-30.2	0.9	
3	3G	-22.4	6.0	OCAM1
4	4G	-26.1	2.4	
5	TOTAL		34.4	

Table 22 Data for OCAM2

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-12.5	56.2	
2	GSM 1800	-37.8	0.1	
3	3G	-27.1	1.9	BA8
4	4G	-14.2	38.0	
5	TOTAL		96.2	

Table 23 Data for OCAM3

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-10.0	100	
2	GSM 1800	-31.2	0.8	
3	3G	-26.0	2.5	OCAM3
4	4G	-16.1	23.9	
5	TOTAL		127.2	

Table 24 Data for OCAM4

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-12.3	58.8	
2	GSM 1800	-36.3	0.2	
3	3G	-22.0	6.3	OCAM4
4	4G	-29.1	1.2	
5	TOTAL		66.5	

Table 25 Data for OCAM5

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-18.7	13.4	OCAM5
2	GSM 1800	-51.7	0.006	
3	3G	-23.9	4.1	
4	4G	-22.1	6.1	
5	TOTAL		23.606	

Table 26 Data for ICAO1

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-26.3	2.344	ICAO1
2	GSM 1800	-52.1	0.0062	
3	3G	-40.2	0.095	
4	4G	-37.6	0.174	
5	TOTAL		2.62	

Table 27 Data for ICAO2

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-27.5	1.778	ICAO2
2	GSM 1800	-53.1	0.005	
3	3G	-39.4	0.115	
4	4G	-35.4	0.288	
5	TOTAL		2.186	

Table 28 Data for ICAO3

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-36.7	0.214	ICAO3
2	GSM 1800	-44.3	0.037	
3	3G	-28.4	1.445	
4	4G	-32.3	0.589	
5	TOTAL		2.285	

Table 29 Data for ICAO4

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-25.2	3.020	ICAO4
2	GSM 1800	-43.6	0.044	
3	3G	-21.4	7.244	
4	4G	-29.6	1.096	
5	TOTAL		11.404	

Table 30 Data for ICAO5

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-26.3	2.344	ICAO5
2	GSM 1800	-40.1	0.098	
3	3G	-22.0	6.309	
4	4G	-28.4	1.445	
5	TOTAL		10.196	

Table 31 Data for OCAI1

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	21.3	7.413	OCAI1
2	GSM 1800	43.2	0.049	
3	3G	28.4	1.445	
4	4G	19.2	12.023	
5	TOTAL		20.929	

Table 32 Data for OCAI2

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	-24.8	3.311	OCAI2
2	GSM 1800	-38.7	0.135	
3	3G	-26.4	2.290	
4	4G	-19.9	10.23	
5	TOTAL		16.828	

Table 33 Data for OCAI3

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	33.1	0.489	
2	GSM 1800	42.6	0.0347	
3	3G	36.3	0.234	OCAI3
4	4G	28.8	1.318	
5	TOTAL		2.076	

Table 34 Data for OCAI4

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	30.0	0.468	
2	GSM 1800	41.7	0.0676	
3	3G	27.6	1.737	OCAI4
4	4G	21.9	6.457	
5	TOTAL		8.729	

Table 35 Data for OCAI5

S/N	SYSTEM	P(dBm)	P(microwatt)	LOC
1	GSM 900	23.0	5.012	
2	GSM 1800	41.7	0.067	
3	3G	29.2	1.202	OCAI5
4	4G	19.3	11.749	
5	TOTAL		18.0299	

Table 36 Day and Evening Data for KTUHP

S/N	SYSTEM	MTN		VODAPHONE		AIRTEL		TIGO		GLOW		TOTAL	LOC
		P(dBm)	P(μw)	P(dBm)	P(μw)	P(dBm)	P(μw)	P(dBm)	P(μw)	P(dBm)	P(μw)		
1	GSM900	-36.5	0.2	-57.1	0	-19.7	10.8	-51.2	0	-33.8	0.41	11.4	KTUHP
2	GSM1800	-41.5	0.07	-49.4	0.01	-68.6	0	-74.4	0	-64.4	0	0.08	
3	3G	-35.2	0.25	-48.4	0.14	-55.9	0	-32.3	0.6	-38.0	0.15	1.14	
4	4G	-22.3	5.9	-58.5	0.00							5.9	
5	TOTAL		6.42		0.158		10.8		0.6		0.56	18.5	

