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Original Article

Assessment of Radio Waves Propagation Pattern from Three Radio Stations in Lokoja, Kogi State, Nigeria

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Abstract *- Lokoja and its environs have been experiencing radio signal distortions, poor quality signals and heavy attenuation that has been of great concern to the citizens. This study uses the field strength meter to assess the patterns of radio wave propagation from three radio stations in Lokoja, Kogi State, Nigeria. Signal strengths and quality of the three radio signals were measured at the stations and six locations in Lokoja and the environs, totalling twenty-one points. The approximate distances between the transmitting and receiving antennas were also determined. Each radio station's wavelength and the signals' free space path loss were calculated. The result shows that the measured signal strengths are inversely proportional to the free space path loss and the approximate distances between the transmitting and receiving antennas. Factors such as reflections by buildings, mountains and vegetation cover, refractions by the rivers or streams, rainfall and absorption of the human abdomen were examined as the likely causes of signal attenuation. Good locations to site FM radio stations were determined from the results. The results also suggested the approximate distances from the stations to receive news during emergencies as part of security measures. Booster stations at approximately 70km from the main stations are recommended. This is expected to help support the signal and increase the signal strength.*

Keywords *- Booster station, Path loss, Propagation pattern, Radio transmitter, Signal strength.*

1. Introduction

Electromagnetism is a branch of physics that deals with studying electromagnetic force [1]. Radio waves combine electric and magnetic fields when electrons oscillate in aerial and are used in telecommunication [2]. The ability to be refracted by the ionosphere when an incident at a critical angle is a significant feature of Radio waves. Radio waves carry audio frequency information through a modulation process, either amplitude modulation (AM), frequency modulation (FM), or phase modulation [24]. When demodulated, a radio receiver picks up the radio wave and obtains the audio frequency information [4, 5, 6]. Electromagnetic radiations have radially emanated energy formed by the vibration of both the electrical and magnetic field combination. Unlike sound, which needs air for propagation, this energy can travel in a vacuum [6, 7]. The electric and magnetic fields are perpendicular to each other in the direction of the traveling wave. It travels at the speed of light until substantial objects like concrete or metal interact with it, which may interfere with its speed [2, 7]. According to Saroj and Smruti [8], Electromagnetic interference is a result obtained when electromagnetic fields interfere with one another, which leads to the distortion of the two fields. Properties such as reflection, refraction, diffraction, absorption, polarization and scattering are exhibited by electromagnetic waves.

Radio propagation is the transmission of radio signals from one point to another within the earth's atmosphere for wireless broadcasting or communication [9, 10]. Sources such as mobile radio communication transmissions, radio and television broadcasting, radar, and cell phones produce radio waves [10]. Strong probabilistic concepts come into play while transmitting radio signals because it is never 100% predictable. Many different protocols have been devised over the century for the propagation of radio waves; the distance between the transmitter and the receiver determines the mode to use [11]. Objects along the paths of a medium of propagation of radio signals influence their transmission. It means that when designing or operating a radio system, such signal strength must be considered [12]. '

The security of citizens' lives and properties is a critical consideration at all levels while embarking on any form of development by the government, individuals and corporate organizations; if such development must be sustained [2, 13]. A secure environment helps in the proper planning, establishment and management of human and material resources required in the establishment and management of any business [2]. Nigeria's government invests heavily in its citizens' security by allocating a significant percentage of its annual budget to security. Unfortunately, insecurity has been increasing at alarming rates in the form of armed banditry, kidnapping, Boko haram and terrorism, and this is gradually becoming a business in Nigeria today [14].

According to Nwankpa et al. [15], keeping society informed in a timely, comprehensive and intelligent manner is vital, especially in conflict situations where most people depend on the media for accurate and timely situational analyses of events as they unfold. Ineffective communication systems occasioned by the poor reception of radio signals from transmitting stations have been a major factor in the challenge, especially in Kogi State. This paper assesses the strengths and quality of radio signals from three radio stations in Lokoja, Kogi State, Nigeria, to suggest ways of improving their signals for more effective and efficient communication with the citizens in remote areas, especially on security matters. The study will help identify locations for the sitting of radio stations for better quality and reception in the area.

