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Regular Research Manuscript

Investigations of Cell Tower Antennas Parameters on Reduction of Radio Frequency Radiation Levels from Radio Base Stations

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ABSTRACT

The widespread deployment of mobile cellular base stations in populated areas has raised public health concerns due to increased exposure to radio frequency (RF) radiation emissions. Exposure to high levels of RF radiation can have potential thermal and non-thermal biological effects. Optimizing the configuration of cell tower antenna parameters is crucial for mitigating these radiation levels. This study therefore aims at systematically investigating the influence of different cell tower antenna parameters on reducing the RF radiation levels from mobile base stations. Field measurements were conducted at two cell sites shared by multiple mobile operators. Electric field strengths were measured at multiple locations around the cell sites. The impacts of various antenna parameters were analyzed, including the deployment of GSM spectrum within LTE services, number of carrier frequencies, antenna down-tilt, and transmission power. The analysis revealed that deploying the GSM spectrum within LTE services can reduce the overall radiation levels. Additionally, decreasing the number of carrier frequencies, increasing antenna down-tilt, and lowering transmission power were found to contribute to significant reductions in measured radiation levels. However, optimizing these antenna parameters to mitigate radiation can also degrade key mobile network performance indicators, such as coverage and capacity. These findings provide valuable insights into effective strategies for balancing the need to minimize RF radiation exposure from mobile base stations while maintaining acceptable mobile network service quality. Careful optimization of cell tower antenna configurations is essential to address public health concerns without compromising network performance.
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1. INTRODUCTION

The widespread deployment of mobile communication networks has led to a significant increase in the number of radio base stations installed in populated areas. This has raised public concerns about the potential health impacts of the radio frequency (RF) radiation emitted from these base station antennas (Koppel et al., 2019; Abdallah et al. 2019). The study by (Okowa et al., 2024) explored the investigations and experiments that have been carried out, particularly on the recent 5G deployment. The results from this study showed that the concerns can be generally classified into three broad groups: health, aviation, and incumbent services.

In addition to Okowa's work, (Balmori, A. 2022) wrote a paper on the effects of mobile phone base stations on the health of people living around them. Another study has shown that urban residents in France are significantly exposed to radiofrequency electromagnetic fields (RF-EMF) from nearby mobile phone base stations (De Giudici et al., 2021). Similarly, research from India has indicated that more than 15% of people are exposed to EMF levels exceeding 12 V/m due to their proximity to these antenna installations (Premlal and Eldhose, 2017). These findings suggest that the deployment of mobile phone infrastructure in cities has led to considerable RF-EMF exposures for the local population living in close proximity to the base stations. The debate on the long-term health effects of non-ionizing electromagnetic radiation, including those from 5G, remains unresolved as reported by (Okowa et al., 2024).

The effects of RF radiation on human health are generally categorized into two main types: thermal effects and non-thermal effects. Thermal effects occur when RF radiation causes the heating of biological tissue (Uluaydin et al., 2019). This process happens as the energy from the RF waves is absorbed by the tissue, leading to an increase in temperature. At higher exposure levels, this can result in burns or heat-related injuries. For instance, the Specific Absorption Rate (SAR) is often used to quantify the rate at which energy is absorbed by the body, particularly in the context of mobile phone usage. Regulatory bodies have established SAR limits to ensure that exposure remains within safe levels, thereby minimizing the risk of significant thermal effects. In contrast, non-thermal effects are less well-defined and understood. These effects can occur at lower levels of RF exposure and may not be directly associated with tissue heating (Uluaydin et al., 2019). Research into non-thermal effects has revealed potential biological changes, such as alterations in cellular function, stress responses, and even changes in DNA repair mechanisms. Some studies suggest that long-term exposure to RF radiation, even at levels considered safe by current standards, could be linked to various health issues, including headaches, fatigue, and potential impacts on reproductive health. The exact mechanisms by which non-thermal effects occur remain a subject of ongoing research and debate among scientists.

To address both thermal and non-thermal effects, international guidelines have been established, such as those from the International Commission on Non-Ionizing Radiation Protection (ICNIRP). These guidelines specify basic restrictions and reference levels designed to limit exposure to RF radiation. The ICNIRP guidelines are based on extensive reviews of scientific literature and aim to protect public health by setting exposure limits that account for both thermal and non-thermal effects. By adhering to these guidelines, regulatory bodies seek to mitigate potential health risks associated with RF radiation, ensuring that exposure remains within safe parameters. Table 1 shows the limits based on the short-term thermal effects or the heating of body tissues (ICNIRP, 2018; Tambe, 2015). Shown in Table 2 are the limits of power and field intensity based on non-thermal effects in sleeping areas for long-time exposure to EMF (Chouhan et al., 2013; Group, 2012; Nyakyi et al., 2013; SBM-2015, 2016).

It has been reported in the studies of (Koppel et al., 2019) and (Abdallah et al. 2019) that, the correct configuration of antenna parameters including transmit power, antenna height, azimuth, and tilt is essential for optimizing the quality of service (QoS) in mobile networks. These settings directly influence the network's coverage, capacity, and overall performance, ensuring that users experience reliable connectivity and high data speeds. Moreover, effective optimization of these parameters helps in managing network traffic efficiently, which is crucial as the demand for mobile data continues to rise (Zhang and Wang, 2019).

However, it is important to recognize that these antenna configurations also have significant implications for the level of radiofrequency (RF) radiation exposure in the surrounding environment. The transmit power determines the strength of the signal transmitted, which can influence both the reach of the network and the intensity of RF radiation emitted. Similarly, the height and tilt of the antenna affect the directionality and dispersion of the signals, meaning that even slight adjustments can alter the exposure levels for individuals in proximity to the antenna.

The azimuth, or the angle at which the antenna is oriented, plays a critical role in directing the signal towards intended coverage areas. While optimizing these parameters can enhance network performance, it is essential to balance these improvements with considerations of RF radiation exposure, especially in populated areas. Studies have indicated that higher antenna placements and increased transmit power can lead to elevated RF levels, raising concerns about potential health risks for those living or working nearby (Renke and Chavan, 2014; Onishi et al., 2021; Ramirez-Vazquez et al., 2024).

