Analysing of Indoor LOS Radio Wave Propagation Model Using Ray Tracing Technique

Kyi Zar Oo, Aung Myint Aye

Abstract— **The demand for wireless communications systems is ever increasing in all the human life activities. In this paper, a new indoor LOS propagation model based on two ray model and reflection coefficient depending on various types of building materials and designs at 2.4 GHz. The objective of this paper is to estimate the path loss values at a frequency of 2.4 GHz using ray tracing technique. The experimental path loss modelling for the indoor radio wave propagation is presented in this paper. All experiments are conducted in two building designs: opened corridor and closed corridor types. The estimating of received signal strength according to the indoor environment can be manipulated by using proposed model. The comparison results of experimental data and estimating data from the proposed system are shown in different methods with the help of MatLab programming language. TP-Link TL-WR1043N router with 8dBi omni-directional antenna, and 3dBi laptop with signal analysing software called InSSIDer are used when conducting all experiments.**

Index Terms— **indoor LOS propagation, Reflection coefficient, Two ray model, WLAN.**

I. INTRODUCTION

A WLAN (wireless local area network) allows mobile users to connect to a LAN through a wireless radio frequency (RF) connection. This technology provides connectivity also where wiring is impossible or costly. The performance of wireless communication systems depends on the radio wave transmission path between the transmitter and the receiver. Wireless system designers have to solve the problems, including reflection, diffraction and scattering of the transmitted signal when communication takes place[1].

In wireless mobile communications, the electromagnetic waves often do not directly reach to the receiver due to obstacles that block the line of sight path. 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 [3].

The experimental data are compared to the predicted data according to the proposed models taking into consideration of the ground 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[5].

II. INDOOR RADIO WAVE PROPAGATION

Radio wave propagation describes a significant role in the performance of radio systems. Radio waves, i.e. electromagnetic waves, are propagated in a radio channel that is understood as the radio path between the transmitter and the receiver with the help of antennas. The radio wave communication path consists of a variable environment and various obstacles that affect the radio waves transmission path when propagating the signal. As there are no obstacles that cause attenuation in the radio path, fixed radio wave communication systems are planned in such a way. This is called line-of-sight (LOS) situation [2]. LOS situation is often impossible to maintain while using mobile radio systems. In such environments, there are usually many objects and reflecting surfaces in the radio path that affect the radio wave propagation. Therefore, such a situation is called non-line-of-sight (NLOS). The basic radio wave propagation models in the environment of LOS are free space model and two ray model [3].

A. Free Space Model

The free space model provides a measure of path loss as a function of Tx-Rx separation when the transmitter and receiver are within LOS range in a free space environment [4]. The model is given by (1) which represents the path loss as a positive quantity in dB:

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

$$L(d) = 32.44 + 20\log(f) + 20\log(d) \tag{2}$$

Where P_t and P_r are the transmitted and received power, G_t and G_r 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 Tx-Rx separation in kilometres, f is the carrier frequency expressed in MHz. When value of antennas gains are assumed as unity, these gains become as $G_t = G_r = 1$ [5].

B. Ground Reflection Two Ray Model

In a mobile radio channel, a single direct path between the base station and a mobile is seldom the only physical means for propagation, and hence the free space propagation model in equation (1) is in most cases inaccurate when used alone. The two ground reflection model shown in Fig. 1 is a useful propagation model that is based on geometric optics, and considers both the direct path and a ground reflected propagation path between transmitter and receiver. [8].

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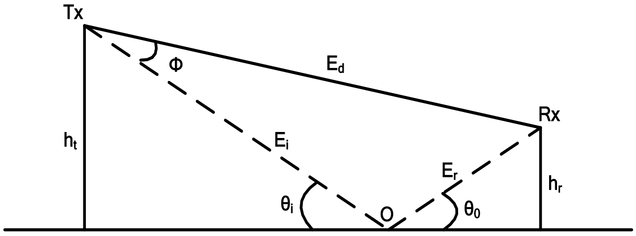


Fig.1. Geometrical view of the two ray ground reflection model

This model has been found to be reasonably accurate for predicting the large-scale signal strength over distances of several kilometers for mobile radio systems that use tall towers (heights which exceed 50 m), as well as for line of sight LOS microcell channels in urban environments [7,8].

