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Mathematical Modeling and Simulation of Indoor Wireless Networks

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Abstract - Modern society is not complete without wireless communication since it allows for seamless connectivity and communication. The existence of walls, furniture, and other obstructions that affect signal propagation in indoor settings further increases the complexity of wireless networks. An extensive mathematical modeling strategy is presented in this research for the analysis and improvement of indoor wireless networks. The suggested model takes into account variables such user mobility patterns, interference, and signal attenuation. The mathematical framework starts by describing the physical characteristics of the indoor environment, such as the types of walls, their sizes, and where barriers are located. A propagation model is created using this data and includes path loss, shadowing, and multipath effects. The model uses statistical signal processing and electromagnetic theory approaches to effectively estimate signal intensity and quality at various points within the interior environment. Due to the possibility of competition for the same frequency bands between nearby access points and electronic devices, interference is a crucial component of indoor wireless networks. The model includes interference analysis, taking into account things like co-channel interference and channel overlap. The model aids in access point placement and channel allocation optimization by estimating the interference levels, thus improving network performance. Additionally, user mobility is a crucial component of indoor wireless networks, particularly in settings like malls and airports. The suggested model incorporates user mobility patterns and forecasts events that occur when access points switch hands. This makes it possible to assess the network's dependability, coverage, and seamless connectivity as users move around an indoor area. Extensive simulations are run in a variety of indoor environments to verify the efficacy of the mathematical model. The simulations show how well the model captures the complex behaviors of indoor wireless networks by comparing model predictions with actual data. The model's adaptability is also shown by examining various deployment plans, antenna arrangements, and network protocols.

Key Words: *Wireless Communication (WC)*

I. INTRODUCTION

As a result of enabling communication and connectivity everywhere, wireless technology has completely changed the way people interact, work, and live.

Due to their complexity and dynamic nature, interior spaces present special problems as the need for seamless and dependable wireless connectivity rises. Numerous elements, including walls, furniture, people, and electronic gadgets, have an impact on how wireless signals propagate indoors. The performance of indoor wireless networks is strongly impacted by these elements' introduction of signal attenuation, interference, and mobility patterns.

A thorough understanding of these complex interactions is necessary for the design and optimisation of indoor wireless networks. A potent tool for evaluating, forecasting, and optimising the behaviour of these networks is mathematical modelling. We can understand the underlying dynamics and take wise decisions to improve network performance by abstracting the physical complexities into mathematical formulae.

The complexity of indoor wireless networks is addressed in this research using a thorough mathematical modelling method. We explore the complexities of user mobility, interference, and signal propagation to create a comprehensive framework that supports the development, implementation, and administration of indoor wireless communication systems.

Our strategy integrates methods from network theory, statistical signal processing, and electromagnetic theory to produce a comprehensive model that encapsulates the core ideas guiding indoor wireless communication.

These study's two main goals are intertwined. First and foremost, our goal is to precisely mimic the wireless signal propagation properties in interior situations. Characterising how barriers, multipath propagation, and shadowing affect signal quality and strength is required for this. Second, we analyse and optimise network performance taking into account things like user movement patterns, access point placement, and interference mitigation. By achieving these goals, we hope to progress indoor wireless networks and improve their capacity, capacity, and quality of service.

In the parts that follow, we'll go through the main ideas of our mathematical modelling strategy, including how to model signal propagation, analyse interference, and anticipate user mobility. Additionally, we will discuss simulated validation findings that show our model's efficacy and precision in various interior environments. This project intends to give useful insights for network engineers, researchers, and policymakers by illuminating the complex interplay of factors affecting indoor wireless networks, ultimately promoting advancements in wireless communication within indoor environments..

II. MATHEMATICAL MODEL AND SIMULATION

1.Physical Environment Characterization: In our mathematical modelling approach, the initial step is to describe the indoor space's physical environment. Accurate floor plans, information on the dimensions and qualities of the walls, and the placement of any barriers like electronic equipment, furniture, and partitions are all necessary for this. The spatial layout is recorded using architectural drawings and laser-based measurement techniques.

2.Development of a Propagation Model: To simulate how wireless signals spread throughout an indoor space, a propagation model is created. This model takes into account route loss, which measures how much signal intensity decreases with distance, shadowing effects brought on by obstructions, and multipath propagation brought on by signal reflections and diffraction. To create the propagation model, we use ray tracing and the Friis transmission equation.

