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Comparative Analysis of the Signal Strength of Two Radio Stations in Okene, Kogi State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors contributed to the study conception and design. Authors SDY, MG, OGO and SII performed material preparation, collected and analyzed the data. Author MG prepared the first draft of the manuscript, reviewed the manuscript, Author SDY re-drafted the manuscript. All authors commented on submitted versions of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

There are significant concerns for the citizens of Okene and its surroundings; regarding the distortions experienced in radio signals due to increased attenuation, which have resulted in poor signal quality. This study carried out a comparative analysis of the signal strength of two radio broadcast stations in Okene, Kogi State, Nigeria, using a field strength meter. The study involved measuring the signal strength for each radio stations at six selected locations in Okene and surrounding area. The wavelength and free space path-loss was calculated at sixteen different locations. The results indicated an inverse relationship between the measured signal strengths and

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the path-loss, as well as the approximate distance amid antennas. The transmitting signal strength was 100.9dBµV (KA) and 102.2dBµV (KB). Distance from station where signal can be receive was 72.0km (KA) and 69.0km (KB). The free space path loss experienced was 109.01dB (KA) and 109.39dB (KB). Even though KA has a lower transmitting signal strength, its longer wavelength 3.21m and lower frequency 93.5MHz gives it an age over KB with higher frequency 109.5MHz and shorter wavelength 2.94m. However, it is recommended that the FM stations should strategically enhance their network infrastructure to improve service delivery, particularly where performance lags. Booster stations at approximately 69km away from the main stations can effectively enhance the signal, leading to better signal quality and improved customer satisfaction.

Keywords: Radio waves; attenuation; impedance mismatch; path loss; EM fields; EM Spectrum; propagation pattern

1. INTRODUCTION

Radio waves consist of electric and magnetic fields that are perpendicular to each other and to their direction of travel, propagating at the speed of light mainly used for communication (Kongban 2009). A key feature of radio waves is their ability to be refracted by the ionosphere. However, very high frequency (VHF) radio waves experience minimal refraction (Daniel et al., 2016, Britannica 202). Typically, audio frequencies are transmitted via radio waves at specific angles through a process called modulation (Commscope 2018). Modulation is the process of superimposing a low-frequency signal on a high-frequency carrier signal for transmission (Kongban 2009). In amplitude modulation (AM), the amplitude of the carrier wave is adjusted to match the low-frequency audio signal. In frequency modulation (FM), the frequency is altered. At the receiving end, a radio receiver captures the radio wave and extracts the information through demodulation (Britannica 2022, Course Hero 2022).

The radio frequency spectrum spans a large part of the electromagnetic spectrum and facilitates wireless broadcasting and communication. Radio frequency fields, or radio waves, are produced by sources like mobile radio communications, broadcasting, radar, and cell phones (Graf 2001). Ellingson (2016) defined radio propagation as the behavior of radio waves as they travel from one point to another within the Earth's atmosphere. As electromagnetic waves, radio signals exhibit phenomena such as reflection, refraction, diffraction, absorption, polarization, scattering, and interference. Saroj and Smruti (2011) noted that electromagnetic interference occurs when fields disrupt each other, causing distortions. This interference is often noticeable in radios when changing frequencies or channels, leading to noise, and in television signals where picture quality deteriorates due to signal distortion. Radio propagation is inherently unpredictable, and probabilistic methods are used in transmission planning. Various protocols have been established for radio wave propagation, with the choice of mode depending on the distance between the transmitter and receiver (Brain 2000). The effectiveness of radio signal transmission is heavily influenced by obstacles and the propagation medium, making signal strength crucial for the design and operation of radio systems (George and Theodore 1982, Amajama et al., 2023).

In areas where communication is crucial, such as those facing rising insecurity, the measurement and analysis of radio signal strength have become increasingly important. In Nigeria, escalating insecurity—manifested through armed banditry, kidnapping, and terrorism—has led to ineffective communication systems due to poor radio signal reception from transmitting stations (NSACC 2021). Ensuring the security of lives and property is a critical concern for governments, individuals, and organizations aiming for long-term sustainability (Achumba et al., 2013, Hussein et al., 2004). A secure environment is essential for effective planning, management, and resource allocation for successful business operations (Hussein et al., 2004). Recognizing this, the Nigerian federal government invests a significant portion of its budget in security. However, communication system shortcomings have hindered security efforts. This paper aims to carry out a comparative analysis of the signal strength and quality of two FM stations in Okene, Kogi State, Nigeria, with the goal of recommending improvements for enhanced signal quality and reception and better communication, particularly for security purposes in remote areas, thereby supporting sustainable development.

