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Validation of Empirical Propagation Models for Mobile Communication in Federal Polytechnic, Ado-Ekiti through Simulation and Measurement Based

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Abstract:
This work uses three widely used models: COST-231 Hata, COST-231 Walfisch-Ikegami (W-I), and the Two-Ray Ground Reflection model to investigate signal propagation and path loss characteristics in a campus environment. A key component of wireless communication, propagation losses were investigated using MATLAB R2024a simulations to replicate real-world conditions at the Federal Polytechnic Ado-Ekiti. The work simulated varying receiver antenna heights (2 m, 4 m, 8 m, and 16 m) at 1800 MHz and evaluated signal attenuation over distances ranging from 1.5 m to 15 m. Higher receiver antenna positions apparently greatly lower path loss. At high altitudes, the Two-Ray Ground Reflection model showed the best performance among the models; the COST-231 Hata model produced consistent predictions for urban settings. Especially in highly developed areas, the results highlight the need of antenna elevation in enhancing network coverage and dependability.

Keywords: *Walfisch-Ikegami, MATLAB, antenna height, path loss, COST-231 Hata, wireless simulation.*

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1. INTRODUCTION

In communications systems that require information to be transmitted and received using wireless mode, they mainly encounter what is referred to as propagation path loss. This said path loss is a major and important factor that reduces the efficiency of wireless communication, and is a major factor in the analysis and design of any kind of wireless communication system.

Since, the transmitter and receiver required the use of electromagnetic waves as the transmitting medium, this medium might experience obstacles that block the line-of-sight path. The travelled signal from the said user equipment to the receiver equipment can as well experience a lot of reflection path which is referred to as multipath propagation which always causes unstable in the communication process or fluctuations in the received signal's phase and amplitude, the main mechanisms causes this fluctuation and as well influence the signal propagation are as follows (Rappaport,1996; Eze, 2020).:

- Reflection.
- Diffraction.
- Scattering.
- Doppler Effect.

The propagation models are important, and this is why it was developed to predict the loss of

signal strength or coverage in a particular zone. Thus, we also have mathematical tools used by engineers and scientists to plan and optimise wireless communication systems (Naseem *et al*., 2021).
Therefore, path loss can be defined as the ratio of the transmitted to received power, usually expressed as the following form in decibels (Rouphael, 2009; Stanford University, 2020).

$$PL(d) = PL(d_o) + 10n(\frac{d}{d_0}) \quad [1]$$

Where d is the distance, d_0 is the reference point at 1 km, and n is the path loss exponent.
But path loss generally includes propagation losses caused by the natural expansion of the radio wave propagation in free space. The paper is arranged as follows:
The paper begins with an overview of different propagation models, followed by a presentation of the simulation models and scenarios. Next, the simulation results are analysed, and the work concludes with key findings and insights.

2. PROPAGATION MODELS OVERVIEW

We can better understand how signals, such as those from a phone tower, move through the atmosphere to reach our devices by using propagation models, which are similar to maps. These models account for factors that can impact the signal's strength or clarity, such as hills, trees, buildings, and even the weather (Tataria *et al*., 2021).
To put it briefly, they assist engineers in forecasting a signal's range and performance in various settings, such as urban or rural areas or interior buildings.

1.1 Free Space Path Loss (FSPL) Model

The signal loss between a transmitter and receiver in free space, that is, in an area devoid of obstructions like buildings or terrain, is estimated using the FSPL model. It is frequently used for deep-space, satellite, and microwave communications and assumes a line-of-sight (LOS) path (Rappaport, 2002).

$$PL(d) = 20[(d) + (f)] - 147.55 \quad [2]$$

Additionally, PL(d) represents the path loss in decibels (dB), d is the distance in meters, and f is the frequency in megahertz (MHz).
The speed of light and unit conversions are used to calculate the constant -147.55 (Rappaport, 2002). Although this model is straightforward, it is only accurate in unhindered situations.

1.2 Two-Ray Ground Reflection Model

By taking into account both the direct LOS path and the signal reflected off the ground, this model goes beyond FSPL. Longer distances are more accurate with it, particularly in open spaces like rural fields or highways (Goldsmith (2005).

$$Pr = \frac{P_t G_t G_r h^2{}_t h^2{}_r}{d^4} \quad [3]$$

P_r stands for received power, P_t for transmitted power, G_t for antenna gains, and hr for the transmitter and receiver heights.
Distance Signal strength decreases significantly more quickly than in the FSPL model, as demonstrated by the d^4 term (It means that after a certain point, the signal strength decreases four times faster than it would in open space. This helps engineers predict coverage more accurately and design networks that work in the messy, unpredictable real world, particularly beyond a specific breakpoint distance.

