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Analytical Comparison of Path Loss Models for Radio Wave Propagation over Yenagoa–Southern Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Using propagation models helps with communication system planning and maximizes the use of the radio spectrum, a limited natural resource. Here is a comparative analysis between some propagation models and actual measurements from Yenagoa, Southern Nigeria. Electric field strength measurements made during drive tests for two television transmitters operating at 210.25 MHz and 577.10 MHz make up the experimental data. Analytical comparisons were made between verified predictions for the free space, Okumura, and Hata models and measured data. The results demonstrate that these empirical models fail to take into account Yenagoa's actual terrain profile for television broadcast. The Okumura model is the best fit, with ideal values for root mean square error (RMSE) of 34.9136 and 33.2841 and average relative error of 0.13212 and 0.4327 for 210.25 MHz and 577.10 MHz, respectively. However, if the Okumura model is tailored for Yenagoa to improve electric field strength prediction and coverage estimation, better results can be attained.

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1. INTRODUCTION

Path loss models are an important aspect of radio wave propagation that helps predict the reduction of signal strength over a given transmission distance. This is crucial in designing wireless communication systems for various applications such as cellular communication, satellite communication, radio broadcasting, and more [1-6]. In general, radio waves experience various types of losses as they propagate through a medium or along a path such as free space, air, water, or buildings. These losses can be attributed to various factors such as absorption, reflection, diffraction, scattering, and refraction, among others [7-11]. Path loss models provide a standardized approach to calculate the attenuation of radio waves in a specific environment over a given distance. These models take critical factors such as frequency, distance, and environmental obstacles into consideration to evaluate the expected power level at a particular location [12-20]. Such models can be classified into two broad categories: empirical models and theoretical models. Empirical models are derived based on measured data in real environments, while theoretical models are based on fundamental electromagnetic principles. Several path loss models are available, including the Hata model, Okumura–Hata model, COST231-Hata model, Extended Hata model, Lee model, and more. Each model has its own set of advantages and limitations, and the choice of the model depends on the specific requirements and characteristics of the communication system. Overall, path loss models play a significant role in optimizing wireless communication systems and in ensuring an optimal signal strength and coverage [20-25]. However, their suitability for television broadcast service has not been established, especially for coverage estimates in Yenagoa, Southern Nigeria.

A drive test measurement of the electric field strength over two transmitters - one VHF (210.25MHz) and one UHF (577.10MHz) - performed inside their respective primary coverage regions is presented in this work. The best propagation prediction model for the chosen location, Yenagoa, Southern-Nigeria, was discovered by measurement. The free-space model put out by Friis, as described in [20], the Okumura model created by Okumura, and the modified Okumura model created by Hata, as published in [26], were compared to the measured data. They were chosen over a number of others due to their simplicity and the compatibility of their necessary parameters with those offered by the chosen transmitters. They both depend on frequency and distance, but the applicability of each varies depending on the region. According to a report in [27], they failed to account for the topographical profile between the transmitter and the receiver, which results in forecasts that are overly optimistic [26]. The various adjustments made to current models are efforts to address these flaws. The optimization of the Hata model for television planning in Lagos State, Nigeria, was described in [28] as a similar endeavor.

2. VERY HIGH FREQUENCY (VHF) AND ULTRA HIGH FREQUENCY (UHF) BANDS OF THE RADIO SPECTRUM

Under the broader ITU classifications for the radio spectrum, the VHF (very high frequency) band has a frequency range of 30 to 300 MHz and a wavelength range of 10 to 1 meter. The lower frequencies are occasionally affected by the ionosphere, but not as much as the bands. Although they can be affected by tropospheric conditions, they are typically thought to exhibit more line-of-sight radio propagation. VHF - FM transmission and more modern digital audio broadcasting typically utilize this part of the radio spectrum; there are some television broadcast in various nations as well that utilize this. This part of the spectrum has radio bands, which are used for point-to-point radio communications, aviation and maritime radio communications, among others.