Therefore, while the technical aspects of antenna configuration are vital for ensuring optimal network performance, they must be approached with a comprehensive understanding of their environmental impact. Ongoing research is necessary to enable network operators to achieve high QoS while minimizing RF radiation exposure, ensuring both effective communication and public health safety. This work, therefore, aims to investigate the influence of various cell tower antenna parameters on the reduction of RF radiation levels from mobile base stations. The study involved field measurements of electric field strengths around two cell sites shared by multiple operators, and analysis of the impact of different antenna configurations on the measured radiation levels. The findings in this study provide insights into the trade-offs between radiation mitigation and maintaining network performance, which can inform strategies for responsible deployment of mobile infrastructure.

Table 1: ICNIRP Reference Limits

Type of Exposure	Frequency range (GHz)	E-field strength (V/m)	H-Field strength (A/m)	Power density (mW/m2)
General	0.4-2	$1.375f^{1/2}$	$0.0037f^{½}$	f/200
Public	2-300	61	0.16	10
Occupational	0.4-2	$3f^{1/2}$	$0.008f^{½}$	f/40
	2-300	137	0.36	50

Table 2: EMF Level Non- Thermal Limits

Power density/ Signal strength	No concern	Slightly concern	Severe concern	Extreme concern
µW/m²	<0.1	0.1 – 10	10 - 1000	>1000
mW/m²	<0.0001	0.0001 - 0.01	0.01 – 1	> 1
Volts per meter (V/m)	< 0.00614	0.00614 – 0.0614	0.0614 – 0.614	> 0.614

LITERATURE REVIEW

Related Works

Radiofrequency (RF) radiation from cellular towers has emerged as a significant public health concern worldwide. While many studies have examined the effects of RF exposure on human health, there is a notable gap in research specifically addressing how antenna installation parameters affect radiation levels.

The International Telecommunication Union (ITU-T) has recommended several strategies to mitigate radiation from base transceiver stations (BTS) (ITU-T. 2018). Key measures include reducing transmitting power, increasing antenna height, decreasing antenna beam tilt, and increasing antenna gain. Research shows that raising antenna height from 20 meters to 35 meters while keeping a 0° tilt, 2.32 dB combined losses, a carrier frequency of 947.5 MHz, 15.5 dBi antenna gain, and 25 Watts transmit power can reduce exposure levels from 0.4 mW/m² to 0.2 mW/m² at a distance of 275 meters. Likewise, reducing the antenna down-tilt from 10° to 0° can decrease exposure from 0.8 mW/m² to 0.2 mW/m² at 225 meters. However, if antenna gain is decreased from 18 dBi to 15.5 dBi under a configuration of 0° tilt, 2.34 dB combined losses, a carrier frequency of 947.5 MHz, and 50 Watts transmit power, radiation levels can increase from 0.1 mW/m² to 0.5 mW/m² at 300 meters. While reducing transmitter power is a straightforward approach to lowering radiation, it can also reduce coverage area, suggesting it should be employed judiciously. Importantly, these recommendations are based on simulations rather than real-world data, and they do not consider the impact of the number of channels or other radio access technologies (RATs).

To evaluate public safety concerning radiation exposure, researchers (Nyakyi et. al 2013) calculated safe distances from cellular towers. They measured power density at various locations using selective radiation meters, with data on antenna gain and power sourced from mobile network operators. Their findings indicated that safety distances vary based on transmitted power, antenna height, and the specific RAT. For an antenna with a fixed gain of 17 dB and a height of 30 meters, the safety distances for transmitted powers of 16 dBm and 20 dBm were 120 meters and 190 meters, respectively. Notably, all field measurements within 50 meters of the antenna exceeded the non-thermal biological minimum exposure level of 10 μW/m² for sleeping areas. However, the study did not analyze how antenna beam tilt impacts electromagnetic field (EMF) radiation levels.

A study conducted in anechoic chambers, titled by (Sieczkarek, et. al., 2016) found that, incorporating tilt in antenna configurations increases emissions. The experiment varied antenna height in increments of 100, 200, 300, and 400 cm. While informative, the laboratory setting underscores the need for real-world testing to understand how these parameters affect radiation levels. The review also suggested using parameters like down-tilt, reduced transmit power, and increased antenna gain to manage emissions from cellular towers but did not consider the effects of channel quantity and RAT.

Researches indicate that antenna parameters are crucial for managing RF radiation levels. For instance, a study by (Abdallah et al., 2019) highlighted how variations in transmission power, antenna height, azimuth, and tilt angle can significantly affect radiation exposure. Their findings suggest that optimizing these parameters can lead to substantial reductions in RF radiation while maintaining service quality.

A comparative evaluation of exposure to electromagnetic fields from GSM and 3G base stations in urban areas done by (Hamiti et. al., 2017) and (Tambe, K. M., 2015) assessed minimum safe distances for public and occupational exposure through both theoretical and empirical assessments. Results showed that radiation levels were generally lower and within the acceptable limits set by ICNIRP guidelines. The minimum safe distances for the general population ranged from 1.42 meters to 3.35 meters from the tower. However, this analysis did not consider how antenna parameters influence radiated power density. The Comparative studies indicate that while EMF exposure increases with the advancement of mobile technology, the levels remain within safety limits. A comprehensive review by (Blettner et al. 2015) compared EMF exposure from GSM, 3G, LTE, and 4G networks, concluding that although newer technologies may result in higher exposure, the associated health risks remain low.

In India, a study explored the health implications of radiation exposure through personal interviews to identify health complaints among residents (Premlal and Eldhose, 2017). Measurements of electric fields inside and outside buildings, along with statistical analyses, examined the relationship between health symptoms and EMF exposure. The study found that 18.86% of participants experienced exposure exceeding the Indian standard of 470 mW/m². Recommendations included maintaining a distance of 300 meters from cell towers.

