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Radiowave propagation models for wireless communication networks: A comparative study

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Abstract

Wireless communication networks heavily rely on accurate radiowave propagation models for optimal system design and performance evaluation. In this research paper, a comparative study of COST 231-Hata, Log-normal and 2-ray radiowave propagation models suitable for wireless communication networks were carried out. The objective is to assess the strengths, limitations, and applicability of these models across different scenarios, aiding network planners and researchers in selecting the most suitable model for their specific requirements. The theory of each of the three models were studied and simulated. Simulation results were analyzed in excel and results showed that 2-ray model is quite different from COST 231-Hata and Log-normal. An experimental measurement of the received signal power for MTN 4G network serving polo park area was also carried out. The experimental result reveals a percentage decrease in received power of 18.09, 35.23, 362.00 and 4.66dBm for Cost 231-Hata, Log-normal, 2-ray and experimental measurement respectively for a distance of 200m from the base station. This result confirmed 2-ray model as an outlier and not suitable for wireless network propagation prediction. The result also show that Cost 231-Hata is the most suitable radiowave propagation model for wireless when compared with Log-normal and 2-ray. For more accurate and robust prediction algorithm, it is recommended that more empirical models be involved and used to develop a system that selects the best model for radiowave propagation prediction.

Keywords: reference signal received power (RSRP), radiowave propagation models, cellular networks

Introduction

In the ever-evolving world of wireless communication networks, the accurate prediction and modeling of radiowave propagation are essential for optimizing network performance, ensuring reliable connectivity, and maximizing spectrum efficiency. Radiowave propagation models serve as indispensable tools for system design, deployment, and optimization, allowing network engineers and researchers to analyze signal coverage, interference, and channel characteristics (Sirkeci-Mergen and Moballegh, 2019) [8].

The efficiency and reliability of wireless communication networks depend heavily on the ability to accurately model radiowave propagation in various environments, such as urban areas, suburban regions, indoor spaces, and rural landscapes (Abonyi, 2019) [1]. These propagation models take into account the complex interactions between radio waves and the surrounding environment, including terrain, buildings, vegetation, and other obstacles. By simulating the behavior of radiowaves, researchers can gain insights into signal attenuation, multipath fading, shadowing effects, and interference patterns.

Numerous radiowave propagation models have been proposed and utilized in the field of wireless communications. Each model is designed with specific assumptions, parameters, and mathematical formulations, tailored to address the unique characteristics of different propagation environments. While some models focus on simplicity and ease of implementation, others aim to capture the intricacies of real-world scenarios with high accuracy.

The objective of this research paper is to perform a comprehensive comparative study of various radiowave propagation models employed in wireless communication networks. By evaluating and analyzing the strengths and limitations of these models, we aimed to provide valuable insights into their performance and applicability across different scenarios. This study will assist network planners, engineers, and researchers in selecting the most suitable propagation model based on the specific requirements and characteristics of their wireless communication systems.

To achieve this objective, we gathered and analyzed existing literature on radiowave propagation models, considering both theoretical advancements and practical implementations. We examined popular models such as the Okumura-Hata, COST-231, and Walfisch-Ikegami models, among others, and evaluated their accuracy, computational complexity, and suitability for different scenarios. Additionally, we explored recent advancements in machine learning-based propagation modeling techniques and assessed their potential for improving accuracy and efficiency.

The comparative analysis involved performance metrics such as signal coverage, path loss, fading characteristics, and interference levels. The influence of environmental factors were also considered, such as terrain irregularities, building density, and foliage, on the performance of these models. Through our study, we aimed to provide a comprehensive overview of the strengths and weaknesses of different radiowave propagation models, facilitating informed decision-making in the design and optimization of wireless communication networks.

In conclusion, this research paper will contribute to the advancement of radiowave propagation modeling in wireless communication networks by presenting a comprehensive comparative study of various existing models. By analyzing their performance characteristics and assessing their suitability for different environments, this study will aid network planners and researchers in selecting the most appropriate propagation model for their specific needs. Ultimately, the research findings will pave the way for improved wireless network performance, enhanced user experience, and efficient spectrum utilization in the era of rapidly evolving wireless technologies.

Theories of Models

COST 231 Model

The COST 231 model is a radio propagation model that was developed by the European Cooperation in the field of Scientific and Technical Research (COST) in 1991. It is also known as the Hata-COST model, as it is based on the Hata model and was further refined by COST to suit European conditions.