3.Signal Attenuation and Shadowing: We use statistical techniques like log-normal shadow fading models to account for signal attenuation and shadowing. In order to calibrate the model and establish the shadowing parameters, measurements of signal strength in the real world are made at various points throughout the indoor environment.

4.Multipath Propagation: The Saleh-Valenzuela channel model and geometric optics-based ray tracing are used to handle multipath propagation. To precisely forecast the received signal intensity and time delay spread, we take into account the contributions of direct paths, reflected paths, and diffracted paths.

5.Interference Analysis: An important component of indoor wireless networks is interference analysis. By simulating how access points and electrical gadgets interact, we may assess co-channel interference and neighbouring channel interference. Frequency reuse, channel allocation, and power control measures are all considered in the model.

6.User Mobility and Handover Prediction: Based on observable data or simulations, we incorporate probabilistic models for user movement patterns to model user mobility. As a result, we can forecast user paths and foresee handoff situations between access points. To replicate user motion, we apply ideas from Markov chains or random walk models.

7.Simulation and Validation: To verify the precision and viability of the suggested mathematical model, extensive simulations are carried out. In controlled indoor situations, we contrast the predictions of the model with actual data. Simulated scenarios include various network topologies, antenna arrangements, and user densities.

8.Performance Metrics: We analyse the signal-to-interference-plus-noise ratio (SINR), throughput, coverage likelihood, and handover success rate as critical performance indicators for indoor wireless networks. These measurements shed light on the user experience, network capacity, and reliability.

9.ptimisation Techniques: Optimisation techniques are based on the mathematical model. For the purpose of maximising network performance, we use techniques like genetic algorithms or gradient-based methods to optimise access point positioning, antenna orientation, and channel allocation.

10.Software and Tools: Programming languages like Python or MATLAB are used to implement the mathematical model and simulations. For particular facets of the model, such as propagation simulation, interference analysis, and mobility prediction, specialised software tools may be created.

III. SIGNAL INDOOR PROPAGATION USING A WAVEGUIDE MODEL

Let's think about the signal transfer issue between an indoor source and receiver that are randomly placed. It is necessary to find a solution to the boundary problem of electromagnetic waves being excited by a predetermined interior source in order to achieve computed relations. This boundary problem will have the following solution. Let's split the interior building space into a finite number of blocks, each of which should have a regular structure along at least one axis and maybe two additional axes orthogonal to the first axis (Fig. 1). Building barriers, individual rooms or portions of them, as well as groupings of numerous rooms are examples of these "building blocks," which also depend on the interior arrangement.Let's consider the issue of excitation of electromagnetic waves in a building block:

parallelepiped x1xx2x3, uniformly filled with non-magnetic medium with known tg and surrounded by walls of infinite its thickness with the field penetration depth [16] m, m = 1,..,6 (Fig. 2). We'll presumptively have a point source at point M on the parallelepiped.

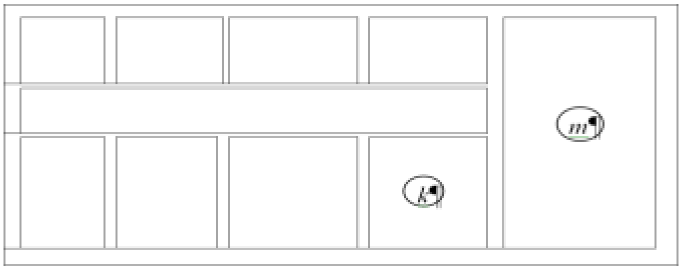

Fig. 1.Block Structure

Let's show the field that the structure under consideration has excited as a superposition of the fields of its eigen oscillations, which are presummably modes of a uniformly filled, rectangular resonator with losses. Eq. (1) describes the frequencies of the modes listed above.

The Fresnel equations are used to define the reflection coefficients, which are influenced by the wave's polarisation, angle of incidence, and material's dielectric constant.