Another study focused on calculating radiation safety distances for GSM, Digital Cellular Systems (DCS), and UMTS microcells (Fayed and El-Din, 2017). Using the standard isotropic power density formula, researchers assumed an Effective Isotropic Radiated Power (EIRP) of 1 kilowatt and a safety limit of 0.57 mW/cm². They concluded that the safety distance from the antenna was 6 meters in the main field's direction. However, this study did not account for critical variables such as antenna height, tilt, and frequency, which could significantly influence exposure levels.

Research has shown that prolonged exposure to RF radiation may pose health risks, including potential links to cancer and other ailments. The World Health Organization (WHO) classifies RF fields as possibly carcinogenic to humans (Group 2B), necessitating investigations into exposure levels and mitigation strategies (WHO, 2011).

Efforts to mitigate RF exposure emphasize both regulatory frameworks and technological advancements. Parajuli (2015) advocates for stricter regulations governing the placement and operation of cellular towers, especially in densely populated areas. Additionally, the adoption of advanced technologies, such as beamforming and smart antennas, can help reduce unnecessary RF exposure by directing signals more efficiently (Imami, 2019).

Various methodologies have been employed to assess RF exposure from cellular towers, including mathematical modeling, field measurements, and electromagnetic software simulations (Chitranshi, Mehrotra, and Pancoli, 2014). Mathematical models, such as those described by (Abdallah et al. 2019), provide valuable insights into the relationship between antenna parameters (and radiation levels, allowing researchers to simulate different scenarios and predict the impact of changes in antenna configuration. Field assessments are also essential for validating theoretical models and ensuring compliance with safety standards. For example, (Eustatiu and Poparlan, 2016) assessed GSM radiation levels in residential areas, highlighting the importance of real-world measurements in understanding exposure risks.

Influence of different antenna parameters on radiation levels

When considering a single radio base station, a simplified calculation of far-field free-space power density obeys the inverse square relationship that exists between the distance from the radiating antenna and power density. The power density received at a distance is subjected to spatial variations at different scales proportional to the environment's complexity.

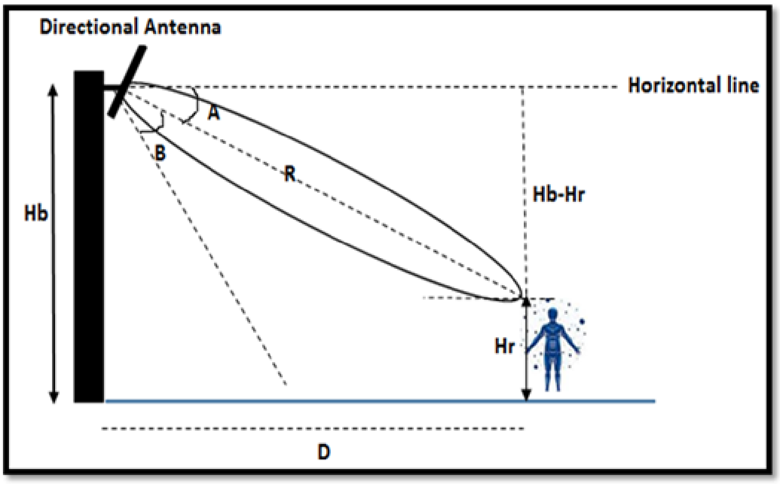

Figure 1: Model of a base station tower and receiving object.

Assuming the model in Figure 1 in the free-space propagation model, the power density received at a certain distance for the case of the single antenna can be approximately given by equation (1) as presented by (Elias, 2013; Nyakyi et al., 2013; Thapa, Sahu, Parajuli, and Shah, 2016).

$$P_d = \frac{P_t G_t}{4\pi R^2} \quad (1)$$

where;

P_d = power density from base station antenna in W/m2.

P_t *and* G_t = Transmit power and gain from the transmit antenna in dBm and dB respectively.

R = The distance from the transmission tower antenna to the receiving station at ground level in meters.

Hb *and* Hr= are the base station antenna height and receiver height respectively.

By considering the height of the transmit antenna and receiving object like a house or human, the distance, R is modified to the equation (2): -

$$R^2 = (D^2 + (Hb - Hr)^2) \quad (2)$$

where Hb and Hr are the height of the transmitting and receiving antenna respectively and D is the distance of the receiving object from the antenna tower.

By substituting (2) in (1), the power density at the top of the receiving object will be given by the equation (3): -

$$P_d = \frac{P_t G_t}{4\pi(D^2 + (Hb - Hr)^2)} \quad (3)$$

Using the tilt angle (A) the distance D given by the equation (4) as described in the studies of (Abdallah, Alyasiri, Ali, & Saloom, 2019; Tero et al., 2004)

$$D = \frac{H_b - H_r}{\tan A} \quad (4)$$

With (4) in (3), the power density received at a distance is given as presented in equation (5): -

$$P_d = \frac{P_t G_t}{4\pi\left(\left(\frac{H_b - H_r}{\tan A}\right)^2 + (H_b - H_r)^2\right)} \quad (5)$$

As it can be seen, equation (5) relates the power density with antenna installation parameters (i.e. antenna height, antenna gain, transmit power, and antenna tilt).

Equations (1) and (5) represent the power density for a single carrier and a single operator. For multiple carriers and multiple operators on the same tower, the power density at a particular point on the ground will be the sum of the individual fields created by each frequency, so the power density will increase. (Kumar, n.d.; Nyakyi et al., 2013).

The electric field represents the intensity of radiofrequency fields and is defined as the amount of the radiated energy crossing per sec per unit area normally through the surface. The electric field intensity at a point from the transmit antenna can be obtained from the power density by equation (6) as explained in the (Parajul, 2014) work.

$$E = 19.42 \sqrt{P_d} \qquad (6)$$

where E is Electric field strength [μV/m] and P_d is the power density [W/m2].

EXPERIMENT SETUPS AND MEASUREMENTS

Experiment Setup

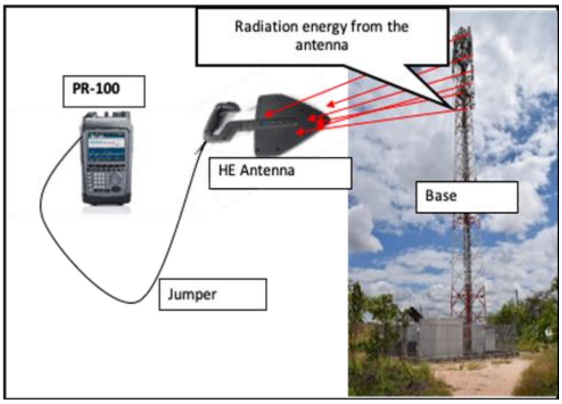

Figure 2: Measurement Scheme of E-field Strength.