The COST 231 model is used to estimate the path loss of a radio wave as it travels between a transmitter and a receiver in a cellular network. It takes into account various factors that affect signal propagation, such as the distance between the transmitter and receiver, the frequency of the signal, the height of the antennas, and the terrain and environment surrounding the antennas (Saleh and Valenzuela, 1987).

The model has been widely used in the design and planning of cellular networks, as it provides a reasonable estimate of signal strength and coverage area (Goldsmith, 2005) [4]. However, it has its limitations and is most accurate in urban and suburban environments, where the terrain is relatively flat and the buildings are not too tall. In more complex environments, such as mountainous areas or dense forests, the model may not provide accurate results.

The COST 231 model has several formulae to estimate path loss under different scenarios. Here are some of the commonly used formulas:

1. Path loss in urban areas (COST 231 Hata model):

$$L = 46.3 + 33.9 * log10(f) - 13.82 * log10(hb) - (3.2 * log10(11.75 * hm))\verb|^|2 - 4.97 + (44.9 - 6.55 * log10(hb)) * log10(d)$$

……………………Eq1

Where L is the path loss in decibels (dB), f is the frequency in megahertz (MHz), hb is the height of the base station antenna in meters (m), hm is the height of the mobile station antenna in meters (m), and d is the distance between the antennas in kilometres (km).

2. Path loss in suburban areas:

$$L = 63.1 + 10 * log10(f) - 20 * log10(hb) - (3.2 * log10(11.75 * hm))\verb|^|2 + (2.77 * log10(11.75 * hm)) - 11.1 * log10(ue) + (44.9 - 6.55 * log10(hb)) * log10(d)$$

…………………Eq2

Where ue is the effective height of the mobile station antenna in meters (m).

These formulas are just examples, and there are variations of the COST 231 model that consider other factors such as terrain, clutter, and polarization. The model is implemented in various software tools and simulators for radio network planning and optimization.

Log Distance Path Loss Model

The log-distance path loss model is a mathematical formula used to estimate the attenuation of radio frequency signals as they propagate through a wireless communication channel. The model is based on the inverse square law, which states that the signal strength decreases with the square of the distance from the source (Sari and Alzubi, 2018) [7].

The log-distance path loss model takes into account both the free space loss and other factors such as environmental obstacles, interference, and reflections. It is expressed as:

$$PL(d) = PL(d0) + 10n\,log10(d/d0) + X\sigma$$

……………………………………………Eq3

Where PL(d) is the path loss at distance d from the source, PL(d0) is the path loss at a reference distance d0, n is the path loss exponent (which depends on the propagation environment), X is a normal random variable representing the shadow fading, and σ is its standard deviation (Fernandez et al., 2012) [3].

The expression is regarded as the log-distance model for an area with similar characteristics of propagation because it considers that the entire area of service can be described by a single value of the parameter n. However, in many cases it is necessary to divide the area into two parts, each of which has their own propagation exponent, denoted as n1 and n2

The log-distance path loss model is commonly used in the design and analysis of wireless communication systems, such as cellular networks and wireless sensor networks, to estimate the coverage area, signal strength, and link quality.

(c) Two-Ray (2-Ray) Model

The 2-Ray model is a radio propagation model used to estimate the path loss of a radio wave in outdoor environments. It assumes that the radio wave is transmitted from a high antenna and reaches the receiver by two paths: a direct path and a reflected path from the ground. The model takes into account the effects of diffraction, reflection, and refraction on the radio wave. The two-ray model is used when a single ground reflection dominates the multipath effect, as illustrated in Figure 1.

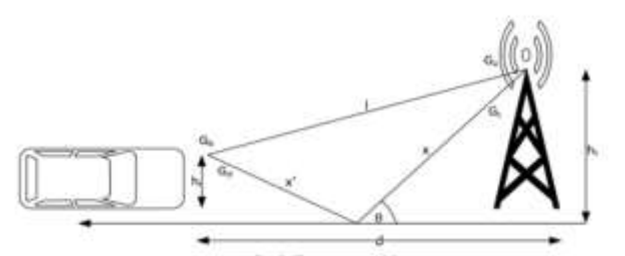

Fig 1: The Two-Ray Model

In the two-ray model the reflected path will bounce back off the ground and the two-ray model become handy in propagation approximations along rural roads, highways, and over water.