2. MATERIALS AND METHODS

2.1 Materials

The materials utilized for this study includes field strength meter; Spectral V5 RF power meter; 8VSB (ATSC) modulator meter; and a GPS device.

2.1.1 The Field Strength Meter

The field strength meter operates based on a straightforward passive (unpowered) circuit design (Fig. 1). In this design, the antenna intercepts radio frequency (RF) energy, which is then rectified to direct current (DC). The rectified DC is utilized to directly drive the meter, indicating the strength of the received RF signal. Its sensitivity is influenced by the following factors:

- Antenna Gain: How it intercepts RF signal;
- Meter movement sensitivity;
- Battery capacity.

2.2 Methods

2.2.1 Area of study

Okene, a strategically positioned town, is located at latitude 7.550° North and longitude 6.240° East, with an elevation of 384km above sea level. The town covers an area of 328km². According to the 2006 census, it has a population of 325,623. It is originally founded on a hill, it is now situated in the Valley of the Ubo River, a minor tributary of the Niger River. Okene operates on the West Africa Time (WAT) zone.

The town's economy thrives on various businesses services and approximately 75% of the population engages in farming. Notable radio stations in Okene include Kogi Radio on 93.5 FM, situated on a hill in the Okene Bar area. It operates with a transmitter power of 10kW but broadcasts only 3kW for public consumption. Another radio station, TAO FM, operates on 100.9 FM and is located in Kuroko, Okehi. It has a combined transmitter power of 2kW that is fully broadcasted. Fig. 2 displays a map of Okene, indicating the locations of these two radio stations.

2.2.2 Method of determining signal strength

The field strength meter was activated and set to the radio frequency mode, specifically tuned to the FM mode to capture only frequencies within that range. With the antenna adjusted the scanning process commenced, and the screen readings were continuously monitored for approximately two minutes. As the readings fluctuated up and down, the peak value within this period was recorded. The distance between the location of the receiving antenna and the transmitting antenna of the radio channel was also noted. To minimize potential interference from external factors such as vegetation cover, trees, and buildings, the readings were taken in an open space. The data collection period spanned from August 19th to September 3rd, 2019, totaling sixteen days. During this period, rainy and cloudy days were avoided due to the equipment's sensitivity.

At six specific locations in Okene town, labeled as points 02 to 07, the strengths of the two radio signals Kogi Radio (KA) and TAO FM (KB) were measured. These locations were selected randomly within Okene and environs.

Fig. 1. High resistance/low conductance field strength meter

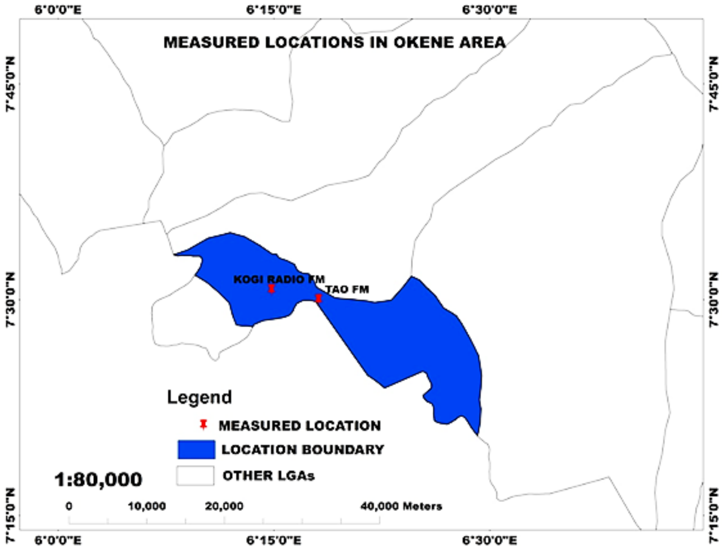

Fig. 2. Map of okene showing locations of the radio stations

The selection of the positions for measurement was based on geographic sampling, considering the northern, eastern, and western parts of Okene town. This approach aimed to capture a representative coverage area. The signal strengths of KA and KB were measured at each FM stations, labeled as 01A and 01B, and compared with the ones measured at the six selected locations. Distance between the FM stations and the selected locations were also recorded. Coordinates of each location coordinates was recorded with Global Positioning System (GPS) and the locations were coded. Table 1 presents the details of the selected locations and their respective codes.