1.3 Log-Distance Path Loss Model

This model, which is used in cluttered environments (such as urban areas), generalises FSPL by adding a random variable X_σ to account for shadowing and a path loss exponent n to represent the rate of attenuation (Rappaport, 2002).

$$PL(d) = PL(d_o) + 10n(\frac{d}{d_0}) + X_\sigma \quad [4]$$

Where X_σ is the Gaussian-distributed shadowing term in dB, n is the path loss exponent (usually 2 to 6), and PL (d_0): Path loss at reference distance d_0
Since direct LOS isn't always feasible in real-world situations with buildings or vegetation, this model can be used for simulation.

1.4 Hata Model (Urban)

Cellular planning frequently uses this empirical model, which was created by Okumura and then simplified by Hata, for frequencies ranging from 150 MHz to 1500MHz. It contains settings for the heights of the transmitter and receiver (Igbonoba, 2023).
Equation (Urban):

$$PL = 69.55 + 26.16(f) - 13.82(h_t) - a(h_r) + (44.9 - 6.55(h_t))(d) \quad [5]$$

Note, f is Frequency in MHz, h_t, h_r is the Transmitter and receiver heights (m), d: Distance in km and a(hr), Receiver antenna height correction factor (varies by city size)

2.4 COST-231 Hata Model

This model is more applicable to contemporary GSM and LTE deployments since it expands the original Hata model for use in frequencies between 1500 and 2000MHz. Depending on the situation, it also has a constant C.

$$PL = 46.3 + 33.9(f) - 13.82(h_t) - a(h_r) + (44.9 - 6.55(h_t))(d) + C \quad [6]$$

Where $C = 0$ for suburban or rural areas and $C = 3$ for urban areas

1.5 COST231Walfisch-Ikegami (W-I) Model

One of the most effective models for rural and suburban environments is the COST-231 Walfisch-Ikegami (W-I) model, especially in scenarios where building heights are relatively uniform. Compared to many other empirical models, it offers more accurate path loss predictions by incorporating detailed parameters such as building separation, street width, and orientation. The model adapts to various terrain types by adjusting specific variables accordingly (Alqudah, 2013; Salem, 2016). It is particularly robust in Non-Line-of-Sight (NLOS) conditions, where signal paths are obstructed, thanks to its specialised equations for rooftop-to-street and multiscreen diffraction losses (Alam, 2014; Oladimeji et al., 2022).

1.5.1 Condition of Line-of-Sight (LOS)

For circumstances in which the path between the transmitter and the receiver is unobstructed and clear:

$$PL_{LOS}(dB) = 42.6 + 26(d) + (f) \quad [7]$$

PL_{LOS} is Path Loss (in dB), d distance between transmitter and receiver (in km) and f is Frequency (in MHz)

1.5.2 Non-Line-of-Sight (NLOS) Condition

State The path loss is computed as follows when obstructions (such as buildings) obstruct the direct path:

$$PL_{NLOS} = L_{RTS} + L_{MSD} + 42.6 + 26(d) + 20(f) \quad [8]$$

But, L_{RTS} is equal Rooftop to street diffraction loss and L_{MSD} is equal to multi-screen diffraction loss

Calculation of L_{RTS} (Rooftop-to-Street Diffraction Loss)

$$L_{RTS} = -16.9 - 10log10(w) + 10(f) + 20(h_b - h_r) \quad [9]$$

Where w is street width (in meters), f is the Frequency (in MHz), h_b is the Base station antenna height (in meters), and h_r is the Mobile (receiver) antenna height (in meters)

Calculation of L_{MSD} (Multi-screen Diffraction Loss)

The following are the elements used to calculate the Multi-Screen Diffraction Loss (LMSD):

$$LMSD = L_{bsh} + k_a + k_d log10(d) + k_f(f) - 9(b) \quad [10]$$

However, L_{bsh} is the basic rooftop-to-mobile station height loss, B is the average building separation (in meters), and ka, kd, and kf are the empirical constants that vary depending on the environment (rural, suburban, or urban).

The following formula provides the basic rooftop-to-mobile station height loss (L_{bsh}):

$L_{bsh} = -18(1 + h_b - h_r)$, provided that the base station antenna height h_b is greater than the receiver antenna height h_r.

The constant k_a is taken as 54 for suburban and rural areas, k_d is 18 for suburban and rural areas and $k_f = -4 + 0.7(\frac{f}{925} - 1)$, where f is the frequency in megahertz (MHz).