2. Materials and Method

2.1. Materials

The materials and specifications used for the assessment of radio wave propagation pattern from three radio stations in Lokoja, Kogi State, Nigeria, includes a hand-held field strength meter, spectral V5, hand-held RF power meter, 8VSB (ATSC) modulator meter, and hand-held GPS.

2.1.1. The Field Strength Meter

The field strength meter used in this study is a simple passive (unpowered) circuit in which the antenna intercepts radio frequency energy, rectifies to DC, and then drives the meter directly. Figure 1 shows a typical field-strength meter used in this study. The maximum sensitivity of this circuit is based primarily on the following factors:

- The antenna's gain depends on how much the signal is intercepted.
- The sensitivity of the meter movement being used.
- The capacity of the battery in the meter.

Fig. 1 High resistance/low conductance field strength meter

2.2. Methods

2.2.1. Area of Study

Lokoja is located on latitude 07.80° North of the equator and Longitude 06.73° East of the meridian and at an elevation of 53meters above sea level. The town is about 165km South West of Abuja and 390km North East of Lagos and is adjoined by Obajana, Okene and Ajaokuta. Lokoja lies at the confluence of the Niger and Benue rivers and is the capital city of Kogi State, Nigeria. While the Bassa Nge, Yoruba, Igala and Ebira are indigenous to the area, other ethnic groups of Nigeria, including the Igbo, Benin/Edo, Tiv and Nupe, have recently established themselves there. It operates in the WAT time zone and covers a total area of 3,180km^2 with a population of 195,261, making it the fourth largest city in Kogi State (2006 census). The town's people run different kinds of businesses such as hotels, filling stations, schools, civil service works, and supermarkets, and 75% of others are farmers (fish and crops farming). Radio stations in Lokoja town include 94.1 FM radio called Confluence FM, which is situated on Mount Patti hill Lokoja with a transmitter power of 35kW but transmits only 20kW of the power for the public consumption, 95.5 FM called Grace FM, which is also situated on Mount Patti hill Lokoja with a transmitter power of 20kW but transmits only 2.5kW of the power for the public consumption, and 101.5 FM known as Prime FM/FRCN which is situated at Stella Obasanjo's Library along Ganaja Village, Jimgbe, Lokoja with a transmitter power of 20kW and transmits the 4kW for the public consumption. The map of Kogi showing Lokoja and the locations of the three radio stations is shown in Figure 2.

2.2.2. Method of Determining Signal Strength

The field strength meter was used in FM mode to measure the signal strength of the three radio stations where the distance between the transmitter and receiver was approximately zero. Three distant locations several kilometers apart were randomly selected from the Northern, Eastern and Western locations to the FM stations based on their likely coverages in Okene and Lokoja, making a total of six selected locations. The strengths of the three radio signals were taken at these locations along with their corresponding distances from the radio stations. A total of sixteen days was used in this process at various selected locations between August 19th and September 3rd, 2019. Readings were taken in open spaces to avoid interference with vegetative cover, trees, buildings and other opaque bodies. Rainy days were also avoided because the meter is very sensitive to water and also to avoid the possibility of signal refraction. LK1A, LK1B and LK1C were used to represent points at the radio stations, while points at the six selected points away from the station were coded as LK2 to LK7. The Global Positioning System (GPS) of each location was taken. Also, the channels' transmitter power and the power being transmitted by the radio stations were obtained from each FM station.