Figure 2 shows the instrument used for the experimental measurement which was the Rohde & Schwarz (R&S) portable receiver, model PR-100. The R&S PR-100 portable receiver was utilized due to its high sensitivity, frequency range, and capability to measure EMF levels accurately across various frequency bands (from 3 kHz to 3 GHz). The R&S PR-100 was coupled with a HE300 directional antenna to focus on signals from the base station. This setup minimized interference from other nearby sources and enhanced the accuracy of the measurements. The use of PR-100 enabled precise measurement of electric field strengths (E-field strengths) around the two selected base stations. The following are the calibration and measurement procedures of PR-100 used in this work:

Calibration Procedures

- Before data collection, the PR-100 was calibrated using a known reference signal at a frequency of 900 MHz, following the manufacturer's guidelines. This calibration ensured the receiver's accuracy in measuring EMF strength.
- Calibration involved setting the receiver to its default settings and verifying its output against a calibrated signal source. Any discrepancies noted during calibration were adjusted according to the manufacturer's specifications.
- Calibration was performed at the beginning of each measurement session, and a log was maintained to document calibration results.
- The calibration process ensured that the receiver's sensitivity and accuracy were within acceptable limits, allowing for reliable data collection.

Measurement Procedures

- At each distance, the receiver was positioned at a height of approximately 1.5 meters above ground level to simulate typical human exposure scenarios.
- The receiver was set to continuously log EMF levels for a minimum of 10 minutes at each location to account for fluctuations in readings.
- Environmental factors, including weather conditions, surrounding physical obstructions (buildings, trees), and traffic conditions, were noted to provide context for the measurements.

Table 3: Description of the Study Area

Site Name	Latitude	Longitude	Special Features
Mbwanga/Nkuhungu	-6.14520034	35.700587745	• 40-meter tower length. • Shared by Aitel Tanzania, Tigo, TTCL, and Vodacom Tanzania mobile operators. • Located near Mnadani Sec school along Dodoma -Singida road.
Swaswa	-6.14373373	35.78362924	• 50-meter tower length. • Shared by Aitel Tanzania, Tigo, TTCL, and Vodacom Tanzania mobile operators. • Along Swaswa Road.

3.2 Study Area

The practical measurements of radiation levels in terms of electric field strengths (E-field strengths) were carried out on two selected operating base stations (both located in the Dodoma region, Tanzania). The description of the study locations is shown in Table 3.

3.3 Environmental Assessment

Prior to conducting the field measurements, the researchers of this work conducted environmental assessments at the two selected cell sites located in the Dodoma region, Tanzania. This assessment aimed to identify and analyze various factors that could influence RF radiation levels. The following observations were made:

- *Terrain features*
  - Topography: The topography around the Mbwanga and Swaswa sites was characterized by gentle slopes and valleys. The presence of elevated terrain to the east of the Mbwanga site was noted, which could potentially obstruct signal propagation in that direction. Hence, to consider this, the researchers found an area where the terrain would not cause adverse effects on signal propagation on the Mbwanga site. Conversely, the relatively flat terrain surrounding the Swaswa site allowed for more uniform signal distribution.
- *Vegetation*
  - Types and Density: The area surrounding both sites included mixed vegetation, with a combination of grasslands and sparse trees. The Mbwanga site had a few tall trees located within 100 meters, which may absorb some RF energy and affect the measured field strengths. In contrast, the Swaswa site was more open, with minimal vegetation, allowing for clearer signal pathways. To take this into account, the field strength values were taken at 100 meters and 300 meters along the bore sight of the main lobe.
  - Seasonal Changes: It was also noted that seasonal variations in vegetation density (e.g., during the rainy season when foliage is denser) could impact RF exposure levels. To avoid this, all

measurements were taken during the dry season.

- *Nearby Urban Structures*
    - Building Proximity: Urban structures near the sites were noted, particularly at the Mbwanga site, which is located adjacent to a school and several residential buildings. These structures may reflect or diffract RF signals, contributing to localized variations in radiation levels. The distance and orientation of buildings relative to the antenna were noted and the researchers found an angle where the structures would not cause adverse effects on signal propagation.

Measurement Methodology

Measuring Timing

Data collection was scheduled during peak usage hours (typically late afternoon to early evening) to capture maximum potential EMF exposure.

Measuring Locations

Measurements were taken at three specified distances from each base station: 100m, 200m, and 300m. Each site was marked, and GPS coordinates were recorded to ensure precise locations for repeated measurements.

Measurement Settings and Steps

The receiver was positioned at a height of approximately 1.5 meters above ground level, simulating typical human exposure scenarios. The measurements were conducted in a stationary position at each designated point, with the receiver set to log EMF levels continuously for a minimum of 10 minutes. This duration allowed for capturing fluctuations in EMF levels due to varying user activity and environmental factors.

A technical site audit was carried out prior to the measurement of electric field strength. The audit intended to collect information on the site installations and configuration parameters. Site configuration parameters include site coordinates in terms of global positioning system latitude/longitude (GPS Lat/Long), absolute radio-frequency channel numbers (ARFCN), transmit power, antenna gain, antenna height, antenna tilt, number of sectors, frequency allocations mechanism, Cell Identifications (Cell ID), azimuth and base station technology. Rohde and Schwarz PR100 Portable Receiver tool was used to measure the electric field strength in each sector; the total E-field strength in each sector was the sum of individual carrier recorded field strength. The field strength values were taken at 100 meters and 300 meters along the bore sight of the main lobe. The same process was repeated in sectors 2 and 3. This experiment was performed in all radio access technologies (RAT). The measurement steps were as follows: -

Step 1: Identification of the available RAT on each tower and documentation of RF technical data of each operator.

