INDOOR RADIO WAVE PROPAGATION WITH RAY TRACING TECHNIQUE

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Abstract- Wireless Local Area Networks (WLANs) are nowadays the most widely used indoor wireless networks that found a large variety of wireless applications. The performance of 802.11b wireless LANs is well understood for indoor environments. The purpose of this study is to present a new radio wave propagation model especially for L-shape of corridors based on original free space model using ray tracing technique. Using this model, the received signal strength values can be estimated with respect to the building parameters and additional reflecting rays from the side walls, opposite wall, floor and roof. All possible experiments are carried out at a carrier frequency range of 2.4GHz with the help of TP-LINK TL-WR1043N router with 8dBi omni-directional antenna, and 3dBi laptop with signal analyzing software called inSSIDer in indoor Non-line-of-sight (NLOS) scenarios. This proposed system presents the comparison results of experimental data and estimating data with the help of Matlab programming language.

Index Terms- 802.11b Wireless LANs, radio wave propagation, free space model, ray tracing technique, Non-line-of-sight (NLOS).

I. INTRODUCTION

Recently, due to the increasing demand for indoor wireless application such as wireless LAN, there is need for measurement and sufficient signal propagation prediction for these wireless systems. Wireless Local Area Networks (WLANs) provide network services where it is difficult or too expensive to deploy a fixed infrastructure. WLANs can coexist with fixed infrastructure to provide mobility and flexibility to users [1].

WLANs operate mainly in an indoor environment. Indoor channels are highly dependent on the placement of walls and partitions within the building. It is very difficult to predict how radio wave travels in an indoor environment because these waves often do not directly reach to the receiver due to obstacles found in the indoor environment. A signal travels from transmitter to receiver over a multiple-reflection path; this phenomenon is called multipath propagation and causes fluctuations in the receiver signal's amplitude and phase. The sum of the signals can be constructive or destructive [2-4].Therefore, the characteristics and patterns of radio wave propagation are needed to analyze in order to achieve an optimized wireless system.

The purpose of this paper is to estimate the received signal strength values at a carrier frequency range of 2.4 GHz. The experimental modeling for the indoor radio wave propagation is presented in this paper. The experimental data are compared to the predicted data according to the proposed models taking into consideration of the wall reflection and reflection coefficient. Based on these comparisons, the proposed model can be recommended and verified using measured and well known models with respect to the various experimental strategies.

II. INDOOR RADIO WAVE PROPAGATION

Radio wave propagation prediction is a fundamental prerequisite for planning, analysis and optimization of radio networks. For instance, coverage analysis, interference estimation or channel and power allocation rely on propagation predictions. Unlike wired channels that are stationary and predictable, radio channels are extremely random. In addition, electromagnetic wave propagation characteristics vary significantly over different frequency bands. Due to multiple reflections from various objects, the electromagnetic waves travel along different paths of various lengths. The interaction between these waves causes multipath fading at a specific location, and the strength of the wave decreases as the distance between the transmitter and receiver increases. Because multipath disturbances are hard to estimate, there are necessary signal strength estimations in indoor wireless communication. Therefore, it is vital to thoroughly understand the propagation characteristics and to develop a channel model for the wireless communication system. There are many propagation models to estimate signal strength and to obtain the optimum signal strength between transmitter and receiver. The basic radio wave propagation models in the environment are free space model and two ray model [4].

A. Free Space Model

The free-space propagation model is an ideal model used to compute the received signal strength when there is a direct LOS between a transmitter and a receiver unit, placed at distance d between them, without any obstacles near the line of sight [5]. The power received in free space (Pr) is given by the Friis transmission equation (1) and (2) in dB.

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 (d)^2 L} \quad (1)$$

$$L(d) = 32.44 + 20\log(f) + 20\log(d) \quad (2)$$

Where, Pt and Pr are the transmitted and received power, Gt and Gr are the transmitting and receiving antennas gains respectively, L is the path losses between antennas, λ is the wavelength in meters, and d is the Transmitter-Receiver separation in kilometers, f is the carrier frequency expressed in MHz [6].