3. SIMULATION MODELS AND SCENARIOS

The MATLAB R2024a software, which was used to analyse channel propagation models of wireless communication systems, is described in this work along with simulation models.

a. Models for Simulation

Three different user equipment receiver antenna heights two, four, eight, and sixteen meters as well as an operating frequency of 1800 MHz are used in this study to analyse the COST-231 Walfisch-Ikegami (W-I), COST-231 Hata, and Two-Ray Ground Reflection models in Federal Polytechnic Ado environments.

By varying the receiver antenna height between 2 and 16 meters, the simulations estimate the path loss of the channel propagation models. This range includes coverage for users on the rooftops or upper floors of the high-rise buildings at Federal Polytechnic Ado, as well as normal mobile device usage at ground level. The transmitter antenna height, which represents base stations positioned on the ground, like those affixed to poles or short towers on campus, is set between 29 and 50 meters. The power output of the mobile transmitter is set at 30-35 dBm, which is in line with the power output of base stations or small cells intended to cover the entire campus, from installations on the ground floor to those on the roof.

b. Simulation Scenario

The Google Map distance location pin point is used in the simulation to account for the distance between the transmitter and receiver. From transmitter equipment to user equipment. Additionally, the base station transmitter power is 35dBm. Additionally, 1800MHz is the operating frequency for every simulation scenario. Additionally, the values of every parameter used in the simulation are shown in Table 1.

Table 1: Simulation parameters

Parameters	Values
Operating frequency	1800 MHz
Distance between TX and RX	1.5m to 15m
Transmitter antenna height	30 meters
Mobile transmitter power	30dBm
Base station transmitter power	35 dBm
Receiver antenna height	2 m, 4 m, 8 m and 16m

The purpose of this simulation scenario was to evaluate the path loss for various channel models. Twelve distinct trials were used for the simulations, and each trial involved varying the receiver antenna height according to the channel model and surrounding circumstances. All of the previously described parameters for both urban and rural settings were used to calculate path loss during each trial.

simulation, which ran at 1800MHz. In the Federal Polytechnic Ado-Ekiti environment, the models' performance was examined over distances between 1.5 and 15 meters, using receiver antenna heights of 2, 4, 8, and 16 meters. The path loss variation with distance for various receiver antenna heights is shown in Figures 4.1 through 4.4.