Step 2: Establishing and identifications of measurement location up to a distance of 300 meters from the tower.

Step 3: The net monitor tool was used to scan the operating ARFCN on sectors 1, 2, and 3 for each MNO. Other parameters shown on the net-monitor display were the Mobile country code (MCC), Mobile Network Code (MNC), GPS Lat/Long, RSSI, RAT, and neighbouring cells. The scanned ARFCN was then converted into equivalent frequencies before recording the emission levels.

Step 4: Starting with sector 1, the PR-100 was used to record the electric field strength of each operator carrier frequency. The measurement approach was fixed frequency measurement to obtain detailed information on the individual source (frequency) contributions. For sectors with more than one channel, the total E-field strength was the sum of individual carrier recorded field strength. The field strength values were taken at 100 meters and 300 meters along the boresight of the main lobe.

The same process was repeated in sectors 2 and 3.
Step 5: The measured values were recorded on a sheet of paper and later transferred to the prepared Excel sheet. The prepared tables were suitable means of organizing bulky amounts of collected data.

RESULTS AND DISCUSSIONS

Results Presentation

The result of Electric Field strength in millivolts per meter (mV/m) and/or microvolts per meter (µV/m) were collected at clear of obstructions distances from the towers (100 meters and 300 meters). The measured electric field levels are presented in Tables 4 through 7. The total electric field was the sum of the individual E-fields created by each carrier frequency. The names of mobile network operators are represented with letters A, T, TT, and V.
The GPS latitude and longitude used at Mbwanga and Swaswa sites are GPS Lat/Long (-6.14520034, 35.700587745) and GPS Lat/Long (-6.14373373, 35.78362924) respectively.

Table 4: E-field Strengths for GSM 900 Band at Mbwanga and Swaswa Site

MBWANGA AND SWASWA SITE TECHNICAL DATA (2G GSM 900)							
1. RADIO PARAMETERS AND ANTENNA DATA							
		MBWANGA SITE READINGS			SWASWA SITE READINGS		
PARAMETER	OPERATOR	CELL 1	CELL 2	CELL 3	CELL 1	CELL 2	CELL 3
FREQUENCY (MHz)	T	935.6	935.2	936	935.2	936.4	936
	A	951.4 & 945.8	952.4 & 945.2	951 & 945.4	950 & 950.6	950.4 & 951	945.2 & 951.8
	V	959	959	957.6	959.8	959.2	958.2
DIRECTION (degree)	T	40	140	300	110	240	340
	A	60	130	320	10	100	240
	V	60	150	290	30	120	225
1ANTENNA HEIGHT(m)	T	30	30	30	42	42	42
	A	24	24	24	32	32	32
	V	30	30	30	34	34	34
Tilt(Mechanical/Electrical)	T	4	4	4	17	17	17
	A	2	2	2	17	17	17
	V	2/8	2/6	1/1	16	18	18
ANTENNA GAIN(dBi)	T	17	17	17	0/2	0/2	0/2
	A	17	17	17	0/4	0/2	0/2
	V	16	18	18	0/1	0/2	1'/3
TX POWER(dBm)	T	43	43	43	43	43	43
	A	41	43	43	40	41.7	43
	V	41.76	41.76	41.76	41.76	41.76	41.76
2. RECORDED ELECTRIC FIELD STRENGTH (in microvolts per meter(mV/m))							
Distance of 100 meters	T	6.7	6.6	6.4	0.0116		20
	A	13.5	13.2	13.7	0.0244		113.6
	V	6.9	7	7.1	0.013		92.3
Distance of 300 meters	T		6.1	6.6	0.0111	0.0143	0.0128
	A		11.3	13.3	0.0241	0.0267	0.0275
	V		4.9	6.7	0.0126	0.0143	0.0134

Table 5: E-field Strengths for DCS Band at Mbwanga and Swaswa Site

MBWANGA AND SWASWA SITE TECHNICAL DATA (DCS/GSM 1800)							
1. RADIO PARAMETERS AND ANTENNA DATA							
		SWASWA SITE READINGS			MBWANGA SITE READINGS		
PARAMETER	OPERATOR	CELL1	CELL2	CELL3	CELL1	CELL2	CELL3
FREQUENCY (MHz)	T	1816.2	1817.4	1815.6	1815.8 & 1819.4 & 1820.2 & 1821 & 1823 &1824.4 &1825.4	1817.8 & 1818.8 & 1820.6 & 1821.6 & 1822.2 &1822.6 & 1823.6	1816.6 & 1819 & 1822 & 1823.8 & 1824.2 &1826.2 & 1827.4
	A	1840.2 & 1841.2 & 1841.4 & 1842 & 1842.8 &1843.6	1827.8 & 1829.4 & 1829.8 & 1843.2 & 1844 &1844.8	1828.3 & 1828.6 & 1829 & 1840.8 & 1840.8 &1842	1840.2 & 1841.2 & 1841.4 & 1842 & 1842.8 &1843.6	1840.2 & 1842 & 1842.6 & 1843.8 & 1844.2	1827.6 & 1828 & 1840.4 & 1841.2 & 1842.4 &1843.2
DIRECTION (degree)	T	110	240	340	40		
	A	60	130	320	60		
ANTENNA HEIGHT(m)	T	42	42	42	33	33	33
	A	32	32	32	24	24	24
Tilt(Mechanical/Electrical)	T	0/2	0/4	0/3			
	A	0/2	0/3	0/1			
ANTENNA GAIN(dBi)	T	17	17	17	17	17	17
	A	17	17	17	17	17	17
TX POWER (dBm)	T	43	43	43	43	43	43
	A	40	41.7	43	41	43	43
2. RECORDED ELECTRIC FIELD STRENGTH (in microvolts per meter(mV/m))							
Distance of 100 meters	T	0.0205		8.6	71.8	71.7	71.6
	A	0.1249		73.3	62.3	73.5	62.5
Distance of 300 meters	T	0.02	0.0207	0.0204		84.6	72.5
	A	0.122	0.1267	0.0983		86.4	61.8