The reflection angle of the radio wave is the same as the incidence angle. The reflection loss depends on the electrical properties of the medium on both sides of the reflecting surface, the frequency used, the incidence angle, and the polarization of the radio wave [7].

The two ray ground reflection model is a simple, but useful model for predicting large scale signal strength not only over long intervals but also over short intervals especially in LOS environment. Ground reflection occurs when one normally has a LOS.

Fig. 1 shows the geometry of the two ray model in the case of horizontal polarization. To find out the total field strength at the receiving point Rx, it must first seek a formula for the phase difference ϕ between the direct field E_d, and the ground reflected field E_r. Since the phase difference ϕ obviously depends on the difference in geometrical path lengths in Fig. 1, and imaging, yields: the phase difference then becomes as follow after some mathematical calculations are taken place[2].

$$\phi = \Delta d \frac{2\pi}{\lambda} = \frac{4\pi h_t h_r}{\lambda d}$$

Here ϕ is the phase delay due to the path length difference, and Δd is the different value between the direct path and reflected path, and ht and hr are heights of transmitter and receiver. But there is also another phase delay which occurs at the point of reflection O in Fig. 1. The reflection coefficient, $R_c = |R_c| e^{j\psi} \approx 1 e^{j\pi} = -1$

$$E_{tot} = E_d + E_r = E_d(1 + R_c e^{j\phi}) \approx E_d(1 - e^{j\phi}) \quad (3)$$

In this above equation, the first portion E_d is the direct field value and $E_d R_c e^{j\phi}$ is the ground reflected field value. After explanation of some mathematical computing, the received signal strength at the point of receiver becomes as follow:

$$P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4} \quad (4)$$

C. Reflection Coefficient

The nature of reflection varies with the direction of polarization of the E-field. The reflection coefficients for vertical and horizontal polarization, Rc_v and Rc_h, respectively, are presented in (5) and (6).

$$Rc_v = \frac{\varepsilon_r \sin\theta_i - \sqrt{\varepsilon_r - \cos^2\theta_i}}{\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}} \quad (5)$$

$$Rc_h = \frac{\sin\theta_i - \sqrt{\varepsilon_r - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}} \quad (6)$$

Where θ_i is the grazing angle, ε_r is the relative permittivity of the materials. The values of reflection coefficient vary from +1 to –1 depending on the type of reflective materials [6]. The Table I shows the values of relative permittivity depending on the type of materials working at 2.4GHz.

Table I. Relative Permittivity of various materials

Materials	Relative Permittivity
Glass	5.9
Concrete	4.5
Dry Brick	4
Dry Wall	2.8
Wood	1.8

The following Fig. 2 shows the theoretical values of reflection coefficient according to the various values of reflective angle and types of materials.

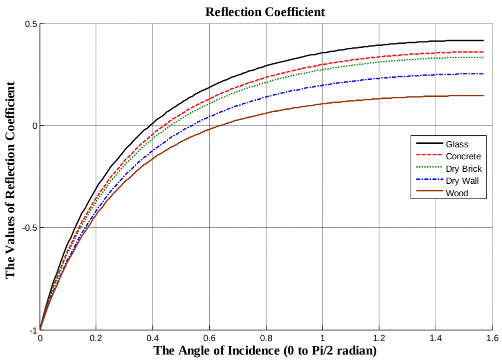


Fig. 2. The values of reflection coefficient for various wall types

III. ANALYSING OF INDOOR LOS RADIO WAVE PROPAGATION MODEL

In creating new indoor radio wave propagation model, the ray components along the corridor are needed to trace and to choose all possible geometrical dimensions. Of course two ray propagation model is intended to use in large scale environment where other reflective paths are impossible expect ground reflective ray. In the case of indoor radio wave propagation along the corridor of building, the free space path, reflective path from the ground, side walls and roof are taken into consideration. Based on two ray model, the additional paths from the side walls and roof wall are also important to compute as shown in Fig. 3(a), and 3(b). There are many additional reflective points such as O_1, O_2 and O_3.