B. Reflection Coefficient

The nature of reflection varies with the direction of polarization of the E-field. The reflection coefficients for vertical and horizontal polarization, Rcv and Rch, respectively are presented in equation (3) and (4).

$$Rc_h = \frac{\sin\Theta - \sqrt{\varepsilon_c - \cos^2\Theta}}{\sin\Theta + \sqrt{\varepsilon_c - \cos^2\Theta}} \quad (3)$$

$$Rc_v = \frac{\varepsilon_c \sin\Theta - \sqrt{\varepsilon_c - \cos^2\Theta}}{\varepsilon_c \sin\Theta + \sqrt{\varepsilon_c - \cos^2\Theta}} \quad (4)$$

Where, is grazing angle, is complex dielectric constant, is the dielectric constant of reflection surface, is the conductivity of reflection surface and is wavelength [7]. In this study, the values of reflection factor were calculated depending on the type of reflective materials and various distances between transmitter and receiver. The Table I shows the values of relative permittivity and conductivity depending on the type of materials working at 2.4 GHz.

TABLE I: RELATIVE PERMITTIVITY AND CONDUCTIVITY OF VARIOUS MATERIALS

Materials	Relative Permittivity ε_r	Conductivity σ
Glass	5.70	0.073
Concrete	4.12	0.014
Dry Brick	5.20	0.01
Wood	4.75	0.05

III. DEVELOPMENT OF INDOOR PROPAGATION MODEL

The objective of this research is to develop indoor radio wave propagation model of L-shape corridor based on free space model with consideration of reflective rays from the ground, roof and side walls. Fig.1 shows the system block diagram of proposed model.

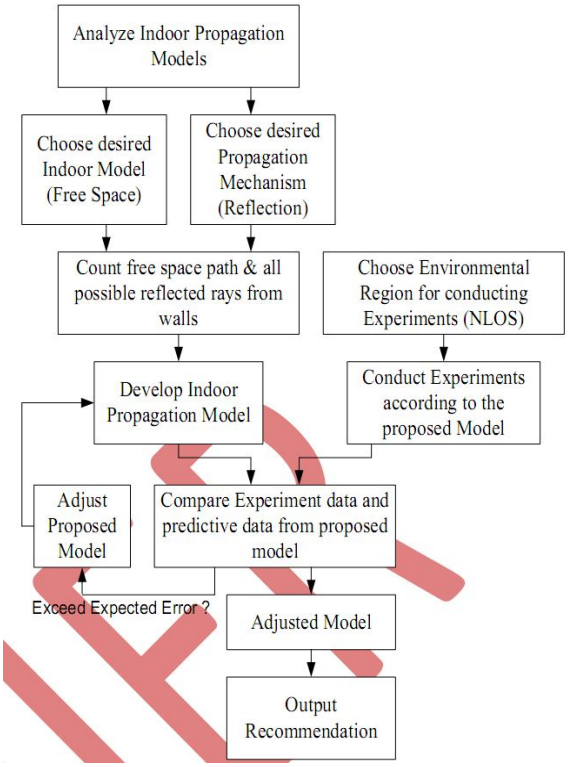


Fig.1: System Block Diagram of Proposed Mode

TABLE II: COMPARISON TABLE OF EFFECTIVE DISTANCE VALUES BETWEEN ANTENNAS

No	Distance Index	Mathematical Expression
1	d_0	$\sqrt{(a/2)^2 + (d + b/2)^2}$
2	d_1	$\sqrt{(3a/2)^2 + (d + b/2)^2}$
3	d_2	$\sqrt{(a/2)^2 + (d + 3b/2)^2}$
4	d_3	$\sqrt{(3a/2)^2 + (d + 3b/2)^2}$
5	d_4	$\left[\sqrt{(2h_c - 2h_t)^2 + (d_0)^2} + \sqrt{(2h_c)^2 + d_0^2} + \sqrt{(4h_c - 2h_t)^2 + (d_0)^2} + \sqrt{(4h_c)^2 + d_0^2} + \sqrt{(6h_c - 2h_t)^2 + (d_0)^2}\right] = \sum_{j=1}^{n}\left[\sqrt{(2jh_c - 2h_t)^2 + d_0^2} + \sqrt{(2jh_c)^2 + d_0^2}\right]$
6	d_5	$\left[\sqrt{(2h_c - 2h_r)^2 + (d_0)^2} + \sqrt{(2h_c)^2 + d_0^2} + \sqrt{(4h_c - 2h_r)^2 + (d_0)^2} + \sqrt{(4h_c)^2 + d_0^2} + \sqrt{(6h_c - 2h_r)^2 + (d_0)^2}\right] = \sum_{k=1}^{n}\left[\sqrt{(2kh_c - 2h_r)^2 + d_0^2} + \sqrt{(2kh_c)^2 + d_0^2}\right]$

In optimization of new indoor radio wave propagation model, the ray components along the corridor are needed to trace and manipulate all possible geometrical dimensions. Therefore, the effective distance values for all possible rays along L-shape corridor are calculated for this proposed system. The Table II shows the calculated distance values between antennas depending on six rays occurred in L-shape hallway.