Table 1. Codes for the selected locations and their GPS points

Locations	Codes	GPS Locations
Confluence FM	LK1A	Lat.N7^{0}48’32.80068” & Long.E6^{0}43’56.4798”
Grace FM	LK1B	Lat.N7^{0}48’33.84” & Long.E6^{0}43’53.15988”
Prime FM	LK1C	Lat.N7^{0}41’57.66252” & Long.E6^{0}44’8.7648”
Ganaja Village, Jimgbe, Lokoja	LK2	Lat.N7^{0}42’52.06428” & Long.E6^{0}44’25.3986”
Felele, Lokoja	LK3	Lat.N7^{0}50’43.2132” & Long.E6^{0}44’53.007”
Kabba/Obajana Junction, Lokoja	LK4	Lat.N7^{0}449’32.37852” & Long.E6^{0}34’57.9666”
Check Point, Okene	LK5	Lat.N7^{0}31’37.32168” & Long.E6^{0}15’18.03816”
Obehira/Okenwe Junction, Okene	LK6	Lat.N7^{0}32’54.69” & Long.E6^{0}12’13.81788”
FC/Lokoja Road, Okene	LK7	Lat.N7^{0}36’35.09568” & Long.E6^{0}15’41.24988”

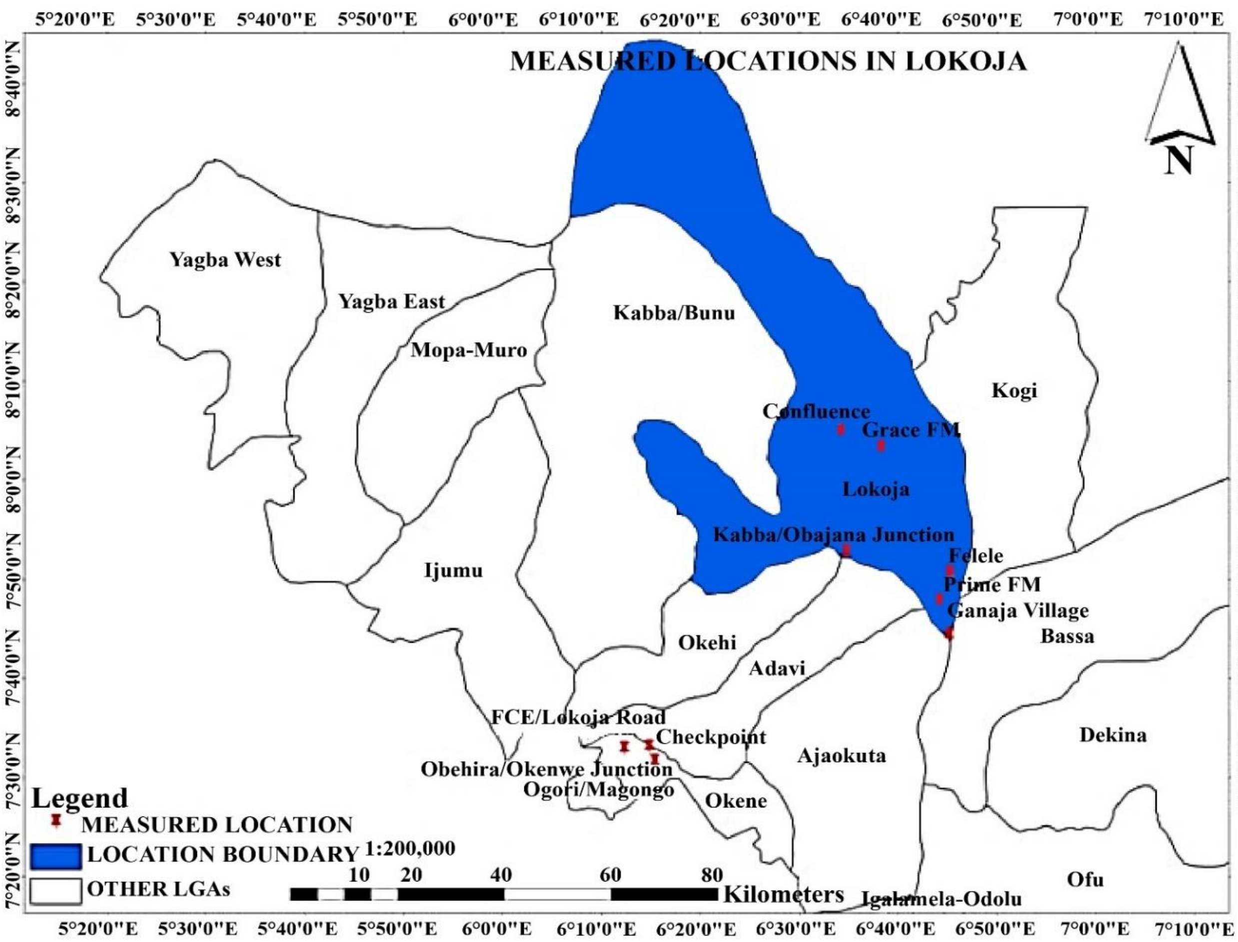

Fig. 2 Map of Lokoja showing locations of the radio stations

The locations, codes and GPS of each location are presented in Table 1, while the map of Kogi showing Lokoja, the three radio stations and all the sampled points is shown in Figure 2.

2.2.3. Method of Calculating Wavelength

The wavelength (λ) of the signals was calculated as follows:

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

Where λ is the wavelength of the signal, c is the velocity and has a constant value of $3 \times 10^8 ms^{-1}$ and f is the transmission’s frequency.

2.2.4. Method of Calculating Free Space Path Loss

The free space path loss (FSPL) of the signals, while it travels through distances, is the attenuation of radio energy between the two antennas, i.e. the channel's antenna and the meter's antenna. FSPL was determined for each of the locations using the equation:

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

Where d is the distance between the antennas, λ is the calculated wavelength from equation 1, and 4π is a constant.

3. Results

3.1. Signal Strength

Tables 2, 3 and 4 present the results of the signal strengths of the three radio stations with the corresponding approximated distances away from the radio channels. The signal's attenuation is the reason there were no signals at certain distant locations away from the FM radio stations, especially in Okene. The signals become weak after going through a long distance and have no energy to go further.

