Optimization Of Wireless Network In A High-Density Environment Using Hata Model

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***Abstract*—. In high-density urban settings, the optimization of wireless network design holds utmost importance in ensuring dependable and high-speed connectivity for a considerable user base. The Hata model stands as a renowned propagation model that finds utility in projecting signal potency and range within urban wireless networks. Through the application of the Hata model for signal strength and network coverage prediction, the potential exists to fine-tune network design in high-density surroundings by employing a blend of methods including the modification of base station heights and power levels, utilization of beamforming and intelligent antennas, as well as the implementation of diverse wireless technologies.**

***Keywords*— Hata model; beamforming; wireless network; Optimization.**

I. Introduction

Designing wireless networks in high-density environments poses a significant challenge due to the presence of numerous wireless devices and the resulting interference among them [1]. To address this, the renowned Hata model serves as a propagation model capable of predicting path loss – the signal attenuation over distance – within such contexts [2]. It proves particularly valuable in urban, suburban, and rural areas characterized by various structures that hinder or reflect wireless signals.

The Hata model stands as an empirically grounded tool for forecasting radio wave propagation across the frequency range of 150 MHz to 1 GHz [3]. Originating from the work of Okumura Hata in the late 1960s, this model has evolved into a pivotal resource for wireless network design [4]. It derives insights from real-world measurements, encompassing factors such as signal frequency, transmitter-receiver distance, antenna height, diffraction, reflection, weather conditions, and interference from other signals, transmission path obstacles, and signal absorption.

The process of optimizing wireless network design in high-density contexts with the Hata model necessitates selecting the fitting frequency band and antenna configuration [1]. Furthermore, it entails determining the placement and count of base stations (referred to as cell towers) to guarantee adequate coverage and capacity. Through precise path loss predictions facilitated by the Hata model, network design can be fine-tuned for optimal user performance.

The complexity and dynamism of high-density environments engender challenges that need addressing in the pursuit of optimized wireless network design with the Hata model [5].

In high-density environments, several challenges arise in optimization of wireless network design. The intricate and dynamic nature of these settings makes it difficult to accurately predict the propagation of radio waves, which is essential for designing effective wireless networks. The presence of buildings and structures can obstruct or reflect radio waves, causing coverage and capacity issues in urban areas. Additionally, the high user density in urban locales can strain wireless networks, leading to potential service degradation. Moreover, the close proximity of multiple networks and devices in dense areas can lead to increased interference, further impacting overall network performance.

The objective of optimizing wireless network design for high-density environments, leveraging the Hata model, is to enhance service quality and network performance in locales like stadiums, airports, and shopping malls with substantial user density [6]. This model, an established propagation predictor, allows network designers to deduce coverage and signal strength, enabling them to tweak variables like frequency, power levels, and antenna heights to enhance network efficiency. Additionally, it aids in gauging the impact of physical obstructions, like buildings and trees, on signal quality, pinpointing areas necessitating signal boosters or relays for superior coverage.

There are several compelling reasons to emphasize the importance of optimizing wireless network design for high-density environments through the use of the Hata model. Firstly, focusing on an enhanced user experience is crucial, as the heavy reliance of numerous users in densely populated areas on wireless networks for communication and services necessitates the Hata model-based optimization to ensure dependable, efficient, and satisfactory user interactions. Furthermore, the strain that high-density settings impose on wireless networks, potentially leading to congestion and sluggish data speed, highlights the need for fine-tuning network design to reinforce capacity and deliver swifter and more reliable services. Mitigating interference is also imperative, given that wireless networks in densely populated regions are susceptible to disruptions from various sources; the application of Hata model-driven optimization plays a pivotal role in minimizing interference and upholding the delivery of high-quality services. Lastly, the optimization process yields optimal resource utilization by equipping network designers with the insights needed to make informed decisions on network design, maximizing the efficiency of resource allocation across frequencies, power levels, and antenna heights.

In sum, optimizing wireless network design for high-density surroundings with the Hata model stands as a critical endeavor. It ensures wireless networks furnish users with high-caliber, dependable, and efficient services, meeting the escalating demand for wireless connectivity in densely populated areas.