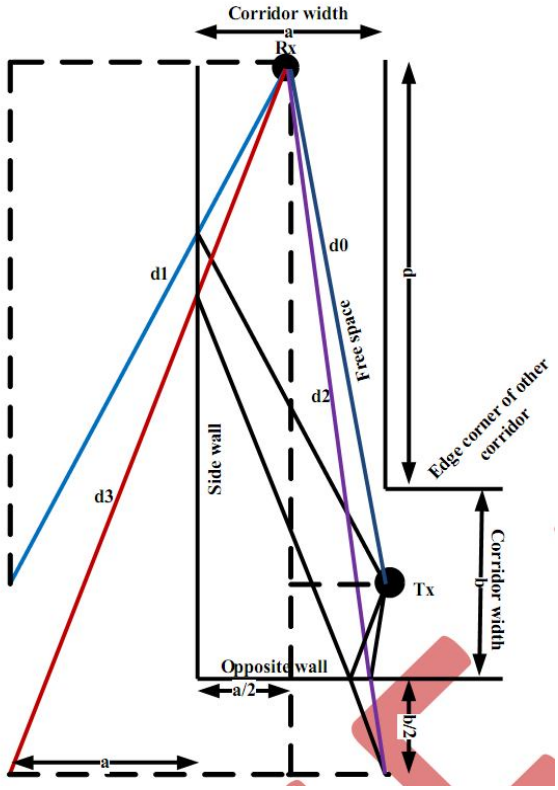


Fig.2: The reflective rays from the side walls and opposite walls while the receiver located at center point

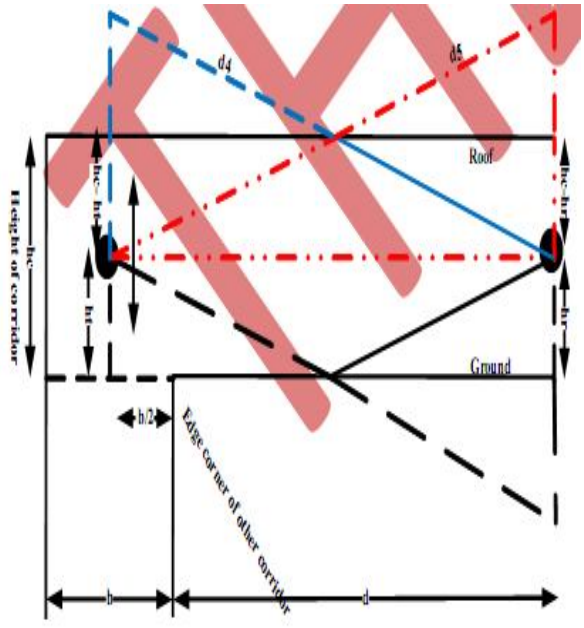


Fig.3: Free space and the reflective rays from the ground and roof

In creating indoor radio wave propagation model along the L-shape corridor, such as corridor (1) and (3) of main building in Mandalay Technological University, not only the free space path but also all possible reflective rays from the ground, roof and side walls are taken into consideration as shown in Fig.2 and Fig.3 Moreover, maximum five reflective waves are also considered in ground and roof waves for this research work.

Finally, the mathematical formula for the proposed radio wave propagation model can be shown as follows:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 (d_f)^2} \tag{5}$$

Where, df is the effective distance values. In this research work, the values of effective distance can be shown by equation (6) and the value of reflection factor Rf varies according to the equation (7).

$$(d_f)^2 = {d_0}^2 \times R_{f_0} + \sum_{i=1}^{3} n {d_i}^2 R_{f_i} + \sum_{j=1}^{n} \left[\begin{array}{l} (2j-1) R_f \sqrt{(2jh_c - 2h_t)^2 + {d_0}^2} + \\ 2jR_f \sqrt{(2jh_c)^2 + {d_0}^2} \end{array} \right] + \sum_{k=1}^{n} \left[\begin{array}{l} (2k-1) R_f \sqrt{(2kh_c - 2h_r)^2 + {d_0}^2} + \\ 2kR_f \sqrt{(2kh_c)^2 + {d_0}^2} \end{array} \right] \tag{6}$$

$$R_f = Rc_h \times \frac{\sqrt[1/3]{h_t \times h_r}}{(h_c \times a)} \tag{7}$$

Where, n is the numbers of reflection time to wall, Rf0 is 1 (reflection factor for free space), Rch is reflection coefficient for horizontal polarization, a is width of corridor (1) and corridor (3), ht and hr are heights of transmitter and receiver respectively and hc is the height of each corridor.