Table 6: E-field Strengths for 3G Band at Mbwanga and Swaswa Site

MBWANGA AND SWASWA SITE TECHNICAL DATA (3G UMTS)							
1. RADIO PARAMETERS AND ANTENNA DATA							
		MBWANGA SITE READINGS			SWASWA SITE READINGS		
PARAMETER	OPERATOR	CELL1	CELL2	CELL3	CELL1	CELL2	CELL3
FREQUENCY (MHz)	T	942.5 & 2122.6 &2127.6 & 2132.4 & 2137.4	942.5 & 2122.6 &2127.6 & 2132.4 & 2137.4	942.5 & 2122.6 &2127.6 & 2132.4 & 2137.4	2122.6	2123.6	2124.6
	A	2162.4 &2167.4 & 947.6	2162.4 &2167.4 & 947.6	2162.4 &2167.4 & 947.6	2162.4 &2167.4 & 947.6	2162.4 &2167.4 & 947.7	2162.4 &2167.4 & 947.8
	V	2142.8 &2147.8 & 2152.8	2142.8 &2147.8 & 2152.8	2142.8 &2147.8 & 2152.8	2142.8 &2147.8 & 2152.8	2142.8 &2147.8 & 2152.9	2142.8 &2147.8 & 2152.10
DIRECTION (degree)	T	40	140	300	110	240	340
	A	60	130	320	120	220	340
	V	60	150	290	30	120	225
ANTENNA HEIGHT(m)	T	33	33	33	42	42	42
	A	24	24	24	32	32	32
	V	30	30	30	34	34	34
Tilt (Mechanical/Electrical)	T	0/2	0/2	0/2	0/2	0/4	0/3
	A	2	2	2	0/2	0/2	0/2
	V	2/4’	2/4’	1’/2	0/1	0/2	1’/2
ANTENNA GAIN (dBi)	T	17	17	17	17	17	17
	A	17	17	17	17	17	17
	V	16	18	18	16	18	18
TX POWER (dBm)	T	43	43	43	43	46	44.2
	A	44.8	46	46	46	46	46
	V	46	46	46	33	33	33
2. RECORDED ELECTRIC FIELD STRENGTH (in microvolts per meter(mV/m))							
Distance of 100 meters	T	85.4	47.1	47.6	0.0404		22
	A	49.6	49.9	49.7	0.1072		95.1
	V	59.2	60.7	60.3	0.1256		44.1
Distance of 300 meters	T		32.7	48	0.037	0.044	35.1
	A		34.1	49.5	0.0995	0.0999	99.617
	V		31.3	59.5	0.1188	0.1269	267

Table 7: E-field Strengths for 4G LTE Band at Mbwanga and Swaswa Site

MBWANGA SITE TECHNICAL DATA (4G LTE)
1. RADIO PARAMETERS AND ANTENNA DATA

		MBWANGA SITE READINGS			SWASWA SITE READINGS		
PARAMETER	OPERATOR	CELL 1	CELL 2	CELL 3	CELL 1	CELL 2	CELL 3
FREQUENCY(MHz)	T	806	806	806	806	806	806
	A	1834.9	1834.9	1834.9	1834.9	1834.9	1834.9
	V	1850	1850	1850	1850	1850	1850
	TT				1860	1860	1860
DIRECTION (degree)	T	40	140	300	110	240	340
	A	60	130	320	10	110	240
	V	30	120	225	30	120	225
	TT				0	120	240
ANTENNA HEIGHT(m)	T	30	30	30	42	42	42
	A	24	24	24	32	32	32
	V	30	30	30	34	34	34
	TT				40	40	40
Tilt (Mechanical/Electrical)	T	0/3	0/3	0/3	0/2	0/2	0/2
	A	2	2	2	0/2	0/3	0/1
	V	2/4’	2/2’	1’/1	0/2	0/4	1’/4
	TT				0/2	0/2	0/2
ANTENNA GAIN (dBi)	T	17	17	17	17	17	17
	A	17	17	17	17	17	17
	V	16	18	18	16	18	18
	TT						
TX POWER (dBm)	T	46	46	46	43	46	44.2
	A	43	43	43	43	43	43
	V	46	46	46	45	45	45
	TT				46	46	46
2. RECORDED ELECTRIC FIELD STRENGTH (in microvolts per meter(mV/m))							
Distance of 100 meters	T	1.6	1.3	1.3	0.0144		3.7
	A	3.0	3.0	2.9	0.0301		2
	V	3.0	3.2	3.0	0.0311		3.5
	TT				0.0311		5.9
Distance of 300 meters	T		1.4	1.4	0.014	0.0019	1.6
	A		3.9	3.3	0.0271	0.0041	5
	V		4.1	3.1	0.0301	0.0043	3.8
	TT				0.0289	0.0052	4.4

Results Analysis and Discussions

Scenario 1: Frequency Vs Radiation Level

During the practical measurement work, it was observed that different frequency bands are used for information transmission in 4G LTE technology. The results obtained from the graphs in Figures 3 and 4 indicate that the level of radiation increases with frequency. The digital dividend band generated little radiation compared to the 1800 MHz band when both are featured in LTE technology. Figure 3 shows the results at 300 meters for the Swaswa site in sector-3 and Figure 4 shows the results for Mbwanga Site. The trend was the same in all sectors except sector-3 for the Swaswa site at 100 meters. Low frequencies are integrated with LTE due to the advantages that the signals have better penetration, less attenuation, and other superior propagation characteristics.

In Figures 3 and 4, the radiation levels increase with frequency. The digital dividend band (800 MHz) generated little radiation compared to 1800

MHz.Operators A, TT, and V were using the same band in LTE but recorded different radiation levels.

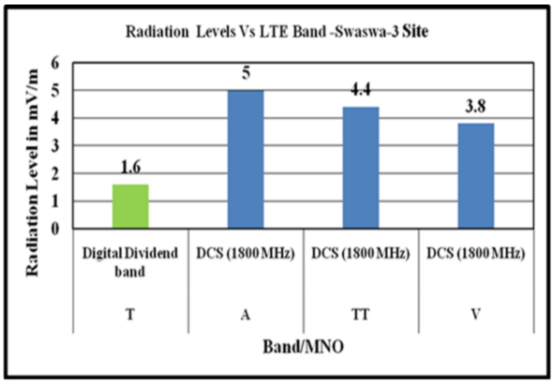

Figure 3: Different LTE Band against Radiation Level-Swaswa Site (Field data).