The formula for the 2-Ray model is:

$$L = 20 * log10(d) + 20 * log10(h\_t) + 20 * log10(h\_r) - 20 * log10(h\_e) - K$$

…………………………………Eq4

Where L is the path loss in decibels (dB), d is the distance between the transmitter and receiver in meters (m), h_t is the height of the transmitter antenna in meters (m), h_r is the height of the receiver antenna in meters (m), h_e is the effective height of the reflecting surface in meters (m), and

K is a constant that depends on the environment and the frequency of the signal (Bhuvaneshwari et al., 2016).

In the 2-Ray model, the direct path and the reflected path have the same amplitude, and the reflected path has a phase shift of 180 degrees. The effective height of the reflecting surface depends on the angle of incidence and the dielectric properties of the ground.

The 2-Ray model is a simple and useful tool for estimating path loss in outdoor environments, especially in situations where the transmitter and receiver are located far apart and there are no significant obstacles between them. However, it has limitations and does not take into account the effects of diffraction around obstacles or the variations in terrain and environment (Rappaport, 1996)

Received Power

The received power (PRx) at a specific distance can be calculated using the path loss equations of the different models and the transmitted power (PTx). The equation for the received power in dBm (decibel milliwatts) is given by;

$$PRx(dBm) = PTx(dBm) - PL(dBm) + GL(dB)$$
……………………………………….Eq5

Where: $PRx(dBm)$ is the received power at the receiver in dBm, $PTx(dBm)$ is the transmitted power from the transmitter in dBm, $PL(dBm)$ is the path loss in dBm calculated using any of the propagation models, $GL(dB)$ is the additional system gain or loss, such as antenna gains or losses, in dB. In this case, the transmitted power (PTx) is also in dBm to maintain consistency with the received power calculation. Additionally, the specific values for path loss (PL) and additional system gain or loss (GL) is determined based on the appropriate model parameters for the given scenario.

In practice, the transmit power of a cellular network base station varies depending on several factors which includes; the cellular technology being used (e.g., 2G, 3G, 4G, 5G), the frequency band employed, and regulatory restrictions imposed by the governing authorities in a particular region.

Generally, the transmit power of a base station in a cellular network is typically expressed in terms of dBm (decibel milliwatts). The actual value of the transmit power can range from a few watts (e.g., 20 dBm) to several tens of watts (e.g., 43 dBm) or even higher, depending on the specific requirements and characteristics of the cellular network. For the simulations on this paper, a transmit power of 25dBm and a negligible additional system gain or loss, $GL(dB)$ will be assumed.

Practically, the transmit power of a base station is typically controlled and adjusted dynamically by the network operator to optimize coverage, capacity, and interference management within the network. This dynamic power control allows for efficient utilization of network resources while maintaining reliable communication quality for the users.

Simulation and Result Discussion

The simulation was carried out on Excel using the different model equations of Eq2, Eq3 and Eq4. The pathloss for the different models; COST 231-Hata, Log-Distance and 2-Ray models were calculated for distances 200m in a space of 200m to 1km as shown on Table 1 and plotted in Figure 2.

In this simulation, a worst case scenario was assumed where the transmitter power is 1 watt, the receiver sensitivity is $-100\ dBm$, the antenna gains are 1 for both transmit and receive antennas, and the antenna heights are 1 meter for both transmit and receive antennas. The distance of the direct path is the same as the distance between the transmitter and receiver, while the distance of the reflected path is assumed to be zero, as the reflection is assumed to come from the ground. The path loss increases with distance due to the spreading of the signal and the attenuation caused by the reflection.