IV. EXPERIMENTAL PROCEDURES

This paper briefly describes the experimental set up used for propagation measurements. All the experiments have been carried out at Non-Line-of-Sight (NLOS) environment of complex building along all L-shape corridors in main building of Mandalay Technological University, the Republic of the Union of Myanmar.

In all measurements, TP-Link TL-WR1043N router with 8dBi omnidirectional antenna was used as transmitter and LAPTOP 3dBi with Microsoft WINDOWS 7 operating system was used as receiver. The wireless signal analyser software called inSSIDer was installed in this laptop in order to survey received signal strength. Carrier frequency was 2.4GHz with 20dBm transmitted power. At first, the placement of transmitter was considered to conduct all experiments. The placement of transmitter was stable at the centre of corridor, when the heights of

transmitter and that of receiver were equal or not equal. The height of receiver was also constant with 1.1m, when the height of transmitter was 1.1m or 1.6m. To conduct all experiments along L-shape form of hallway, the experimental points are marked as 1 meter from the transmitter for each point and moved the receiver to each experimental point along the corridor to the end of it. All experiments were carried out at different days and times. In all experiments, the receiver is rotated to four sides of it at each point in order to get the average values of received signal strength. And then, all experimental data were used to draw received signal power with the help of Matlab programming language.

V. BUILDING LAYOUTS

All experiments were conducted at the main building of Mandalay Technological University, the Republic of the Union of Myanmar.

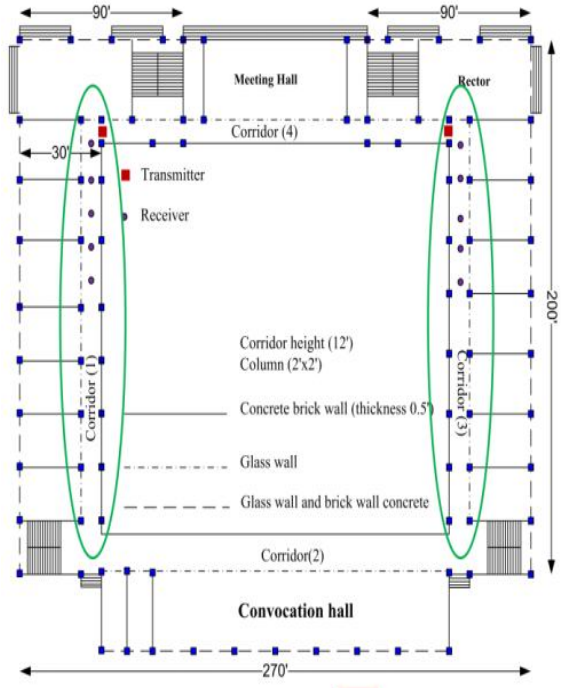


Fig.4: Building Layout of experimental region

All building materials are constructed with brick wall and concrete type floors, and glass windows with wood frame doors. Although it is constituted with three floors of four corridors and two floors of 1 corridor, all experiments are conducted in L-shape form of two corridors, namely corridor (1) and corridor (3) at each floor. While conducting all experiments, all doors and windows are closed and people are restricted not to pass in this experimental region. So, opened and closed position of doors, and the effect of walking people between antennas are not considered in this proposed system. The height between two floors is 4 meters. The width of corridor 1 and 3 is 2.67m and that of corridor 4 is 3m. There is free space outdoor compound area at the middle of the building as shown in Fig. 4.

VI. EXPERIMENTAL RESULTS

The propagation of Wi-Fi signals is governed by the properties of materials in the propagation medium. All measurement values of received signal strength were collected, and then stored at the Matlab database. When optimizing indoor radio wave propagation, the measured results from Matlab database and Equation (5) are used to describe the accuracy of proposed model with the help of MatLab Programming Language.