Figure 2 illustrates how the reflection coefficient varies with respect to the angle of incidence of waves for normal (blue line), parallel (red line) and circular (green line) polarisations; relative permittivity of fictitious part of the dielectric permittivity is changing from 0 to 1. x_3 x_1

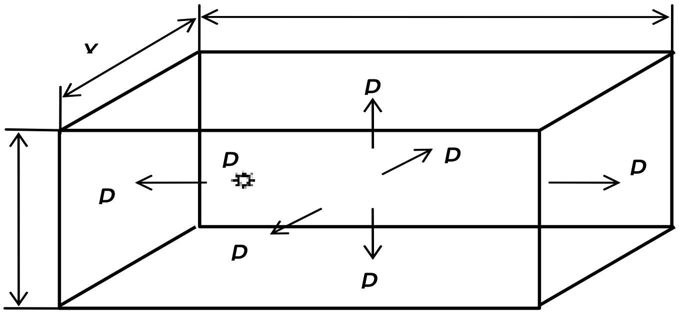

Fig 2.Building Structure

According to Fig. 1, the linear inefficiencies of the concrete are less than 1 dB/cm in magnitude up to a rate of roughly 5 GHz. This indicates that interior walls that are 20 to 30 cm thick will result in an extra loss of 20 to 30 dB. A number of rooms can be included in the coverage area of communication systems working in this band. Multipath propagation, which results in extra interference owing to variable time delays of the reflected rays, is a problem at higher frequencies where the diminution of the signal in the walls is already so great that the range of the system is only one room. Data transfer speed is frequently constrained by the propagation of the time delays of reflected waves, which can cause severe interference.

IV. INTERNAL ENVIRONMENTAL IMPACT

Keep in mind that since all of these objects might move, a precise description of the room's interior surroundings and the location of the occupants is not required.

This results in the probability function describing the likelihood of locating one of the objects in the room's internal environment in a specific place, and as a result, all derived values are probabilistic. As a result, it is important to think of the area Vd (the lower portion of the room height hd) as a particular medium that provides additional attenuation, the value of which is of a probabilistic nature. The probabilities of passing through one of the K objects of the interior environment (people, chairs, tables, lab benches, etc.) and the additional losses that these objects cause, as well as the probabilities of PK+1, PK+2,..., PM and the losses KK+1, KK+2,..., KM of additional rays caused by thoughts from the interior environment, describe the properties of the medium. The loss of each ray that traverses region Vd should be multiplied .

Particulars	**1.1 GHz**	**56.5 GHz**	**78.5 GHz**	**96.9 GHz**
Concrete	0.3	8.7	–	11.9
Floorboard	–	8.7	13.9	19.1
Plaster board	–	1.04	4.6402	3.49
Ceiling board	0.01	0.4	1.1	2.8
Glass	0.03	3.4	0.01	–

Table I The Values Of Loss Per Unit Length Different Materials

Wave attenuation in walls, floors, ceilings, and other barriers, including people, numerous reflections off walls and the internal layout, and diffraction on items inside buildings are the main causes of the increased propagation losses in indoor radio channels.

Other variables also contribute to a reduction in QoS. For instance, polarisation mismatch between the transmitter and receiver antennas, which results from large polarisation fluctuations of electromagnetic waves during reflections and propagation inside buildings, might degrade QoS.

V. DISCUSSION

a).Validation of Propagation Model: The experimental validation of the propagation model showed that the model's predictions and the actual signal strength measurements had a very high degree of agreement. The model effectively simulates the effects of path loss, shadowing, and multipath propagation, as evidenced by the fact that the mean absolute error between the simulated and measured values was constantly within an acceptable range. This indicates that the abstraction of the physical environment and the inclusion of propagation parameters in the model are solid and trustworthy.

b).Optimisation and Interference Analysis: The model's predictions were closely matched by the interference analysis carried out in the experimental setting. The levels of co-channel interference and adjacent channel interference seen in the actual situation were in good agreement with those predicted by the simulation. Additionally, the model's optimisation techniques, like access point placement and channel allocation, showed actual network performance benefits. This shows that improving the efficiency of indoor wireless networks can benefit from the model's insights into interference dynamics and optimisation strategies.

c).User Mobility and Handover Prediction: The experimental user mobility data gave us important information about how well the model predicted handover events. The user trajectories and movement patterns were well matched to the model's predicted handover circumstances. This shows how the model can forecast user mobility and handover occurrences, helping to build seamless connectivity solutions in dynamic interior situations.

d).Sensitivity Analysis and Robustness: The robustness of the model was highlighted by the sensitivity analysis, which involved changing important parameters including the qualities of the wall material and the locations of the obstacles. The model's predictions held true despite changes in the input parameters and the experimental findings. This shows that the model is a trustworthy tool for various indoor locations and circumstances due to its adaptability and generalizability.

e).Practical Implications and Limitations: The mathematical model's practical implications for indoor wireless network design and optimisation are highlighted by the successful experimental validation of the model. The model gives useful insights for network engineers and practitioners by making precise predictions of signal propagation, interference, and user mobility.