Table 2. Signal strength of Confluence FM

Positions	Signal Strength (dBμV)	Distance b/w antennas x10^3 (m)	Frequency (MHz)
LK1A	108.2	0.0	94.1
LK2A	58.7	4.0	94.1
LK3A	79.9	3.0	94.1
LK4A	66.7	5.0	94.1
LK5A	Nil	75.0	94.1
LK6A	38.8	72.0	94.1
LK7A	38.9	68.0	94.1

From Table 2, the signal strength from location LK1A is very strong with a value of 108.2dBμV, and the distance between the antennas at this point is approximately 0.0m. Location LK2 has 58.7dBμV against a distance of approximately 4,000m away from the transmitting antenna. Location LK3, whose distance is 3,000m from the transmitter, has a strength of 79.9dBμV. In comparison, location LK5 does not have a signal due to factors ranging from fading due to the distance between the antennas of approximately 75,000m, reflection, refraction, and diffraction of signals by obstacles as it propagates media could also be responsible. Location LK6, with an approximate distance of 72,000m, has a signal strength of 34.8dBμV. It shows that the distance between the antennas and the signal strength has direct proportionality.

From Table 3, location LK1B is assigned to the radio station which housed the transmitter. The strength of the signal here is not very strong compared to other radio channels.

Table 3. Signal strength of Grace FM

Positions	Signal Strength (dBμV)	Distance b/w antennas x10^3 (m)	Frequency (MHz)
LK1B	46.9	0.0	95.5
LK2B	Nil	4.0	95.5
LK3B	34.3	3.0	95.5
LK4B	Nil	5.0	95.5
LK5B	Nil	75.0	95.5
LK6B	Nil	72.0	95.5
LK7B	Nil	68.0	95.5

It has a value of 46.9dBμV with the approximate distance between the antennas equal to 0.0m. Position LK3 has a signal strength of 34.3dBμV against a distance of approximately 3,000m away from the transmitting antenna. Every other location, LK2, LK4, LK5, LK6, and LK7, did not have signals though some positions are close to the transmitting antenna. Factors such as Impedance mismatch and faulty transmitters could be responsible for these.