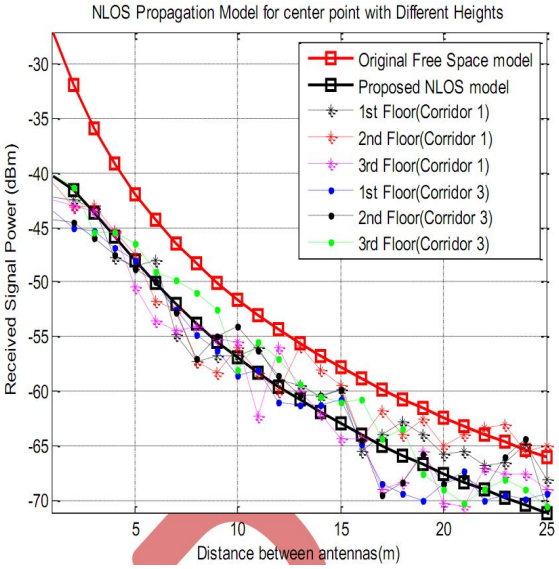


Fig.5: The comparison results of proposed model, original free space model and experimental data for corridor (1) and (3)

Fig.5 shows received signal power (dBm) versus distance (meters) between transmitter and receiver for all floors of corridor (1) and (3) of the experimental region when conducting the experiment with different heights of transmitter and receiver located in centre point.

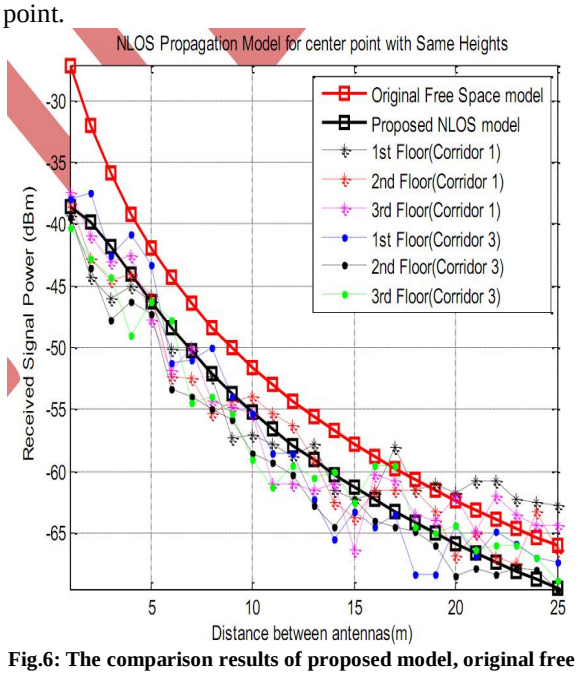


Fig.6: The comparison results of proposed model, original free space model and experimental data for corridor (1) and (3)

Fig.6 shows received signal power (dBm) versus distance (meters) between transmitter and receiver for all floors of corridor (1) and (3) of the experimental region when conducting the experiment with same heights of transmitter and receiver located in center point. After conducting some experiments according to the proposed model, the comparison results are illustrated in Fig.5 and Fig.6 It is shown that the predictive data are almost identical with experimental data in all corridors. Experimental data with various heights and positions of receiver are more accurate from the start point to the last point. It shows that this proposed model can be recommended to the distance value of 25 meters from the corner of the corridor.

CONCLUSIONS

The NLOS radio wave propagation model with different reflective rays from all possible side walls is developed based on ray tracing technique. The results from predictive data according to this proposed model are compared with the experimental data.All possible reflective rays are considered, so the reflection factor values due to these reflective points are also calculated in this proposed model. There are some concrete columns (0.67m x0.67m) at the side of opened corridors. As the reflective rays from these columns were not considered in this system, there are some fluctuation points in the experimental data due to these columns. Therefore total path losses are more than that in original free space model. So the curve according to the proposed model is lower than that according to the original free space model. In the results of proposed model, the results of the experiments and predictive data from this model are well coincided with each other. Therefore, the proposed model can be applied in all type of indoor radio wave propagation to estimate received signal strength using such building type. Moreover, the wireless designer can easily estimate the received signal values according to this proposed model with respect to the distance between antennas and the height of transmitter. As for system limitation, all reflective walls are assumed as the brick wall of building, so it is also needed to calculate depending on various types of wall. As for further works, the different types of wall at the different building are also needed to conduct in various experiments.

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