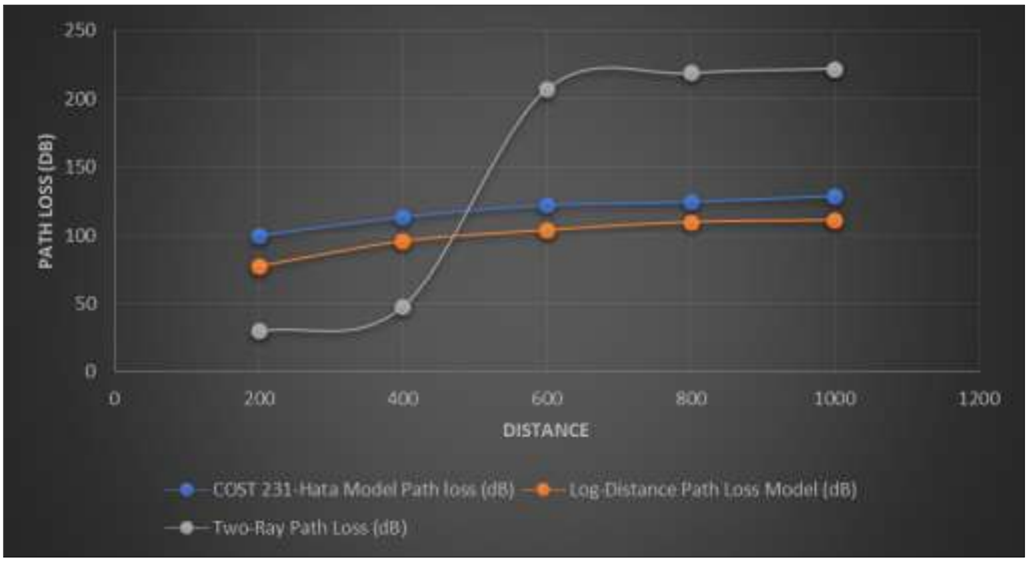

Fig 2: The Comparative analysis of the models

Using Eq5, the received signal power was also calculated for distances 200:200:1km and results shown in Figure 3. This figure shows that COST 231-Hata is closer to Log-Distance than it is to a 2-Ray models. This is a sign that the approximation by 2-ray of all multipath and fading effects on the radiowave propagation to a single ground reflected ray may be unrealistic.

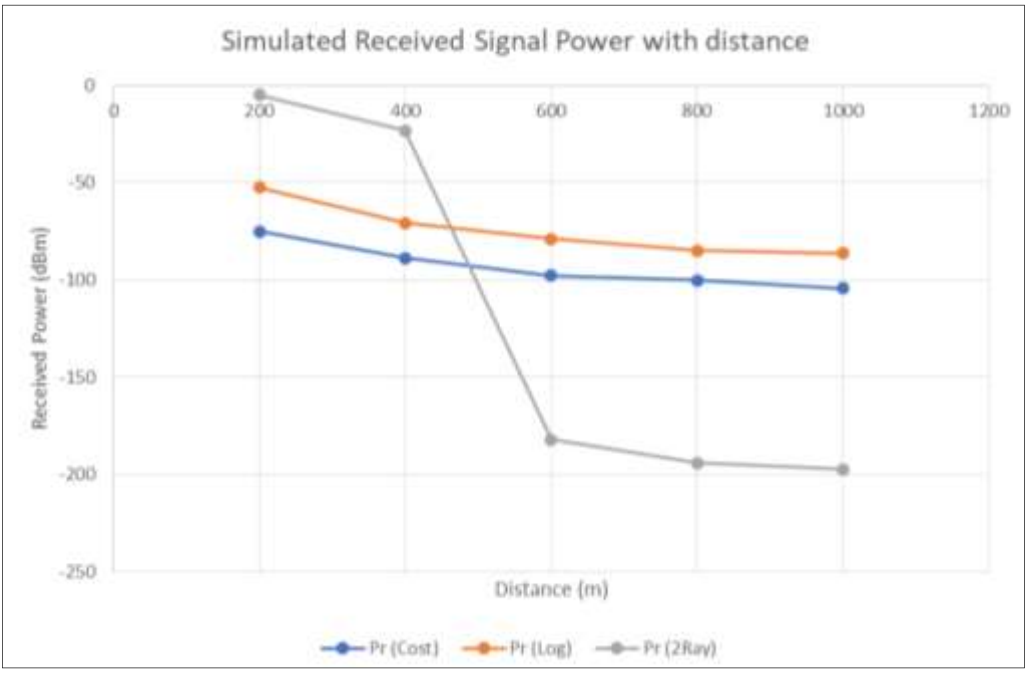

Fig 3: Simulated Received Power with distance

Experimental Measurement and Result Discussion

Experimental Testbed

To further investigate the relationship between the empirical pathloss models and the real world radiowave propagation and signal reception in a wireless cellular network, a field measurements were conducted via drive test. The experimental site was Polo Park GRA Enugu, Enugu North Local Government of Enugu State, Nigeria shown on the google map of Figure 4.