Table 4. The signal strength of Prime FM/FRCN

Positions	Signal Strength (dBμV)	Distance b/w antennas x10^3 (m)	Frequency (MHz)
LK1C	73.2	0.0	101.5
LK2C	68.4	0.2	101.5
LK3C	48.6	4.0	101.5
LK4C	42.6	6.0	101.5
LK5C	Nil	75.0	101.5
LK6C	50.0	73.0	101.5
LK7C	34.2	65.0	101.5

In Table 4, the radio channel location recorded a signal strength of 73.2dBμV with the approximate distance between the antennas of 0.0m. Location LK2 has a signal strength of 68.4dBμV against a distance of approximately 200m away from the transmitting antenna. Locations LK3, LK4 and LK5 of distances 4,000m, 6,000m and 75,000m have signal strengths of 48.6dBμV, 42.6dBμV, and no signal, respectively. The lack of signal recorded in location LK5 could be due to fading as the signal propagates a long distance. Reflection, refraction, and diffraction by obstacles could also be responsible for the lack of signal. Meanwhile, position LK6 has 50.0dBμV as against an approximate distance of 73,000m which has a higher signal value and longer distance compared to location LK7 of 34.2dBμV and distance of 65,000m.

3.2. Wavelength

The wavelength (λ) was determined using Equation 1 from the values in Tables 2, 3 and 4 for the FM radio stations and results are presented in Table 5. Here, signal frequency and wavelength are proportional to the velocity of the electromagnetic wave, i.e. the speed of light of value $3x10^8ms^{-1}$.

Table 5. Calculated signal wavelength

Radio Stations	Frequency (MHz)	Velocity (ms^{-1})	Wavelength (m)
Confluence FM	94.1	$3.00x10^8$	3.19
Grace FM	95.5	$3.00x10^8$	3.14
Prime FM/FRCN	101.5	$3.00x10^8$	2.96

From Table 5, it is evident that attenuation is much faster in higher frequency electromagnetic signals with a smaller wavelength than a lower frequency signal with a larger wavelength; the Prime FM is expected to have the fastest attenuation, while Grace FM will attenuate faster than Confluence FM as they pass through various physical medium such as opaque bodies.

3.3. Free Space Path Loss

Using Tables 2, 3, 4 and 5, the free space path loss of the signals in each selected location was determined from Equation 2 and presented in Tables 6, 7 and 8.

Table 6. Calculated free space path loss for Confluence FM

Positions	Signal Strength (dBμV)	Distance b/w antennas $x10^3$ (m)	Wavelength (m)	Free Space Path Loss
LK1A	108.20	0.00	3.19	0.00
LK2A	58.70	4.00	3.19	$2.49x10^{-4}$
LK3A	79.90	3.00	3.19	$1.40x10^{-4}$
LK4A	66.70	5.00	3.19	$3.89x10^{-3}$
LK5A	Nil	75.00	3.19	0.09
LK6A	38.80	72.00	3.19	0.08
LK7A	38.90	68.00	3.19	0.07

Table 7. Calculated free space path loss for Grace FM

Positions	Signal Strength (dBμV)	Distance b/w antennas $x10^3$ (m)	Wavelength (m)	Free Space Path Loss
LK1A	46.90	0.00	3.14	0.00
LK2A	Nil	4.00	3.14	$2.56x10^{-4}$
LK3A	34.30	3.00	3.14	$1.44x10^{-4}$
LK4A	Nil	5.00	3.14	$4.00x10^{-3}$
LK5A	Nil	75.00	3.14	0.09
LK6A	Nil	72.00	3.14	0.08
LK7A	Nil	68.00	3.14	0.07

Tables 6, 7 and 8 show that the main cause of attenuation is the distance since frequency and wavelength are constant. It is because as the signal travels through the atmosphere, it will attenuate to amplitudes below the receive sensitivity threshold of a receiving radio.

Table 8. Calculated free space path loss for Prime FM/FRCN

Positions	Signal Strength (dBμV)	Distance b/w antennas $x10^3$ (m)	Wavelength (m)	Free Space Path Loss
LK1A	73.20	0.00	2.96	0.00
LK2A	68.40	0.20	2.96	$7.23x10^{-4}$
LK3A	48.60	4.00	2.96	$2.89x10^{-4}$
LK4A	42.60	6.00	2.96	$6.51x10^{-3}$
LK5A	Nil	75.00	2.96	0.100
LK6A	50.00	73.00	2.96	0.096
LK7A	34.20	65.00	2.96	0.080

Therefore, the signal will arrive at the receiver, but it will be too weak to be detected. The relationship between signal strength, distance and free space path loss for Confluence FM, Grace FM and Prime FM are presented in Figures 3, 4 and 5.