2.2.3 Method of calculating wavelength

The wavelength (λ) of the wave, which represents the linear displacement between two consecutive crests or troughs can be expressed as:

$$\lambda = \frac{c}{f} \quad (1)$$

Table 1. Location codes and their GPS points

Locations	Codes	GPS Locations
Kogi Radio Station	OK1A	Lat. N7°33'3.52116" & Long. E6°13'59.38392"
TAO FM Station	OK1B	Lat. N7°33'7.78788" & Long. E6°14'16.208"
Obehira/Okenwe Junction, Okene	OK2	Lat. N7°32'54.69" & Long. E6°12'13.81788"
Ogaminana Clinic	OK3	Lat. N7°35' 50.93412" & Long. E6°13'50.8512"
Check Point, Okene	OK4	Lat. N7°31'37.32168" & Long. E6°15'18.03816"
Railway Station	OK5	Lat. N7°36' 55.257" & Long. E6°15'45.268"
FC/Lokoja Road, Okene	OK6	Lat. N7°36'35.09568" & Long. E6°15'41.24988"
NIOMCO	OK7	Lat. N7°38'30.53508" & Long. E6°20'34.25856"
Usunkwe, Kabba Road, Okehi	OK8	Lat. N7°37'30.1908" & Long. E6°12'45.16128"
Ageva	OK9	Lat. N7.47100N & Long. E6.16330
Magongo	OK19	Lat. N7°28'60.02141" & Long. E6°13'0.25124"
CUSTEC Osara	OK11	Lat. N7°40'33.5" & Long. E6°24'47.1"
Osara Gada	OK12	Lat. N7°40' 46.68816" & Long. E6°25'18.7716"
Kabba/Obajana Junction, Lokoja	OK13	Lat. N7°449'32.37852" & Long. E6°34'57.9666"
Felele, Lokoja	OK14	Lat. N7°50'43.2132" & Long. E6°44'53.007"
Central Park, Kabba	OK15	Lat. N7.8342 & Long. E6.0742
Ganaja Village, Jimgbe, Lokoja	OK16	Lat. N7°42'52.06428" & Long. E6°44'25.3986"

Where: λ represents wavelength, v denotes velocity of the wave; given as $3 \times 10^8 ms^{-1}$, and f represents the frequency of the wave.

2.2.4 Method of calculating free space path loss

The reduction in radio energy as it travels across distances between feed points of two antennas is called free space path loss (FSPL). Assuming the antennas are isotropic and have no directivity. This means that the antennas are lossless, polarization of the antennas is the same, no multipath effects, and the radio wave path is sufficiently far away from obstructions that it acts as if it is in free space, then the FSPS can be expressed following Whitaker (2018) as follows:

$$FSPL = \left\{\frac{4\pi d}{\lambda}\right\}^2 \quad (2)$$

Where, d is the distance between the antennas, λ is the calculated wavelength, and 4π is a constant. Here, d must be large enough that the antennas are in the far field of each other (d ≫ λ) (Mailloux et al., 1984). In terms of frequency, we can express FSPL as follows:

$$FSPL = \left\{\frac{4\pi df}{c}\right\}^2 \quad (3)$$

Expressing it in decibel (dB) we have:

$$FSPL = 10\log_{10}\left(\left\{\frac{4\pi df}{c}\right\}^2\right) = 20\log_{10}\left(\frac{4\pi df}{c}\right) \quad (4)$$

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \quad (5)$$

$$FSPL = 20\log_{10}(d) + 20\log_{10}(f) - 147.55 \quad (6)$$

Where d is in meters f is in hertz (s^{-1}), and c is in meters per second

For typical radio applications, it is common to find d measured in kilometers and f in gigahertz, in which case the FSPL equation becomes:

$$FSPL = 20\log_{10}(d_{km}) + 20\log_{10}(f_{GHz}) + 92.45 \quad (7)$$

3. RESULTS

3.1 Signal Strength

Tables 2 and 3 is result of the signal strength measurements with the estimated distances from the radio channel, as recorded from each FM stations. However, it should be noted that at certain remote locations far from the transmitter, no signals were detected due to the attenuation of the signals. As the signals travel over long distances, they gradually weaken and experience attenuation. This phenomenon was predominantly observed when taking readings from the distant area in Lokoja.