Fig 4: Google Location of the experiment site

This location was used for the study due to its constant exposure to high population of not less than 1,500 people buying and selling at the shopping mall (Innocent and Gold, 2020), with a big percentage of them using the network communication system for their businesses.

The MTN 4G network servicing the Polo park area with serial number M72320 was used for the experiment. A drive test which is a process of moving round the network base station area while monitoring and taking record of the required network data was conducted. The materials used for the drive test include; A car, Laptop for data logging, Mobile phone, Global Positioning System (GPS), Google Map software, Spectrum analyser (SPECTRAN HF 6080 model), Uninterruptible power supply (UPS), and Network Communication Software (Aaronia)

The Laptop installed with network communication software (Aaronia) was used to monitor the signal strength of the networks when connected to a spectrum analyser. A mobile phone installed with net monitor software was deployed for proper identification of the service provider that operates the network base station from where data is being collected. GPS was employed to capture the distance in meters (m) from the base station to the receiver starting from 100m, in a space of 100m then to 1000m distance from the network base station. Google map software was installed in the Hp laptop to capture the information about the terrain of the environment. UPS was used as an alternate source of power in case of any power failure while the car was used for mobility during the driving test. The experimental setup is shown in Figure 5.

Fig 5: Experimental Setup

The result of the drive test for four different days for the same location are shown in Figure 6. The essence of carrying out the measurement for different days is to statistically justify the validity of the received results.

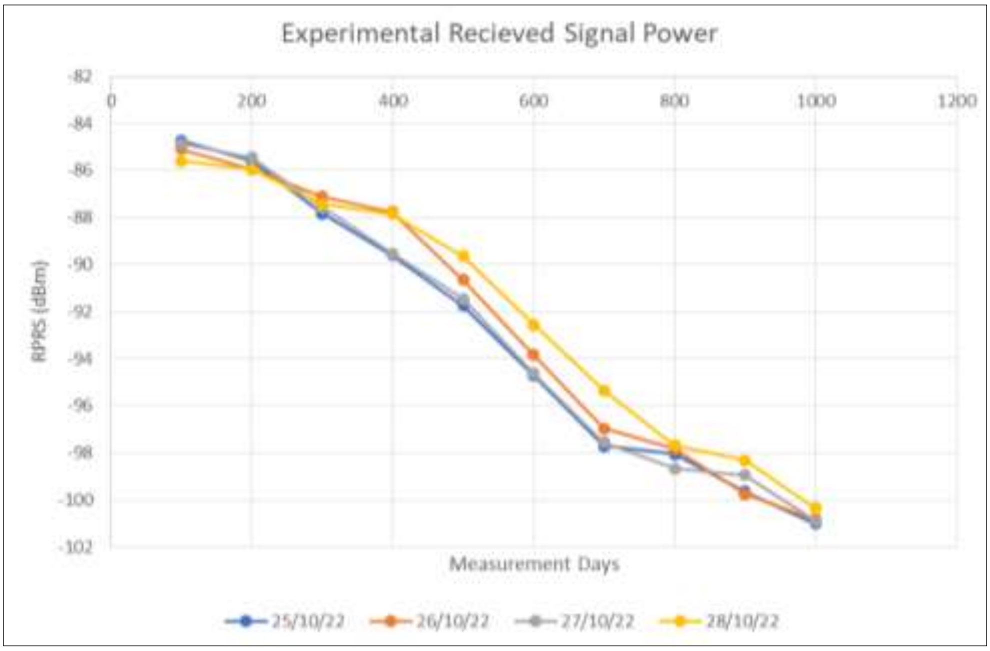

Fig 6: Measured Received Signal Power with distance

From Figure 6, it can be seen that the results for the different days follow the same pattern and the slight differences may be due to the weather conditions peculiar to the days of the measurement. The result is also in alignment with the known theory of reduction in received power as distance increases.

To check which of the modeled empirical models best describe the Polo park environment, the percentage reduction in distance as the radiowave propagates was calculated and result shown in Table 2.

Table 2: Percentage decrease of Signal Power with Distance

% Decrease with distance			
COST 231-Hata (%)	**Log-Distance (%)**	**2-Ray (%)**	**Experiment (%)**
18.09	35.23	362.00	4.66
10.02	11.68	688.40	5.73
2.46	7.41	6.59	3.53
4.20	1.56	1.62	2.99

From this result, among the three simulated models and the experimental measured results for 200m, 400m, 600m and 800m, the 2-ray model is an outlier still confirming the findings from the simulated results that the approximation by the model makes it unsuitable for the prediction of radiowave propagation in a wireless communication network.