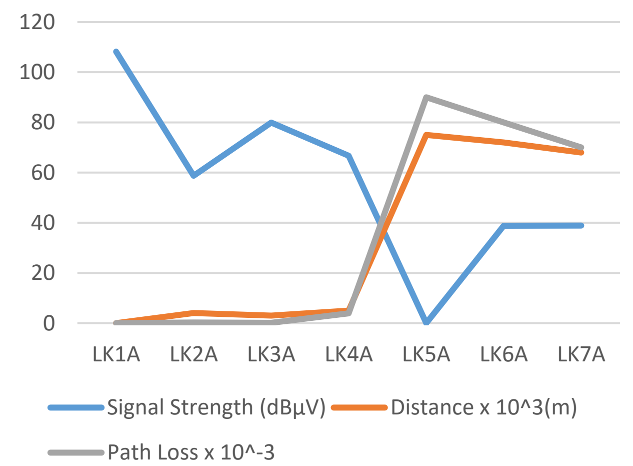

Fig. 3 Relationship between signal strength, distance and path loss for Confluence FM

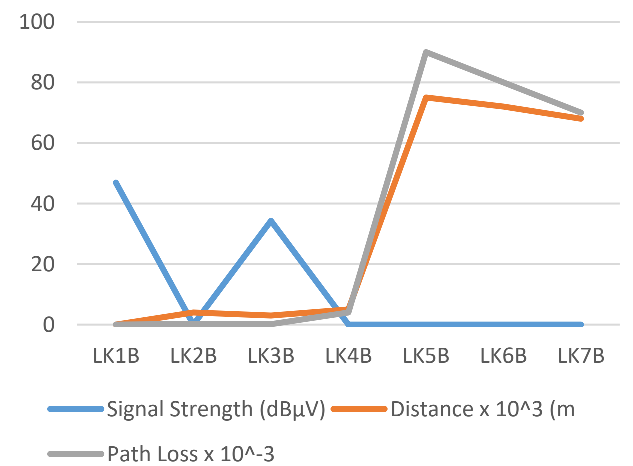

Fig. 4 Relationship between signal strength, distance and path loss for Grace FM

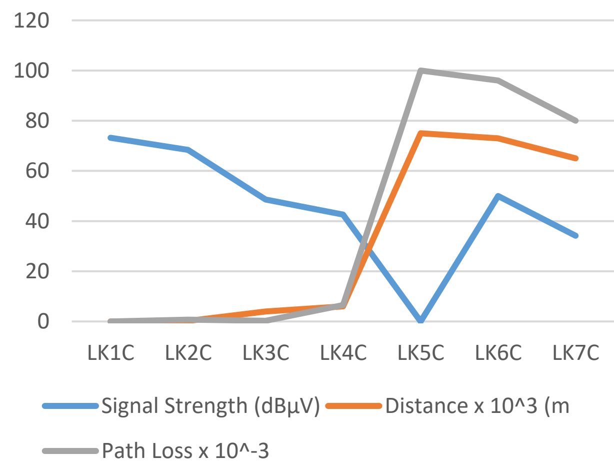

Fig. 5 Relationship between signal strength, distance and path loss for Grace FM

4. Discussion

Findings have shown that the free space path loss depends on the distance between the antennas (transmitter and receiver). Part of the discoveries is that the free space path loss at the radio stations is very low and approximately zero because the distances between the transmitting and receiving antennas are short. The distance has direct proportionality to the path loss. Strong signals were experienced at the respective stations due to the nearness to the transmitters, except at the Grace FM, where low signal strength was measured. It might be due to the power of the transmitter or its efficiency, which may not be noticeable to their engineers. Impedance mismatch might also be responsible, where the cable links the transmitter to the antenna. The antenna itself and the transmitter must be 75Ω each; otherwise, impedance mismatch occurs, affecting the signal output through the reflection of the part of the signals. Though, the rain was gradually drizzling at the time of the visit to the site, which is capable of causing signal diffraction in the process and reducing the signal strength, as supported by Yee et al. [16] through an experimental investigation of near sea-surface radio wave propagation.