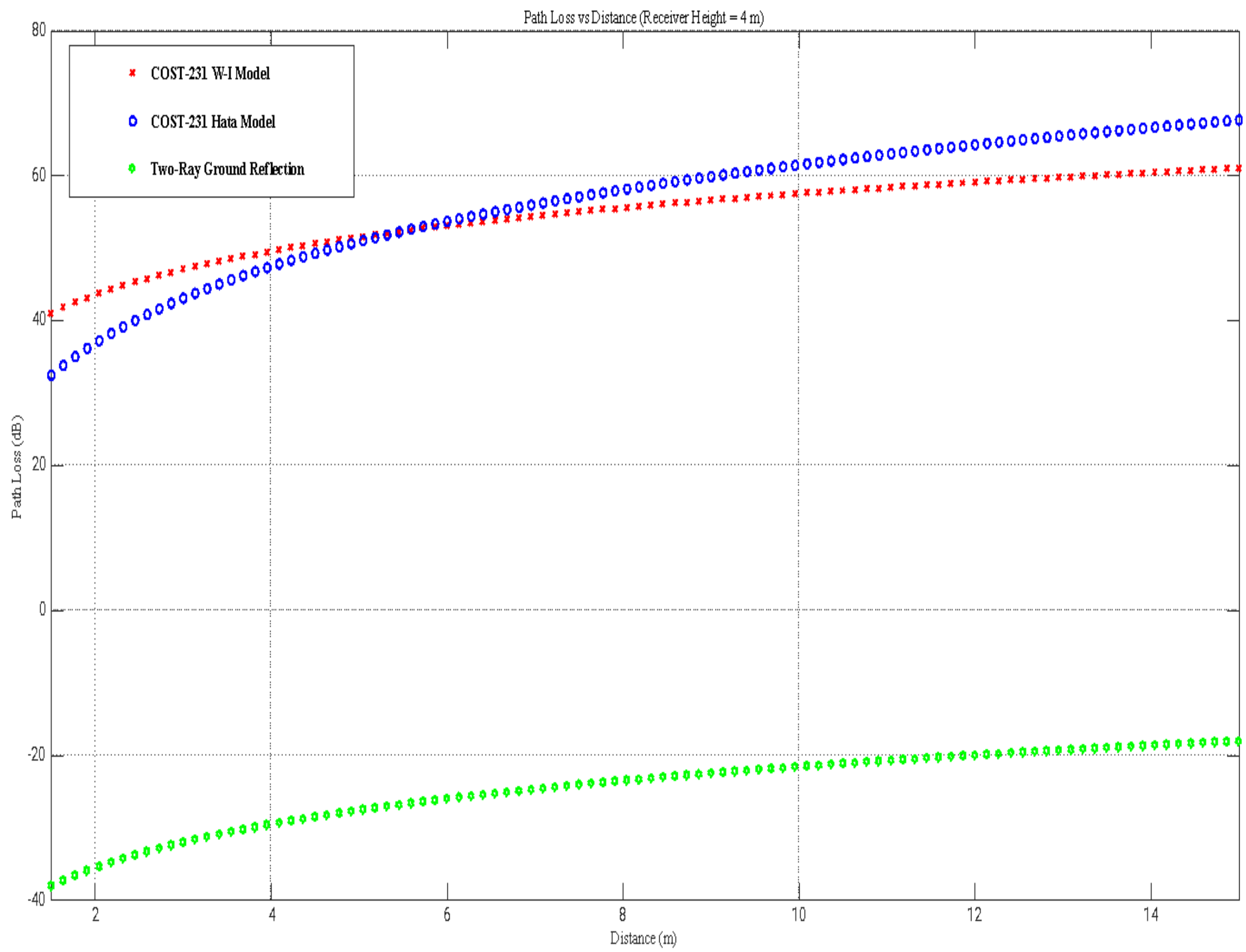

Figure 4.2: Path loss for 4 m receiver antenna height in Federal Polytechnic Ado environment.

4. SIMULATION RESULTS

The outcomes of the simulations are shown in this section. Three propagation models, COST-231 Walfisch-Ikegami (W-I), COST-231 Hata, and Two-Ray Ground Reflection, were used in the

Furthermore, simulations covering the conditions in the Federal Polytechnic Ado-Ekiti environment are displayed in Figures 4.1 through 4.4, respectively, for receiver antenna heights of 4 m, 7 m, and 14 m.

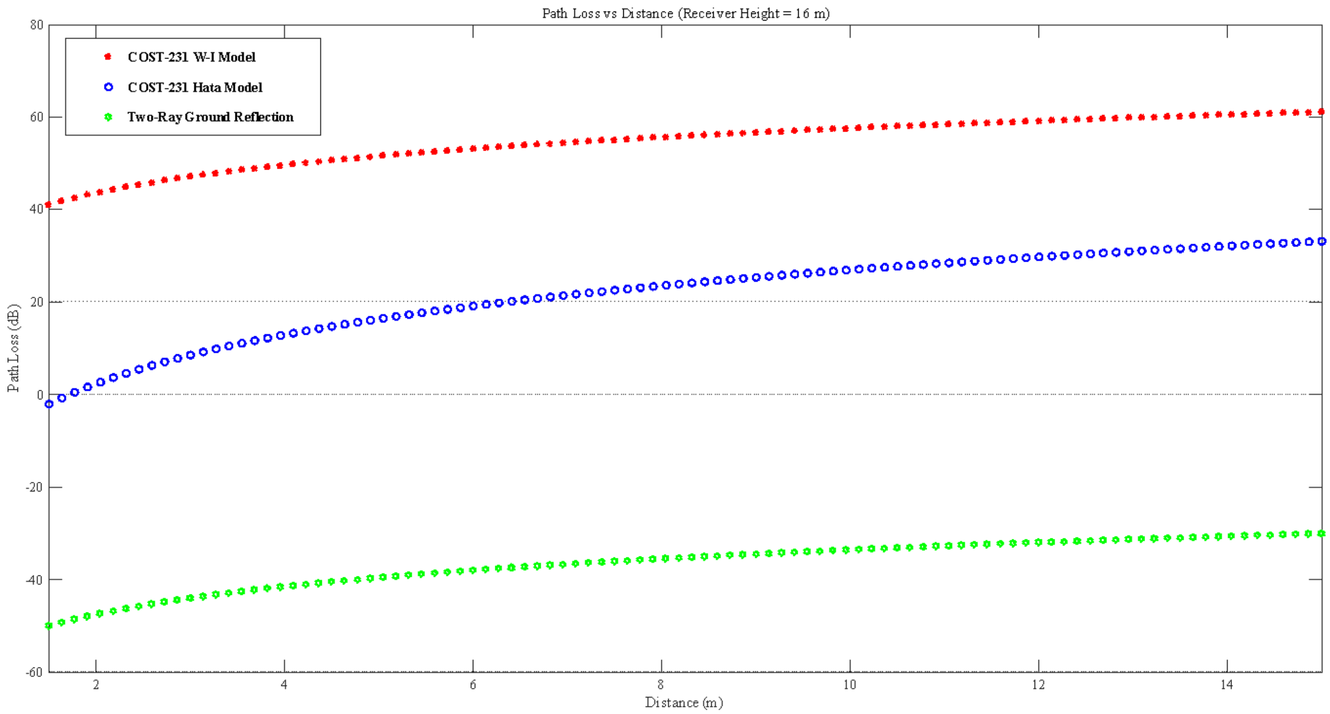

Fig. 4: Path loss for 16 m receiver antenna height in Federal Polytechnic Ado environment.