The outlier 2-ray model was removed from further comparative investigation and a plot of the percentage decrease in received signal power with distance for Cost 231 Hata, Log-normal and experimental was plotted for the four distance levels, 1 to 4 at 200m, 400m, 600m and 800m distances respectively. The result is shown in Figure 7.

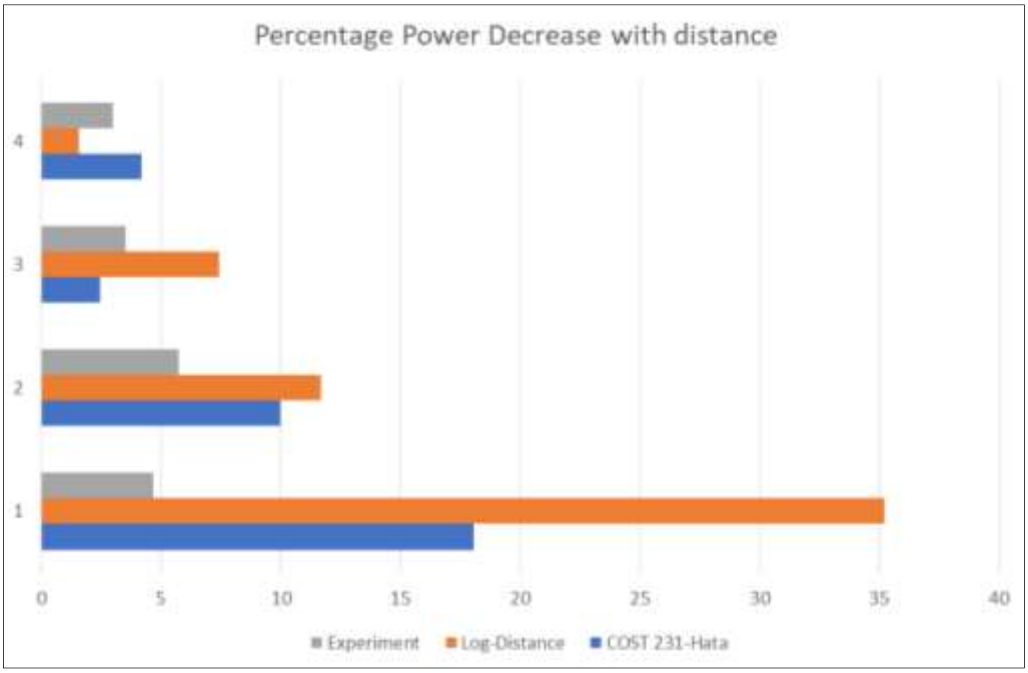

Fig 7: Percentage Signal Power decrease with distance showing the most suitable model for wireless network application

The result of Figure 7 has shown that Cost 231-Hata is the empirical model that is closest to the measured experimental data. This shows that it best describes the real world radiowave propagation than others that were compared with it. It will therefore give a more accurate prediction result for network planning than others compared with it in this paper.

Conclusion

In this research paper, a comprehensive comparative study of radiowave propagation models for wireless communication networks was conducted. The analysis encompassed three popular models COST 231-Hata, log-normal and 2-ray models. Through this study, we aimed to provide valuable insights into the strengths, limitations, and applicability of these models across different scenarios. Both simulation and experimental measurements were carried out. The Simulation results revealed the 2-ray model as an outlier among others which can be related to the approximation of all multipath into only two paths by the 2-ray model. The experimental result showed a percentage decrease in received power of 18.09, 35.23, 362.00 and 4.66dBm for Cost 231-Hata, Log-normal, 2-ray and experimental measurement respectively for a distance of 200m from the base station. This result confirmed 2-ray model as an outlier and not suitable for wireless network propagation prediction. The result also show that Cost 231-Hata is the most suitable radiowave propagation model for wireless when compared with Log-normal and 2-ray. For more accurate and robust prediction algorithm, further study will compare Cost 231-Hata with other empirical radiowave propagation models like ITU-R and Winner-11 models. Findings can then be used to develop a system that selects the best model for radiowave propagation prediction.

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