Losses of signals resulted from vegetation covers, hills, mountains, trees, sea, rivers, bushes and buildings between these antennas. Properties such as refractions, diffractions, and reflection of signals from hard surfaces like buildings, trees, rivers and mountains present along the propagation paths of the signals play a role. These were observed in the following areas and stations: from the checkpoint in Okene, signals from Prime FM could not be accessed; there were no signals of Grace FM station at Ganaja village, Kabba/Obajana junction, checkpoint, Obehira and FC; confluence FM signal was not accessible at a checkpoint. This fact was supported by Meng et al. [21] in the analysis of signal loss modeling for near-ground radio wave propagation through forests with a tree-canopy reflection effect. Gökhan and Levent [18] supported this through similar research on surface wave propagation along multi-mixed paths with irregular terrain over spherical earth in two-dimension (2D). The first time in the literature systematically investigated the sea-land-sea (island) transition problem, including non-flat (hilly) islands.

It was observed that, at close ranges from the transmitting antennas to the receiving antennas, signals were weak in densely populated areas because human bodies have a lot of influence on transmitted signals. This phenomenon was observed at Ganaja village, Jimgbe, Lokoja, when the signal from Confluence FM was measured. The signals of Grace FM and Prime FM, as read from Felele, Lokoja, also established that there was obstruction of signals by human bodies due to the market scene, Motor Park, Kogi state polytechnic students and travelers. Aguirre et al. [19] supported this through research work where analysis of the influence of the human body in dosimetry evaluations was carried out. A simplified human body model has been implemented, including the dispersive nature of internal organs' material parameters. It was observed that the received power level is lower when placed between the transmitter and the receiver. It could be due to these stations' Single Input–Single Output systems. According to Tidula et al. [20], such a system's speed is not suitable for high-speed applications, and it does not fulfil the requirements of demands of the user. It was also shown that the influence of the person facing the transmitter is also considerable. It was perceived that the received power levels for the measurement of the front part of the human body, specifically the abdomen and the knee, are higher values of power than the rear part, back and back knee. This is due to the human body penetration losses present in the electric radio path. However, it was observed that these losses are greater in the abdomen than in the knee due to the higher volume of mass and the higher volume of liquid content in the first case. Tidula et al. [20] argued that, Since the channel conditions are sometimes changing in a Radio environment leading to fading problems, Adaptive MIMO can switch to the antenna's various transmission modes to increase the coverage and service quality and provide the proper throughput to the users. In this way, it will avoid fading and fulfil the demands of the users. Therefore, booster stations with Adaptive MIMO at certain distances from the stations could be of great importance.

When compared with the measured signal strengths at most locations, the path loss showed that they are inversely proportional to each other. It implies that the higher the signal strengths, the lower the path loss at those locations and the lower the signal strengths, the higher the free space path loss.

5. Conclusion

In conclusion, none of the radio stations transmits less than 2kW from their stations, and their locations are majorly on hills which add up to the height of the antennas. Despite the availability of these factors, which many believe will help the radio stations to maintain a wide coverage of signals, other physical factors have limited the coverage of these signals from reaching the targeted audiences. Factors such as the availability of forests and vegetation, buildings and hills, human beings and sea or waters have all contributed to limiting the signal coverage. The results obtained have clearly shown everyone the best areas to stay and receive particular radio stations based on the signal strengths measured in the area. Quality radio signals are, therefore, best enjoyed as analyzed in the results. The results also show that most locations' signal strengths are inversely proportional to the free space path loss calculated. The higher the path loss, the lower the signal strengths. It is recommended that the radio stations have booster stations at approximately 70km from the main stations depending on the locations of the targeted audiences. It is also recommended to prospective radio stations in the better areas to site their radio stations as this will serve as a guide for them.

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