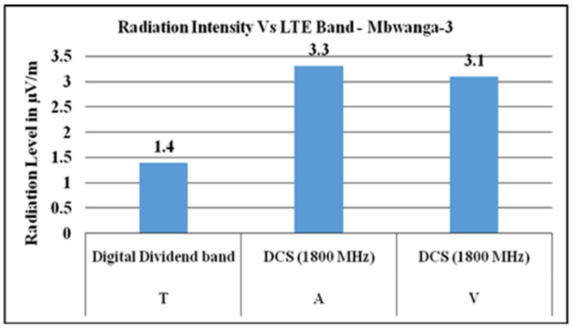

Figure 4: Different LTE Band against Radiation Level-Mbwanga Site (Field data).

Scenario 2: Antenna Beam Tilt Vs Radiation Level

The results of the Mbwanga site in Figure 5 show the analysis of antenna beam tilt for operator named **V**. Measurements results indicate that antenna tilt of 8 generates more radiation levels at 100 meters compared to a distance of 300 meters in GSM 900. Similar results were observed for a tilt value of 3 and 6 at 100 meters and 300 meters respectively in UMTS technology. These results show that when down-tilt is applied to the antenna, the radiation increases near the base station and as you move away. Generally, the increase in antenna down-tilt reduces radiation levels at the expense of coverage footprint reduction.

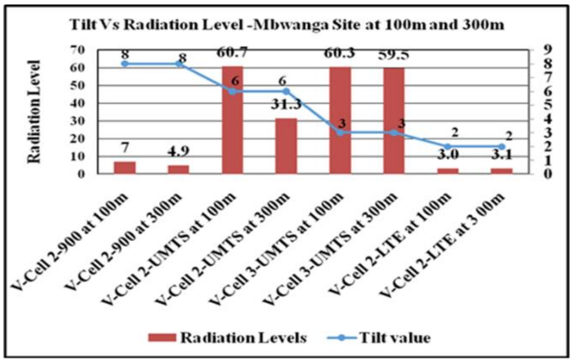

Figure 5: Antenna Beam Tilt Vs Radiation Level- Mbwanga Site (Field data)

Scenario 3: Number of Carrier Vs Radiation Level

As shown in Figure 6, when all other parameters remain fixed, the E-field strengths increase with the increase in the number of channels. The comparison was made for network operator **T** at the Mbwanga site. In this scenario, sector 1 with 5 channels generated more radiation intensity than 3 channels that were configured in sector 2 and sector 3. Therefore, decreasing the number of channels decreases the radiation levels but reduces the network capacity.

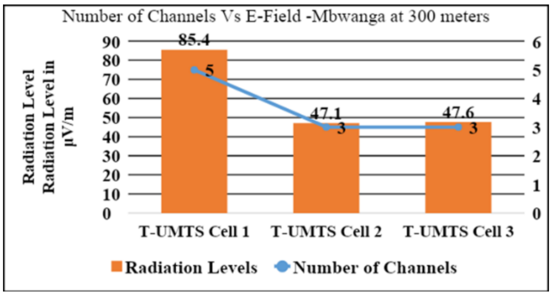

Figure 6: Number of Carriers Vs Radiation Level – Mbwanga Site (Field data)

Scenario 4: Transmission Power Versus Radiation Level

As shown in Figure 7, the transmission power of 43 dBm recorded a radiation of 0.0144 mV/m while the transmission power of 44.2 dBm created a radiation of 3.7 mV/m at 100 meters under fixed antenna height, tilt, number of channels, and gain. This demonstrates that the increase in transmission power results in an increase in the level of the E-field strengths. The analysis results are presented in Figure 7 for the Swaswa site in Sectors 1, 2, and 3 in **LTE** technology for network operator **T** and Sectors 2 and 3 in GSM 900 for operator A at 300 meters.

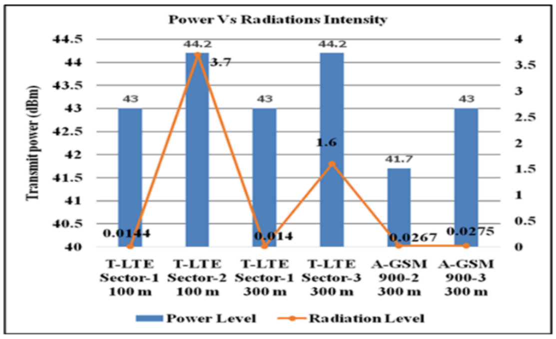

Figure 7: Transmission Power Vs Radiation Level – Swaswa Site (Field data).

GSM 900 (Figure 8) in Sector 1 and Sector 3 at the Mbwanga site shows an increase in radiation intensity with an increase in transmission power. The same trend was seen in the UMTS band under fixed antenna heights, antenna beam tilt, the same number of channels, and antenna gain. In this analysis, the measurements support the literature review about the increase of radiation level with an increase in transmission power.

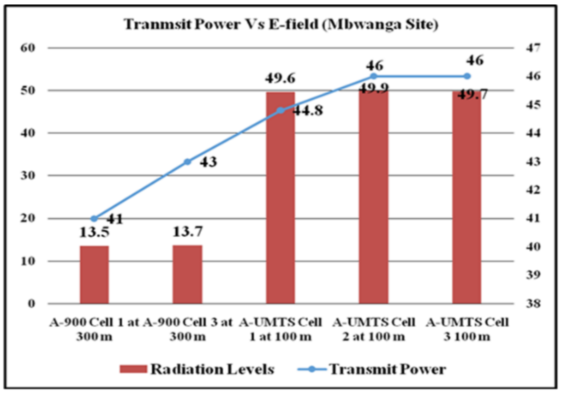

Figure 8: Transmit Power vs. Radiation Level – Mbwanga Site (Field data).