On the other hand, it is clear that the UHF band has a higher frequency than the VHF band. Since it spans 300 to 3000 MHz, frequency allocations in this band provide a wider bandwidth. Several radio applications are suited for radio propagation because it provides a link that is more akin to line of sight. UHF is utilized for numerous short-range wireless networks, including Wi-Fi and other wireless LAN applications, as well as mobile phone communications and television broadcasts. Moreover, it is used for a number of point-to-point radio communication systems and for distant sensors, nodes, and other components of the Internet of Things. Within this band, there are also allocations for amateur radio.

3. PATH LOSS EQUATION

Path loss equations are mathematical formulas used to determine the attenuation or reduction of signal strength as electromagnetic waves are propagated through a medium. Knowledge about path loss equations is essential in the design of efficient wireless communication systems. The basic formula for the path loss equation is as follows:

$$Path\ loss = 20\log(\frac{P_t}{P_r}) \quad (1)$$

where P_t is the transmitted power
P_r is the received power.

The path loss equation can be derived in different ways depending on the type of signal transmitting medium. The following are the most common derivation methods used in wireless communication systems.

1. **Free Space Path Loss (FSPL):** The free space path loss model assumes that the transmission medium is free from any obstacles or obstructions. The signal propagates in a straight line from the transmitter to the receiver in a vacuum. In this case, the path loss equation is derived from the Friis transmission equation, given by:

$$P_r = PtGtGr(^{\lambda}/_{4\pi d})^2 \quad (2)$$

where P_r is the received power

Pt is the transmitted power
Gt and Gr are the gains of the transmitting and receiver antennas respectively
λ is the wavelength of the transmitted signal, and
d is the distance between the transmitter and receiver.

The path loss is then calculated as:

$$Path\ loss = 10log\left(\frac{P_r}{P_t}\right) = -20\ log(d) - 20\ log\left(\frac{\lambda}{4\pi}\right) + Gt + Gr \quad (3)$$

In equation 3, the first term represents the loss due to distance, while the second term represents losses due to the environment. The last two terms represent the gain factors of the transmitting and receiver antennas.

2. **Two-Ray Ground Reflection Model:** This model is commonly used in radio wave propagation near the earth's surface. It assumes that the transmitted signal is reflected off the ground, resulting in two paths with different phases. The path loss equation is derived as follows:

$$Pr = (PtGtGrHtHr)/[(d^2) \times (\lambda^2)] \quad (4)$$

where *Ht* and *Hr* are the heights of the transmitting and receiver antennas respectively.

The path loss equation is then calculated as:

$$Path\ loss = 10\log\left[\frac{(Ht \times Hr)^2}{(d^2)\times(\lambda^2)}\right] + Gt + Gr \quad (5)$$

The first term represents the loss due to distance and reflection, while the last two terms represent the gain factors of the transmitting and receiver antennas.

3. **Log-Distance Path Loss Model:** The log-distance model is mainly used in urban areas where the signal propagation is affected by numerous obstructions such as buildings, trees, and other structures. The path loss equation is derived using empirical measurements and constants. The equation is given by:

$$Path\ loss(dB) = 10n\log(^{d}/_{d_0}) + A \quad (6)$$

where n is the path loss exponent

d is the distance between the transmitting and receiving antennas
d_0 is a reference distance, and
A is the path loss intercept.

The path loss exponent, n, is a constant that depends on the environment, frequency of the signal, and building materials. The path loss intercept, A, represents the path loss for a reference distance, d_0.