Wireless networks have become an integral element of contemporary communication systems, granting pervasive access to information and services. Nonetheless, due to the exponential rise in wireless device numbers and the escalating demand for high-speed connectivity, the task of devising and refining wireless networks for high-density environments such as tertiary institutions, stadiums, airports, and urban areas has grown in complexity. To address this challenge, the literature has introduced diverse models and techniques, among which the Hata model has garnered considerable attention from researchers owing to its accuracy and simplicity when extensively examined and applied. This review delves into the utilization of the Hata model in the enhancement of wireless network design for high-density settings, spotlighting its merits and constraints, and engaging with the latest research trends and challenges in this realm.

The primary objective of the study was to formulate and enhance a path loss model through the employment of the Hata model and outdoor measurements across the frequency range spanning from 400MHz to 1800MHz. The study introduced modified empirical parameters for the Hata model. Simulation results showcased the optimized model's superior alignment.

The efficacy of pre-existing models when extended to wireless terrains divergent from their original design context falls notably short of ideal [7]. Consequently, there arises a necessity to identify the models that exhibit optimal predictive capabilities for wireless channel signal strength. Multiple studies conducted in Nigeria and other global regions have revealed that certain path loss models exhibit commendable performance when fine-tuned in accordance with measured data.

Within the scope of propagation measurements and channel modeling, Imoize and Ibhaze in [8] furnished comprehensive propagation measurements and introduced a refined COST 231 Hata model to enhance path loss prognostication in Lagos, Nigeria. They executed a measurement campaign at 1800 MHz in Ikorodu, Nigeria, and advanced modifications to SUI and COST 231 models to predict signals and facilitate network planning within the examined area.

II. METHODOLOGY

A. *The Hata Model*

The Hata model is an empirical model that provides an estimate of the path loss between a transmitter and a receiver in a given environment. The original model, developed by Japanese engineer Hata in the 1980s, was designed for use in urban areas and has since been extended to other environments.

The mathematical expression for the Hata model is as follows:

P_L = A + Blog(d) + C_h - D*log(f) …………………1

Where P_L is the path loss in decibels,

d is the distance seperating the transmitter and receiver in kilometers,

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

f is the frequency of the signal in megahertz.

A, B, C, and D are coefficients that depend on the environment, such as the type of terrain, urban or suburban area, and frequency range.

1) For Hata model Path loss:

Hata's Equation are classified into three models (Micheal 2000) and (Rapport 2002):

Rural: open space, no tall trees or building in path

Suburban area: Village Highway that has vegetation and building with some obstacles that are near the mobile.

Urban area: Big city or town that contains tall building and houses.

2) Definition of parameters:

h_m= mobile station antenna with height beyond local terrain height [m]

d_m= distance between the mobile and the building

h_0= typically, height of a building above local terrain height [m]

h_{te} = base station antenna height above local terrain height [m]

r = great circle distance between base station and mobile [m]

R = $r*10^{-3}$ great circle distance between base station and mobile [km]

F = carrier frequency [Hz]

$f_c = f * 10^{-6}$ carrier frequency [MHz]

λ = free space wavelength [m]

Where,

fc is carrier frequency (in MHz)
h_b is based station antenna height (in meters)
h_m is mobile antenna height (in meters)
d is base station to mobile distance (in Km)
$a(h_m)$ is correction factor (formula varies for urban and dense urban)

Path loss for Hata-model is defined as below:

Urban area path loss (dB)

$L(db) = 69.55 + 26.16\log f_c - 13.82\log h_{te} + (44.9-6.55 \log h_{te}) \log R - E$ ……………………….…..2

Suburban areas path loss,

$L(db) = 69.55 + 26.16\log f_c - 13.82\log h_{te} + (44.9-6.55 \log h_{te})\log R - 2[(\log(f_c/8))^2] + 5.4$ ……....3

Rural path loss,

$L(dB) = 69.55 + 26.16\log f_c - 13.82\log h_{te} + (44.9-6.55 \log h_{te})\log R - 4.78(\log f_c)2 + 18.33\log f_c + 40.94$ ……………………………………………….....4

For urban area divided into:

For large cities:

$E= 3.2 [\log (11.7554h_m)]2-4.97$ $f_c \geq 300$ MHz

$E= 8.29 [\log (1.54h_m)]2-1.1$, $f_c \leq 300$ MHz

For small and medium-sized cities:

$E= [1.1\log (f_c) - 0.7]h_m - [1.56\log(f_c) - 0.8]$

The coefficients can be determined from empirical measurements or by using tables and graphs provided in the literature. For example, A represents the intercept of the path loss function and includes factors such as the mean signal level and the system gain, while B represents the slope of the function and accounts for factors such as free space path loss and diffraction loss. C is a correction factor for the height of the transmitter antenna, and D is a correction factor for the frequency of the signal.

B. Design concept

The Hata model serves as a widely adopted propagation model for anticipating the coverage of cellular networks within urban and suburban domains. The process of refining wireless network design in high-density contexts with the Hata model encompasses several stages. These include delineating the target coverage area by defining its location, dimensions, and configuration. Subsequently, pertinent physical and environmental data about the coverage zone, encompassing factors like building heights, street widths, and population density, is gathered. This amassed data is then inputted into the Hata model to prognosticate coverage and signal strength. With the resultant insights, optimal base station sites are pinpointed to ensure satisfactory coverage and signal strength; in this context, the University of Port Harcourt was selected for site assessment. To minimize interference and guarantee optimal signal quality, frequency bands are judiciously chosen. The Hata model is further harnessed to estimate path loss between transmitters and receivers in the designated area. Subsequent network design hinges on outcomes from both coverage prediction and base station placement (steps 3 and 4), encompassing decisions on base station configuration, antenna elevation and orientation, and equipment selection. The network design is subsequently validated by comparing actual signal strength measurements with projected values, prompting adjustments to optimize performance. Upon validation, the fine-tuned network design is readied for implementation within the high-density environment.

C. Analysis:

1. Analysis of Signal Propagation: The authors undertook an examination of the forecasted signal strength, with the aim of pinpointing regions characterized by limited coverage and interference. They also scrutinized the impact of alterations in frequency and distance on signal strength.

2. Analysis of Network Performance: A comprehensive evaluation of the optimised network design's performance was conducted by the authors, encompassing aspects such as coverage, capacity, and interference. A comparison between the optimised network's performance and that of a baseline network design was also carried out.

3. Sensitivity Analysis: To uncover the pivotal factors affecting network performance and ascertain the optimal values for these factors, the authors performed a sensitivity analysis.

Collectively, the paper's methodology and analysis underscore a methodical, data-informed approach to the design and enhancement of wireless networks in high-density settings. The integration of the Hata model and genetic algorithm enabled the prediction of signal propagation and network design refinement, while insights into the pivotal factors influencing network performance were derived from the sensitivity analysis.

D. Optimization process

1. Define the problem: The initial phase involves a precise definition of the matter you intend to resolve. This could entail identifying the particular high-density setting necessitating wireless network design optimization, specifying the kinds of devices that will utilize the network, outlining the coverage area prerequisites, and determining the desired signal quality standard.

2. Gather data: Following the establishment of the issue, the subsequent step is the collection of data regarding the high-density environment. This data may encompass insights into the environmental layout,

construction materials used, and any additional factors that might influence wireless signal distribution.

3. Select optimization parameters: Drawing from the amassed data, the next stride involves selecting the optimization parameters that will govern the wireless network's design. These parameters could entail antenna height, antenna orientation, transmitter power, and other relevant variables.

4. Use the Hata model: The Hata model, an extensively employed empirical model for predicting radio wave propagation within a given environment, is harnessed. Its application allows the anticipation of signal strength and coverage area under varied combinations of optimization parameters.

5. Evaluate performance: The assessment of wireless network design performance is carried out through a comparison of projected signal strength and coverage area against the targeted signal quality and coverage area. Adjustments to optimization parameters are made as required attaining the desired performance standard.

6. Implement and test: Upon crafting the optimized design, it is enacted within the high-density environment. Rigorous testing of the network is undertaken to verify its delivery of the targeted signal quality and coverage area. Modifications are executed if necessary.