From the data in Table 2, the signal strength at location O1A is 100.9dBµV at distance of approximately 0.0m, indicating close proximity. Conversely, at location O15A and O16A there was no signal, which can be attributed to various factors such as signal attenuation due to the considerable distance (≈ 74km) and potential obstructions causing reflection, refraction, or

Table 2. Signal strength with distance from KA

Positions	Signal Strengths (dBµV)	Approximate distance btw the antennas x10^3 (m)	Frequency of the signal (MHz)
OK1A	100.9	0.0	93.5
OK2A	74.4	5.0	93.5
OK3A	79.2	5.0	93.5
OK4A	59.1	5.5	93.5
OK5A	62.5	7.5	93.5
OK6A	45.2	10.0	93.5
OK7A	62.0	10.0	93.5
OK8A	41.2	18.0	93.5
OK9A	36.3	23.0	93.5
OK10A	25.1	27.0	93.5
OK11A	29.2	30.0	93.5
OK12A	24.4	36.0	93.5
OK13A	30.3	71.0	93.5
OK14A	37.5	73.0	93.5
OK15A	Nil	73.0	93.5
OK16A	Nil	75.0	93.5

Table 3. Signal strength with distance from KB

Positions	Signal Strengths (dBμV)	Approximate distance btw the antennas x10^3 (m)	Frequency of the signal (MHz)
OK1B	102.2	0.0	101.9
OK2B	64.2	4.0	101.9
OK3B	58.1	10.0	101.9
OK4B	42.9	5.0	101.9
OK5B	54.4	12.0	101.9
OK6B	46.7	5.0	101.9
OK7B	51.8	14.5	101.9
OK8B	21.3	23.0	101.9
OK9B	41.2	10.0	101.9
OK10B	23.4	23.0	101.9
OK11B	27.1	32.5	101.9
OK12B	35.8	38.5	101.9
OK13B	36.4	69.0	101.9
OK14B	Nil	72.0	101.9
OK15B	Nil	75.5	101.9
OK16B	Nil	73.0	101.9

diffraction of the signals. Location O2A, at 5km, exhibits a signal strength 74.4dBμV. Though there is some variations in signal strength at different locations having same distance due to signal attenuation by obstructions like hills and valleys, overall, we can see that the signal strength is directly proportional to the distance.

From Table 3, location O1B, corresponding to the radio FM station, registered a signal strength of 102.2dBμV at distance 0.0m, indicating close proximity. However, locations O14B, O15B and O16B did not detect any signals; and this could be attributed to fading, which occurs as signals traverse different media over longer distances, such as 72km and above in these respective locations. In addition to fading, the absence of signals could be attributed to other factors such as obstructions along the paths of signal propagation.

3.2 Wavelength

From Tables 2 and 3, the wavelengths (λ) of the FM radio stations was determined using equation 1. The results of these calculations are presented in Table 4. In this context, it is important to note that both the frequency of the signal and the wavelength are directly related to the velocity of the electromagnetic wave, which is essentially a constant with an approximate value of $3x10^8$m/s, representing the speed of light.

From Table 4, it is clear that higher frequency signals characterized by smaller wavelengths, tend to experience faster attenuation compared to lower frequency signals with larger wavelengths. As a result, it can be inferred that KB, which operates at a higher frequency, is expected to attenuate more rapidly than KA when passing through different physical mediums such as brick walls and vegetation.

3.3 Free Space Path Loss

From Tables 2, 3 and 4 the path loss of the FM signals for each selected locations were calculated using equation 6 and are presented in Tables 5 and 6.

From Tables 5 and 6, it is clear that; in terms of path loss, the primary factor contributing to signal attenuation is the distance traveled by the signal through the atmosphere. As the signal propagates, it gradually gets attenuated below the sensitivity threshold of the receiving antenna.

Table 4. Calculated values of the wavelengths

Radio Stations	Frequency (MHz)	Velocity (ms^{-1})	Wavelength (m)
Kogi Radio	93.50	$3.00x10^8$	3.21
TAO FM	109.50	$3.00x10^8$	2.94

Consequently, the weak signal becomes difficult to be detected by the receiver. Figs. 3 and 4 further illustrate the relationship of distance, signal strength, and path loss for both KA and KB. It implies that as the distance increases, the path loss increases, while the signal strength decreases, even though not at same rate for the two stations but the trend is the same. However, KA outperforms KB as KB's network experience more attenuation as compared to KA at approximately same distance.