4. **Okumura-Hata Path Loss Model:** The Okumura-Hata model is a modification of the log-distance model and is commonly used in urban and suburban areas. The path loss equation can be derived by the following formula:

$$Path\ loss = A + B \times \log 10(d) + C \times \log 10(f) + D \times \log 10(h) \quad (7)$$

where f is the frequency in MHz,

d is the distance between the transmitter and receiver,

h is the height of the transmitting antenna in meters, and

A, B, C, and D are constants that vary based on the location and environment, Conclusion

Path loss equations are instrumental in designing wireless communication systems. The derivation and the type of model used depend on the type of transmission medium and signal frequency. Free space path loss, two-ray ground reflection, log-distance, and Okumura-Hata models are some of the most commonly used methods for deriving path loss equations. Therefore, knowledge about path loss equations is essential in managing and optimizing wireless communication systems.

4. ASSESSMENT OF FIELD STRENGTH

The measuring setup included a mobile GPS receiver (GERMIN GPS 76), a portable spectrum analyzer/field strength meter operating at 2 GHz, and a laptop computer for data logging. On 210.25 MHz and 577.10 MHz, respectively, the electric field strengths for the Niger Delta Television (NDTV) and Nigerian Television Authority (NTA Yenagoa) were experimentally measured. Table 1 shows the transmitter parameters.

To measure the electric field strength of the transmitters, the following steps were taken:

1. A location near the transmitter was selected: Here a spot that is close to the transmitter but is still safe to access. It was ensured that there was no obstructions around that may interfere with the measurement.
2. Preparation of the equipment: Here the field strength meter was calibrated and an antenna to conduct the measurement properly connected. The antenna used is designed for this specific frequency range as produced by the transmitter.
3. Powering the equipment: Here both the field strength meter and the antenna was turned on.
4. Taking measurement of the electric field strength: Here the antenna is moved around in a circular pattern to find the direction of maximum field strength. Then, it was held steady and readings taken. The antenna was slide about 1/4 wavelength in each direction while taking readings until a full circle was completed.
5. Recording the measurements: The readings gotten from the meter was written down along the frequency and time of day as these can also affect measurements.
6. Repeating of the measurements: The measurement process was repeated at several locations around the transmitter to get a more complete picture of the transmitter's electric field strength. The whole process is repeated at 1Km intervals away from the transmitter.

5. RESULTS

Yenagoa's electric field strength was calculated as a suburban region. Figs. 1 and 2 compare the measured and anticipated field strengths for two terrestrial television lines in Yenagoa. These models produce comparable findings because they make predictions without taking into account the actual terrain profile for propagation. However, as a result of Yenagoa's terrain and clutter, the measured field strength reveals the true variation of the transmitted signal. Lower distances, particularly between 1 and 3 Km for the two transmitters, show good agreement between the predictions of Hata and free space. Generally, the aforesaid models overestimated the field strength for television transmissions in Yenagoa, making it impossible for them to correctly anticipate the measured field strength. On the other hand, despite the topographical carelessness, Okumura's prognosis is near to those measured. On the two transmitters, it gave a decent performance.

Table 1. Transmitter parameters

Station	Transmission Frequency (MHz)	Transmitter Height (m)	Transmission Frequency band
NTA Yenagoa	210.25	150	VHF
NDTV	577.10	175	UHF