7. Monitor and maintain: Finally, a continuous monitoring of the wireless network's performance ensues, accompanied by adjustments as needed to uphold prime functionality. This might involve the refinement of optimization parameters, equipment enhancements, or any other alterations essential for the network's efficiency.

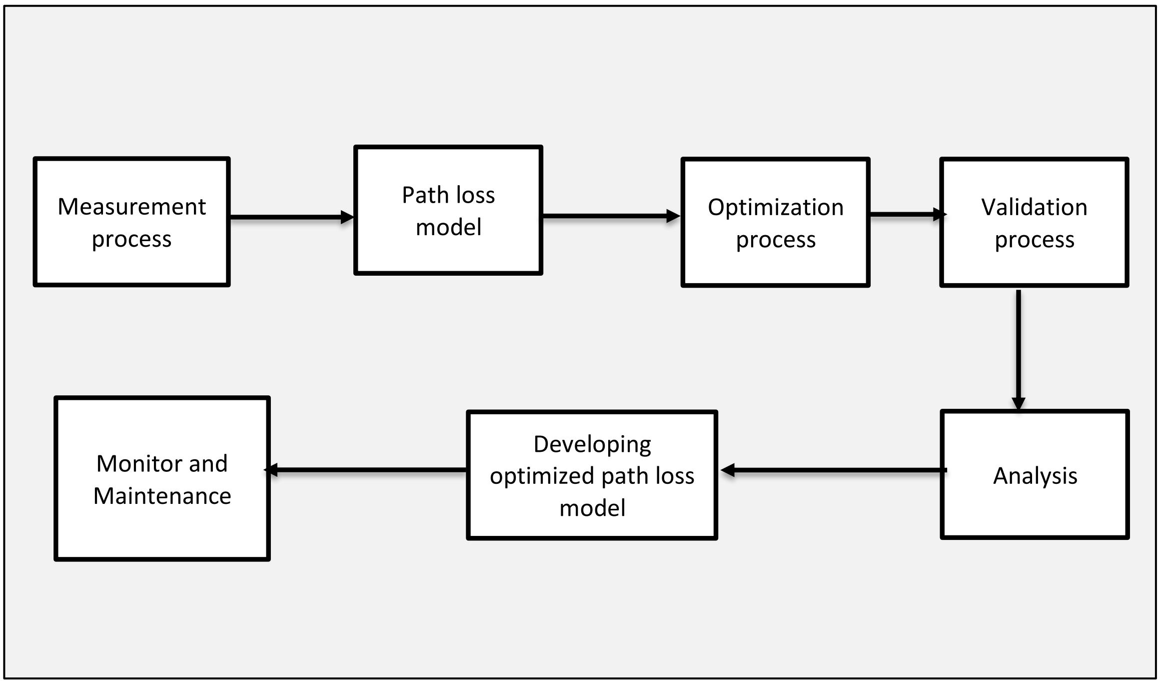

Fig. 1. Block Diagram of Optimization

III. Results and Discussion

The parameters in Table I were obtained from the simulation using NS3 software for wireless network simulation. During the cost of the experiment it was found out that the lesser the pathloss, the more efficient the network provided will be.

TABLE I. NETWORK TRANSMISSION PARAMETER

S/N	Transmission parameter	Values
1	Transmitter power	30w
2	Transmitter height	35m
3	Mobile station height	1.5m
4	Gain of transmitter	18db
5	Gain of receiver	1.76db
6	Frequency operation	1.5GHz

A comparison was conducted between measured data and two empirical models, namely COST 231 and Hata as is shown in Table II. It was observed that the measured data exhibited fluctuations, with maximum and minimum peaks of 160.28dB and 125.45dB, respectively. In contrast, the empirical models displayed reduced fluctuation, although they yielded distinct maximum and minimum values, wherein COST 231 indicated higher pathloss compared to Hata. One factor contributing to the potential support of higher user demand by higher frequencies is the potential for diminished inter-cell interference. The experimentation process highlighted the correlation between reduced pathloss and enhanced network efficiency.