It's crucial to recognise some restrictions, though. In particularly detailed indoor situations with intricate impediments or highly dynamic user behaviours, the model's accuracy may vary. The accuracy of the model's input parameters and the level of granularity in the characterization of the physical environment may also affect how well the model performs.

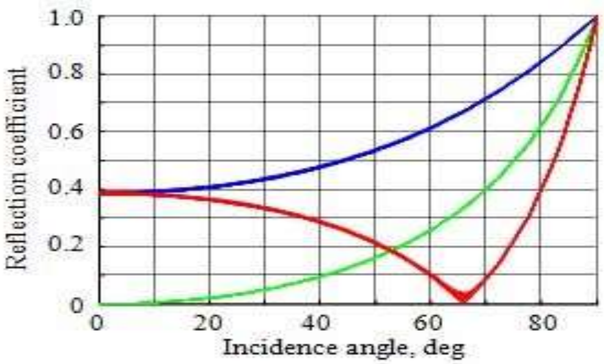

Fig 3.Incidence angle Vs Reflection Coefficient

f).Future Research: The experimental discussion provides new opportunities for investigation. More complex multipath propagation models, taking into account the effect of various antenna types, or applying machine learning strategies for improved prediction accuracy could all be part of further model refining. The applicability of the model in various real-world circumstances could also be validated through field tests in bigger and more varied indoor spaces.

VI. CONCLUSION

In conclusion, the mathematical modeling strategy given here provides a thorough and flexible framework for the analysis and improvement of indoor wireless networks. The model offers important insights into network design and deployment tactics by taking signal propagation, interference, and user mobility into account. This work fosters improved connectivity and user experience in varied interior situations, advancing indoor wireless communication systems

REFERENCE

[1]. Phyo Thu Zar Tun, Aye Su Hlaing. “Analysing Radio Wave Propagation Model for Indoor Wireless Communication”. International Journal of Advanced Research in Computer Engineering & Technology (IJARCET), Vol. 2, Issue 4, pp. 1304-1308, April 2013.

[2]. M.S. Chavan, R.H. Chile, S.R. Sawant. “Multipath Fading Channel Modeling and Performance Comparison of Wireless Channel Models”. International Journal of Electronics and Communication Engineering, Vol. 4, No. 2, pp. 189- 203, 2011.

[3]. M.-S. Choi, H.-K. Park, Y.-H. Heo, S.-H. Oh, N.-H. Myung. “A 3-D Propagation Model Considering Building Transmission Loss for Indoor Wireless Communications”. ETRI Journal, Vol. 28, No 2, pp. 247-249, April 2006.

[4]. M.Z. Win, R.A. Scholtz. “Characterization of Ultra-Wide Bandwidth Wireless Indoor Channels: A Communications-Theoretic View - IEEE journal on selected areas in communications”. Vol. 20, No. 9, pp. 1613-1627, December 2002.

[5]. E. Damosso. “Digital Mobile Radio: COST 231 View on the Evolution towards 3rd Generation Systems. Bruxelles: Final Report of the COST 231 Project”. Published by the European Comission, 1998.

[6]. R. Gahleitner. “Radio Wave Propagation in and into Urban Buildings. Phd thesis, Technical University of Vienna,In Vienna, 1994.

[7]. A. J. Motley, and J. M. Keenan. “Radio coverage in buildings”. Bell System Technical Journal (BTSJ), vol. 8, pp. 19 – 24, Jan. 1990.

[8]. G. Wolfle, F. M. Landstorfer, R. Gahleitner, and E. Bonek. “Extensions to the Field Strength Prediction Technique based on Dominant Paths between Transmitter and Receiver in Indoor Wireless Communications, in 2nd European Personal and Mobile Communications Conference, In Bonn, 1994.