Table 5. Calculated free space path loss for KA

Positions	Signal Strengths (dBµV)	Approximate distance btw the antennas x10^3 (m)	Wavelength (m)	Free Space Path Loss (dB)
OK1A	100.90	0.00	3.21	0
OK2A	74.40	5.00	3.21	85.85
OK3A	79.20	5.00	3.21	85.85
OK4A	59.10	5.50	3.21	86.67
OK5A	62.50	7.50	3.21	89.37
OK6A	45.20	10.00	3.21	91.87
OK7A	62.00	10.00	3.21	91.87
OK8A	41.20	18.00	3.21	96.97
OK9A	36.30	23.00	3.21	99.10
OK10A	25.10	27.00	3.21	100.49
OK11A	29.20	30.00	3.21	101.41
OK12A	24.40	36.00	3.21	102.99
OK13A	30.30	71.00	3.21	108.89
OK14A	37.50	73.00	3.21	109.13
OK15A	Nil	73.00	3.21	109.13
OK16A	Nil	75.00	3.21	109.37

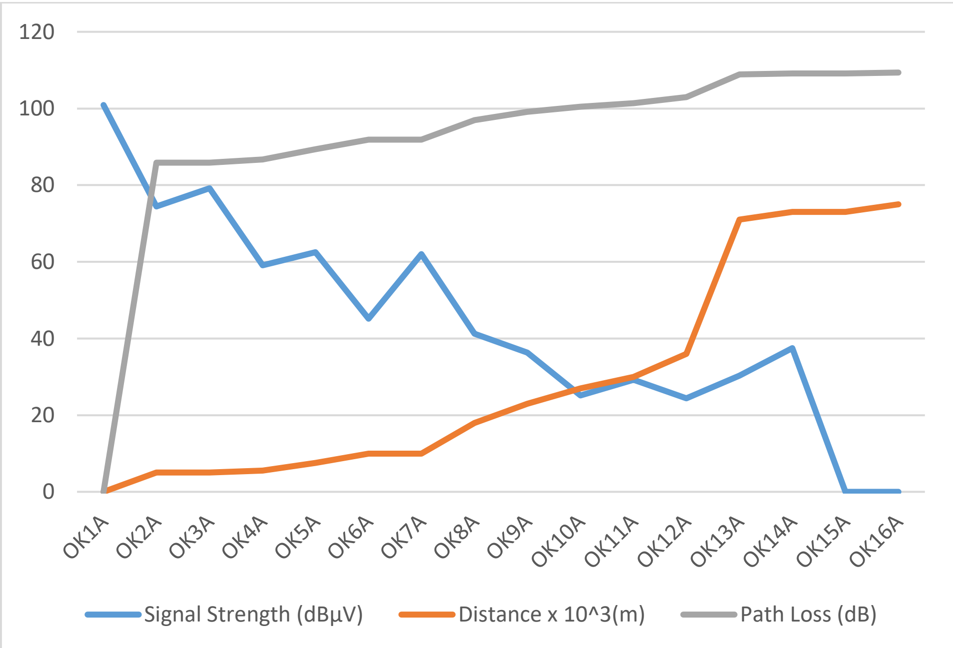

Fig. 3. Relationship between signal strength, distance and path loss for KA

Table 6. Calculated free space path loss for KB

Positions	Signal Strengths (dBµV)	Approximate distance btw the antennas x10^3 (m)	Wavelength (m)	Free Space Path Loss (dB)
OK1B	102.20	0.00	2.94	0
OK2B	64.20	4.00	2.94	84.65
OK3B	58.10	10.00	2.94	92.61
OK4B	42.90	5.00	2.94	86.59
OK5B	54.40	12.00	2.94	94.20
OK6B	46.70	5.00	2.94	86.59
OK7B	51.80	14.50	2.94	95.84
OK8B	21.30	23.00	2.94	99.85
OK9B	41.20	10.00	2.94	92.61
OK10B	23.40	23.00	2.94	99.85
OK11B	27.10	32.50	2.94	102.85
OK12B	35.80	38.50	2.94	104.32
OK13B	36.40	69.00	2.94	109.39
OK14B	Nil	72.00	2.94	109.76
OK15B	Nil	75.50	2.94	110.17
OK16B	Nil	73.00	2.94	109.88