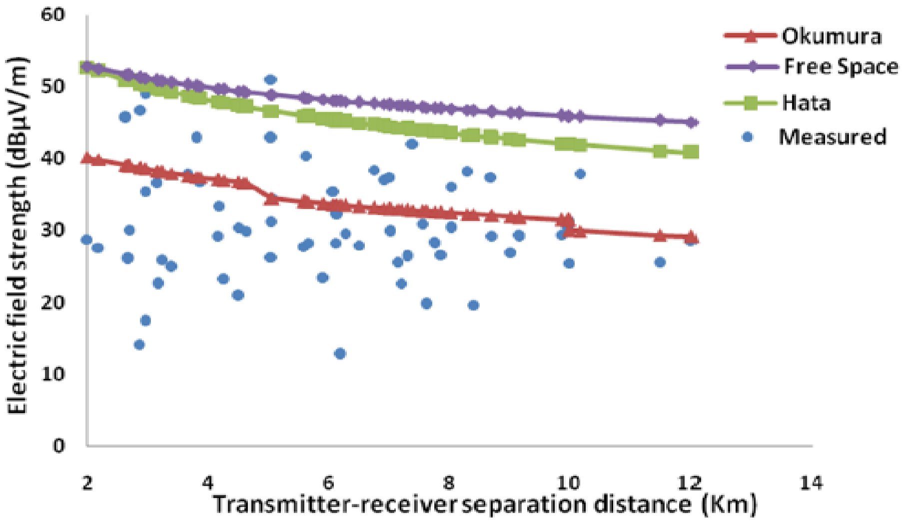

Fig. 1. Comparison of the measured and predicted field strength of NTA yenagoa

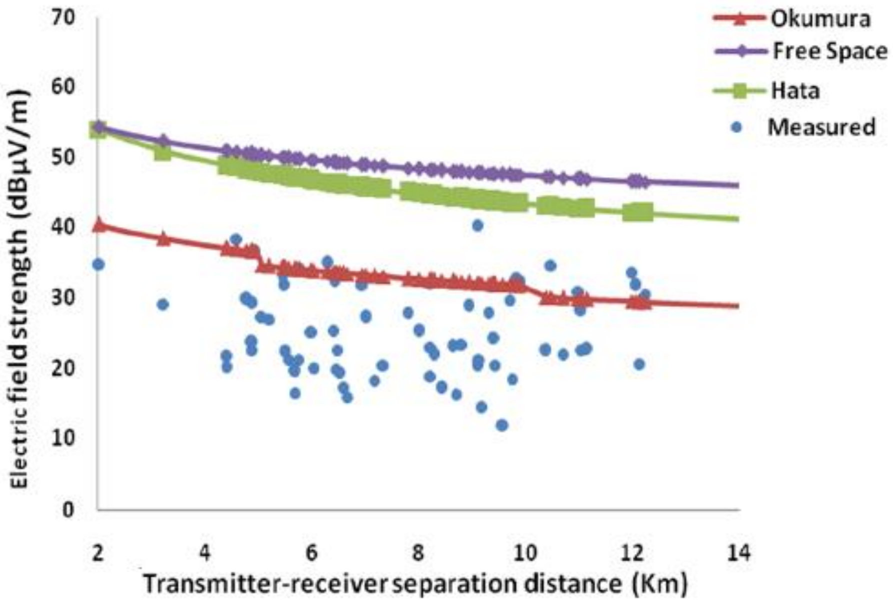

Fig. 2. Comparison of the measured and predicted field strength of NDTV

Table 2. Statistics of the models

Transmission Frequency	Propagation model	Standard Deviation	Root Mean Square	Average Relative Error
210.25 MHz	Okumura	3.7374	34.9136	0.1321
	Free Space	2.4119	48.6218	0.5811
	Hata	3.7012	46.2736	0.5017
577.10MHz	Okumura	3.4026	33.2841	0.4327
	Free Space	2.1622	48.8601	1.1186
	Hata	3.3144	45.6125	0.9274