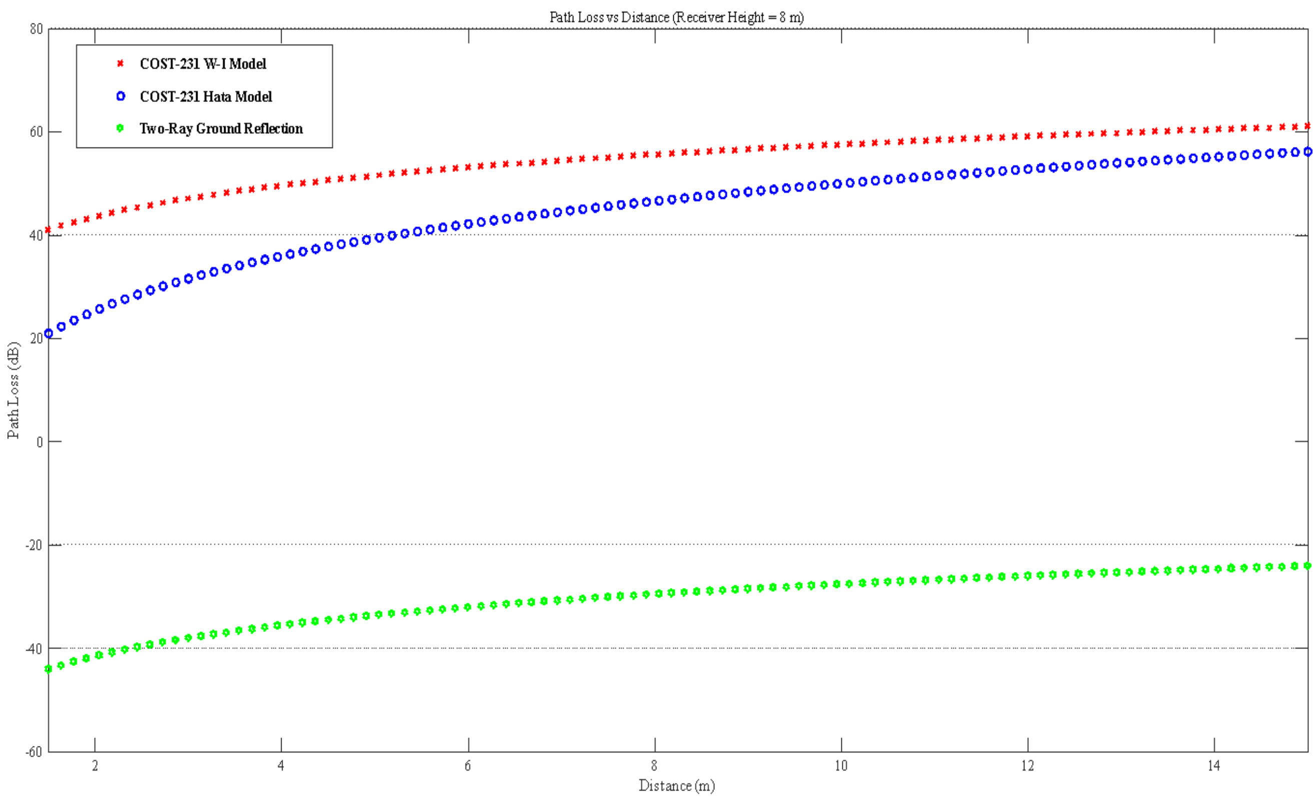

Figure 4.3: Path loss for 8 m receiver antenna height in Federal Polytechnic Ado environment.

5. CONCLUSION

The simulation results verify that a higher receiver antenna height improves signal quality by drastically lowering path loss. The Two-Ray Ground Reflection model is appropriate for high-rise, rooftop, and aerial communication scenarios because it has continuously demonstrated the best performance at higher antenna positions. In the meantime, COST-231 W-I offered a balance between accuracy and complexity, while COST-231 Hata remained a reliable and conservative model for urban settings.

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