EVENING		
SYSTEM	P(dBm)	P(microwatt)
GSM 900	-17.7	17.1
GSM 1800	-37.8	0.1647
3G	-24.9	3.2
4G	-14.2	37.9 **Total = 58.364**

Table 37 Day and Evening Data for KTULP

S/N	SYSTEM	MTN		VODAPHONE		AIRTEL		TIGO		GLOW		TOTAL	LOC
		P(dBm)	P(μw)	P(dBm)	P(μw)	P(dBm)	P(μw)	P(dBm)	P(μw)	P(dBm)	P(μw)		
1	GSM900	-35.1	0.31	-65.3	0.03	-24.0	3.98	-69.7	0.00	28.0	1.585	5.8	KTULP
2	GSM1800	-40.6	0.09	-49.8	0.01	-67.9	0.00	-74.1	0.00	-61.5	0.00	0.10	
3	3G	32.9	0.51	-55.7	0.00	-61.0	0.00	-29.8	1.05	-38.3	0.15	1.71	
4	4G	-23.3	4.68	-59.8	0.00							4.68	
5	TOTAL		5.6		0.04		3.98		1.05		1.73	12.4	

EVENING		
SYSTEM	P(dBm)	P(microwatt)
GSM 900	-21.2	7.585
GSM 1800	-44.7	0.0338
3G	-28.3	1.47
4G	-26.72	2.137 **Total = 11.23**

Table 38 Day time data for KNUSTHP

S/N	SYSTEM	MTN		VODAPHONE		AIRTEL		TIGO		GLOW		TOTAL	LOC
		P(dBm)	P(µw)	P(dBm)	P(µw)	P(dBm)	P(µw)	P(dBm)	P(µw)	P(dBm)	P(µw)		
1	GSM900	-36.0	0.25	-49.1	0.01	-32.4	0.6	-49.6	0.01	-37.2	0.18	1.05	K
2	GSM1800	-36.7	0.21	-45.4	0.02	-58.7	0.0	-62.0	0.0	-48.8	0.01	0.24	N
3	3G	-32.4	0.6	-42.7	0.05	-41.6	0.06	-33.0	0.5	-34.4	0.36	1.51	US
4	4G	-15.9	25.8	-45.1	0.03							25.8	TH
5	TOTAL		26.9		0.11		0.7		0.51		0.55	28.8	P

EVENING

SYSTEM	P(dBm)	P(microwatt)
GSM 900	-16.2	24.1
GSM 1800	-29.6	1.1
3G	-25.9	2.6
4G	-12.2	59.6 **Total = 87.4**

Table 39 Day time data for KNUSTLP

S/N	SYSTEM	MTN		VODAPHONE		AIRTEL		TIGO		GLOW		TOTAL	LOC
		P(dBm)	P(µw)	P(dBm)	P(µw)	P(dBm)	P(µw)	P(dBm)	P(µw)	P(dBm)	P(µw)		
1	GSM900	-19.5	11.2	-49.9	0.01	-32.8	0.5	-49.6	0.01	-29.6	1.1	12.9	K
2	GSM1800	-35.5	0.28	-47.7	0.016	-63.0	0.0	-64.0	0.00	-52.8	0.00	0.30	N
3	3G	-38.4	0.14	-43.7	0.042	-45.6	0.02	-34.0	0.39	-27.2	1.9	2.45	US
4	4G	-18.7	13.5	-48.9	0.01							12.5	TL
5	TOTAL		25.1		0.08		0.52		0.40		3.0	29.1	P

EVENING

SYSTEM	P(dBm)	P(microwatt)
GSM 900	-23.5	4.5
GSM 1800	-32.7	0.5
3G	-30.3	0.9
4G	-22.1	6.165 **Total = 12.1**

Table 40 Data for Different sectors of a Base station

Systems	Ang1		Ang2		Ang3	
	P(dBm)	P(μw)	P(dBm)	P(μw)	P(dBm)	P(μw)
GSM900	-11.8	66.1	-13.2	47.8	-12.7	53.7
GSM1800	-49.4	0.01	-45.6	0.03	-51.5	0.007
3G	-24.1	3.9	-26.2	2.4	-23.8	4.2
4G	-19.3	11.7	-21.7	6.8	-23.0	5.0
Total		81.7		52.2		62.9