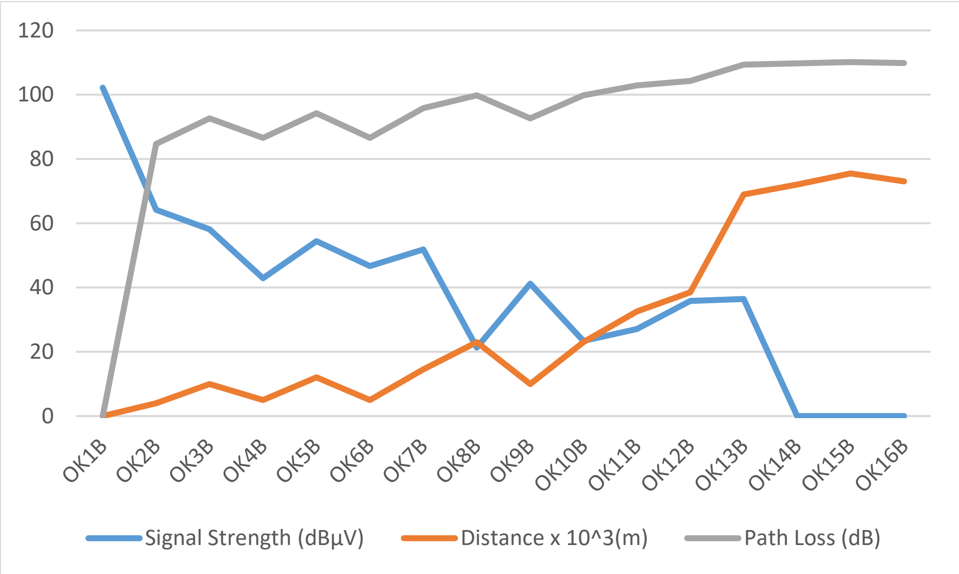

Fig. 4. Relationship between signal strength, distance and path loss for KB

4. DISCUSSION

Findings indicate an inverse relationship between the wavelength and frequency of the signal. Higher frequency channels exhibit shorter wavelengths. The path loss depends on the distance between transmitting and receiving antennas. However, it is minimal and approaches zero at the FM stations due to the short distances between the antennas. Distance directly affects path loss and inversely affects signal strength. Larger distances result in greater path loss. The strong radio signals at the stations are attributed to their proximity to the transmitters. Signal losses occur due to obstacles like vegetation, hills, mountains, trees, water bodies, bushes, and buildings that obstruct signal propagation. Refractions, diffractions, and reflections from such obstacles impact signal quality, as observed with KA, and KB. Previous studies by Meng, Lee, Ng (2010), Gökhan, Lavent (2000), and Aguirre et al. (2012) support these findings regarding signal loss and the influence of human bodies on transmitted signals. At close ranges, signal weakness is observed in densely populated areas due to human presence. The body's impact on signal strength is confirmed by studies analyzing dosimetry evaluations. These losses are more significant in the abdomen region compared to the knee due to greater mass and liquid content. Comparing path loss with measured signal strengths reveals an inverse relationship. Higher signal strengths correspond to lower path loss, while lower signal strengths result in higher free space path loss. Findings from the study revealed that, even though KB operates at a higher transmitting signal strength 102.2dBµV compared to KA with 100.9dBµV, KB experienced higher free space path loss 109.39dB compared 109.01dB for KA. This was due to the fact that KB operates on shorter wavelength 2.94m at higher frequency 109.5MHz compared to KA with longer wavelength 3.21m and lower frequency 93.5MHz. Also, KA was received at 72km compared to 69km for KB. Therefore, KA network outperform that of KB. The FM stations can improve their competitive advantage by investing in network infrastructure to boost their signal for better and quality service delivery.

5. CONCLUSION

In conclusion, despite the radio stations transmitting at a minimum of 2kW from elevated locations, limitations of their signal coverage has been identified. The results obtained clearly indicate the areas where optimal signal reception can be expected based on the measured signal strengths. It is evident that the quality of radio signals is greatly influenced by these factors. Moreover, the results demonstrate an inverse relationship between signal strengths and the calculated free space path loss at most locations. Higher path loss corresponds to lower signal strengths. To improve signal coverage, it is recommended for the radio stations to consider installing booster stations approximately 69km away from the main stations, taking into account the locations of their target audiences. Additionally, prospective radio stations can use these findings as a guide for selecting suitable locations to establish their own stations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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