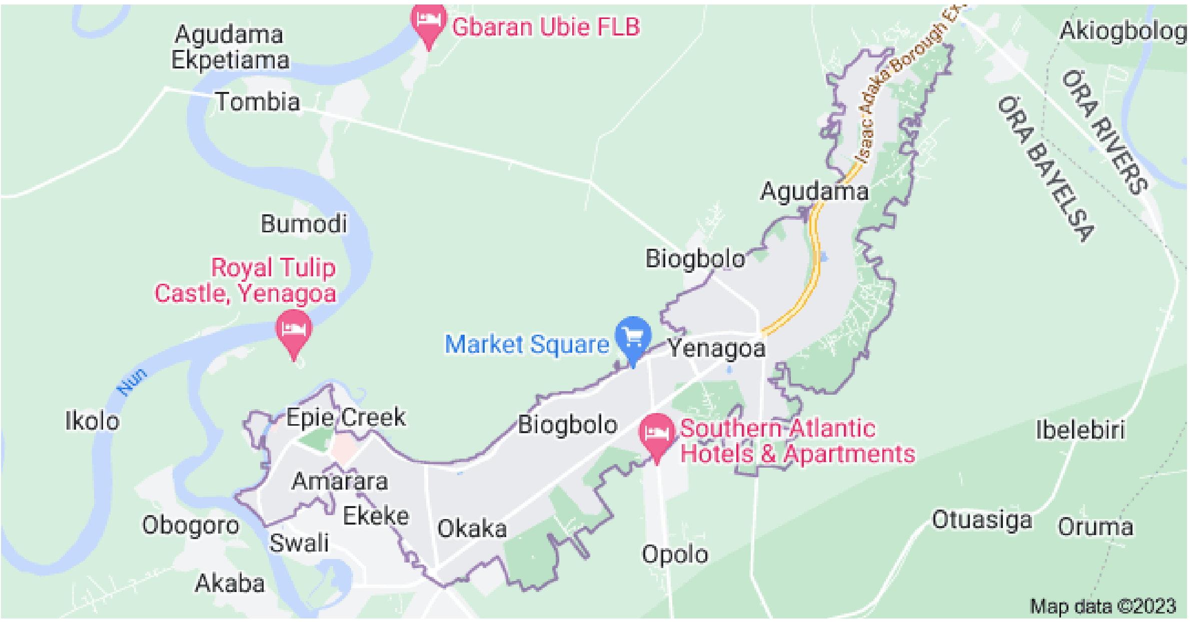

Fig. 3. Map of study area (Yenagoa)

The comparison statistics for the three models and the measured data are shown in Table 2. The test models were ranked according to the root mean square (RMS) error and the average relative error. The RMS is calculated as:

$$RMS = \sqrt{\mu^2 + \sigma^2} \quad (8)$$

where μ is the mean and

σ is the standard deviation

and the average relative error used to evaluate the performance of the models is given as:

$$E = \frac{E_P - E_M}{E_M} \quad (9)$$

where E_M denotes the measured field strength and

E_P denotes the anticipated field strength.

It was noted that empty space had the lowest standard deviation. For the two transmitters, free space also had the largest root mean square and average relative inaccuracy; thus performed better. The performance of the Okumura model, however, stands out since it has the lowest average relative errors for the two transmitters as well as the lowest root mean square error. Losses were found to be larger at higher frequencies.

The topography's influence on electrical field strength is shown by the dramatic fluctuation in the observed electrical field strength. The chosen propagation models with their too optimistic projections ignored this. This is consistent with the findings of Obiyemi et al. [6], which state that the Okumura model is inappropriate for terrains with erratic topography. The Okumura model can be adjusted to the surroundings, nevertheless, to produce a superior performance.

6. CONCLUSION

In Yenagoa, Southern Nigeria, two terrestrial television transmitters operating on 210.25 MHz and 577.10 MHz have been used to measure field strength within the primary coverage. By comparing the measured electric field intensity with the equivalent predictions made by the free space, Okumura, and Hata models for the identical reference sites, it was determined whether certain empirical propagation models were applicable. The selected models' predictions of electric field strength are overly optimistic due to their evident ignoring of the topography profiles of the propagation environment, as demonstrated by experimental results. However, the study shows that the Okumura model is the most appropriate for Yenagoa-specific VHF and UHF communication system designs, as well as for television broadcast services and other communication system designs in general; this can be clearly deduced from Fiqures 1 and 2 as the plotted values Okumura model was the closest to our measured values. However, if carefully optimized for accurate electric field strength prediction and coverage estimation for the preferred location, the Okumura model can perform better.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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