Implications of the findings

The findings of this study highlight the significant potential for optimizing mobile base station antenna parameters to reduce radio frequency (RF) radiation exposure in nearby communities. By strategically adjusting factors such as transmission power, antenna tilt, and the number of active carrier frequencies, it is possible to enhance public health protection while maintaining service quality. These insights call for informed regulatory frameworks that reflect current scientific understanding, as well as proactive community engagement strategies to foster transparency and trust between mobile operators, policymakers, and residents. Ultimately, the implications underscore the need for a balanced approach that prioritizes both technological advancement and the well-being of affected populations. In the following subsections, we will explore the specific health implications, regulatory recommendations, and strategies for community engagement that arise from these findings.

Public Health Implications

Non-Thermal Effects

While the thermal effects of RF radiation, such as tissue heating, are well-documented and understood, the implications of non-thermal effects are increasingly recognized in the scientific community. Recent research indicates that prolonged exposure to RF radiation, even at levels below those set by regulatory bodies, may be associated with a range of adverse health outcomes. These include headaches, fatigue, sleep disturbances, and potential effects on cognitive functioning. Our study demonstrates that by optimizing antenna parameters such as down-tilt, transmission power, and the number of active carrier frequencies, we can achieve significant reductions in RF exposure. This reduction is vital for populations residing near mobile base stations, as it may mitigate the risks associated with non-thermal effects.

Vulnerable Populations

Certain demographic groups are particularly vulnerable to RF exposure. Children, for example, have developing nervous systems and may be more susceptible to the potential impacts of RF radiation. Similarly, the elderly and individuals with pre-existing health conditions may experience heightened sensitivity to RF exposure. Our findings highlight the necessity of adopting protective measures specifically aimed at these vulnerable populations. Public health initiatives should prioritize these groups in risk assessments and consider their specific needs when developing policies related to RF emissions.

Regulatory Frameworks

The results of this study suggest a pressing need to revisit and potentially revise existing regulatory frameworks governing RF exposure. Current guidelines may not fully account for the dynamic nature of mobile communications, where transmission power can vary based on demand. Implementing policies that encourage mobile network operators to adopt technologies allowing for real-time adjustments in transmission power could enhance service quality while simultaneously reducing RF exposure in residential areas. This proactive approach not only aligns with public health goals but also supports the sustainable development of mobile telecommunications.

Public Awareness and Education

Effective risk management requires an informed and engaged public. Our findings advocate for increased transparency from mobile network operators regarding the levels of RF exposure associated with their infrastructure. Public awareness campaigns are essential to educate communities about safe distances from cell towers and the potential health implications of RF radiation. By providing accessible information and resources, we can empower individuals to make informed decisions regarding their exposure to RF emissions. Additionally, engaging communities in discussions about the deployment of new technologies can foster trust and collaboration between operators and residents.

Comparison with Safety Guidelines

ICNIRP Guidelines

The ICNIRP sets limits for RF exposure based on both thermal and non-thermal effects. For general public exposure, the recommended maximum electric field strength is approximately 61 V/m for frequencies between 2 GHz and 300 GHz, while for occupational exposure, the limit is higher, reflecting the assumption of reduced exposure time. Our measurements across various antenna configurations indicate that electric field strengths were consistently below these thresholds, suggesting compliance with ICNIRP guidelines.

However, while our findings align with ICNIRP's safety thresholds, it is important to recognize that the guidelines are based on the best available science at the time of their formulation. Recent studies suggest that non-thermal effects, which may occur at lower exposure levels, could pose health risks that current guidelines do not fully address. Therefore, while our results demonstrate compliance with existing standards, they also highlight the need for ongoing research into the potential long-term health implications of RF exposure, particularly in residential areas near mobile base stations.

Comparison with Other International Standards

In addition to ICNIRP, other organizations, such as the Federal Communications Commission (FCC) in the United States and Health Canada, have established similar exposure limits. Our findings indicate that the measured RF radiation levels at both the 100-meter and 300-meter distances from the towers are well within the limits set by these organizations. This consistency across different regulatory frameworks reinforces the reliability of our measurements and the effectiveness of current safety standards.

Community Engagement

Effective risk management requires an informed and engaged public. Our findings advocate for increased transparency from mobile network operators regarding the levels of RF exposure associated with their infrastructure. Public awareness campaigns are essential to educate communities about safe distances from cell towers and the potential health implications of RF radiation. By providing accessible information and resources, we can empower individuals to make informed decisions regarding their exposure to RF emissions. Additionally, engaging communities in discussions about the deployment of new technologies can foster trust and collaboration between operators and residents.

CONCLUSION AND RECOMMENDATION

In this paper, we have investigated the influence of cell tower antennas parameters on the reduction of radio frequency radiation levels from radio base stations. Through the analysis, it has been found that radiation levels from radio base stations are reduced when lower energy frequencies are featured in higher-order radio access technologies (for example deployment of GSM spectrum inside LTE). Furthermore, radiation levels from the base station are reduced by antenna down-tilt, decrease of transmission power, and decrease of number of carrier frequencies. However, tuning of antenna parameters for the reduction of radiations may negatively impact the delivery of the quality of mobile services. This study, therefore, recommends the following: -

1. There is a need for an in-depth exploration of the best trade-off between cell phone tower radiation mitigation techniques and quality of service requirements.

2. Future Policy Adjustments

Given the evolving nature of mobile communication technologies and the increasing density of RF-emitting devices, it is crucial to periodically review and update safety guidelines. Our study underscores the importance of adopting a precautionary approach, particularly for vulnerable populations, and suggests that regulatory bodies should consider incorporating new research findings into their guidelines. This proactive stance will help ensure that public health is safeguarded in light of emerging evidence regarding the potential risks associated with RF exposure.

3. Ongoing Research and Monitoring

To fully understand the long-term health impacts of RF exposure, ongoing research is essential. We recommend further studies that focus on longitudinal health outcomes in populations living near mobile base stations. Such research should also consider the cumulative effects of RF exposure from various sources, including Wi-Fi and other wireless devices. Continuous monitoring of RF radiation levels and health outcomes can inform future policy adjustments and ensure that public health remains a priority as technology evolves.

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