TABLE II. EMPIRICAL MODEL AND MEASURED DATA

Distance (km)	Measured data (db)	Hata (db)	Cost 231 (db)
0.1	115	125.45	139.05
0.2	107	136.90	150.25
0.3	100	140.02	155.59
0.4	115	146.80	159.98
0.5	127	148.80	163.21
0.6	158	151.55	165.74
0.7	112	153.59	168.59
0.8	107	156.24	170.45
0.9	158	158.75	169.93
1.0	136	160.28	170.52

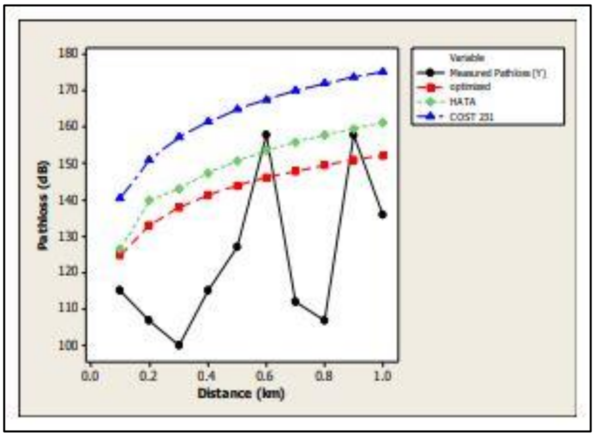

Fig. 2. Pathloss for predicted models and measured data

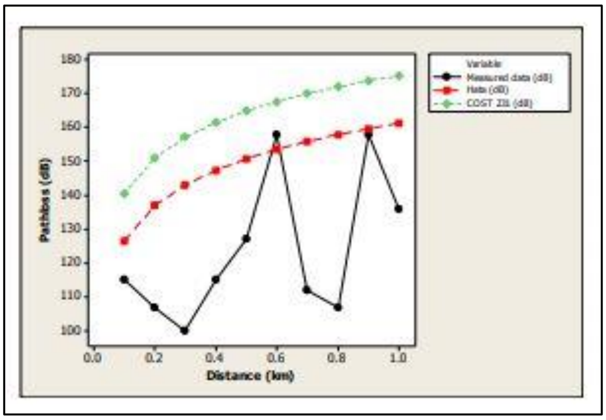

Fig. 3. Graph showing Pathloss predicted from existing models, measured Data and optimized at 1.5 GHz

IV. CONCLUSION

The research paper titled "Optimization of wireless network design for high-density environments using the Hata model" introduces a fresh methodology for refining wireless network designs in densely populated settings. The paper highlights the Hata model, a widely used mathematical framework for predicting radio wave propagation across various environments. The methodology of employing the Hata model to enhance wireless network designs within high-density contexts, such as urban areas, stadiums, and airports, is advocated.

A case study is presented, focusing on a university campus, where the Hata model was utilized to optimize the configuration of a Wi-Fi network. The outcomes demonstrated that the Hata model has the potential to enhance network performance, particularly within zones characterized by high user density. However, the paper also addresses the inherent limitations of the Hata model and suggests avenues for further research to enhance its precision.

Overall, the paper provides a robust framework for refining wireless network designs in high-density surroundings through the application of the Hata model. This approach is poised to enhance service quality and user experience within densely populated wireless networks, a consideration of growing significance in our interconnected world.

In conclusion, the exploration of "Optimization of wireless network design for high-density environments using the Hata model" underscores the critical research domain of crafting and deploying wireless networks in densely populated conditions. While the Hata model serves as a valuable tool for predicting coverage and signal strength within such contexts, its efficacy is best realized when integrated with other models and software tools, thereby ensuring a more accurate prediction.

Furthermore, the incorporation of site surveys, measurements, and multi-layer strategies is vital in refining wireless network designs within high-density environments. It is equally important to account for the influence of obstructions and interference to ensure the stipulated coverage and performance.

Ultimately, the specific requirements of each environment and the study's objectives significantly dictate the most appropriate approach for optimizing wireless network design via the Hata model. The ongoing evolution of wireless technologies and the increasing demand for wireless services in densely populated landscapes will continue to drive the demand for innovation and research in this domain.

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