When using two ray model in indoor environment, the proposed model based on two ray model is needed to develop. Finally, the mathematical expressions are justified as follows:

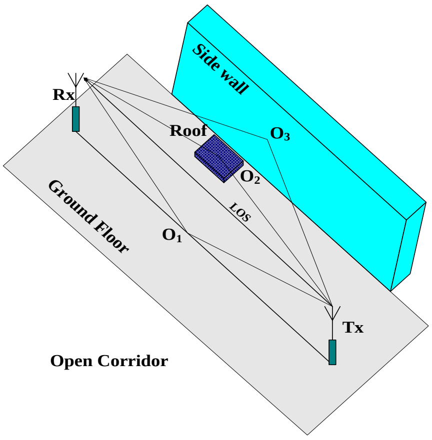
$$\begin{aligned} E_{total} &= E_d + E_{r1} + E_{r2} + E_{r3} + E_{r4} \\ &= E_d + E_d Rc_1 e^{j\phi 1} + E_d Rc_2 e^{j\phi 2} + E_d Rc_3 e^{j\phi 3} + E_d Rc_4 e^{j\phi 4} \\ &= E_d \left(1 + Rc_1 e^{j\phi 1} + Rc_2 e^{j\phi 2} + Rc_3 e^{j\phi 3} + Rc_4 e^{j\phi 4}\right) \qquad (7) \\ &= E_d \left(1 + Rc\left(e^{j\phi 1} + e^{j\phi 2} + e^{j\phi 3} + e^{j\phi 4}\right)\right) \\ when\ &\left(Rc_1 = Rc_2 = Rc_3 = Rc_4\right) \end{aligned}$$

Where Rc_1, Rc_2, Rc_3 and Rc_4 are the values of reflective coefficients for the ground floor, side walls, and roof wall respectively, ϕ_1, ϕ_2, ϕ_3 and ϕ_4 are also the values of phase differences for these four paths. If the values of reflection coefficients are assumed as -1, the total electric field becomes

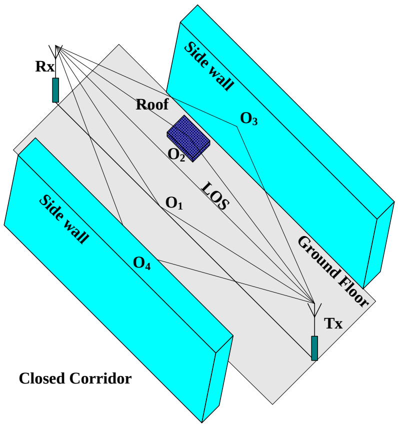
$$E_{total} = E_d\left(1 - e^{j\phi 1} - e^{j\phi 2} - e^{j\phi 3} - e^{j\phi 4}\right) \qquad (8)$$

The reflective rays from the side walls and the roof wall are considered to be equal ($\Phi=\Phi_1=\Phi_2=\Phi_3= \Phi_4$) with the ray reflective from the ground in two ray model, the proposed model can be minimized as:

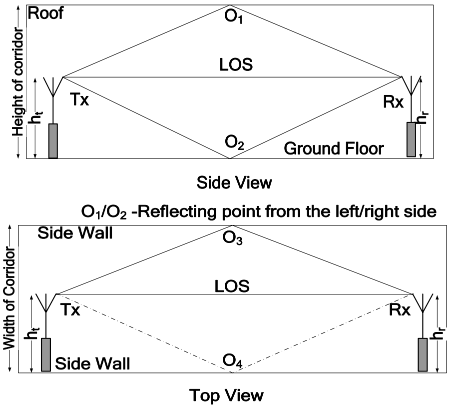
$$E_{total} = E_d\left(1 - 4e^{j\phi}\right) \qquad (9)$$



(a) 3D view (opened corridor)



(b) 3D view (closed corridor)



(c) 2D view

Fig.3. Ray tracing points of view in a corridor:

IV. EXPERIMENTAL REGION

All experiments are conducted in different building structures according to the proposed model specification. There are two types of experiments such as opened corridor and closed corridor depending on the proposed model. At the main building of Mandalay Technological University, the Republic of the Union of Myanmar, all opened type corridors are used to conduct experiments. There are three floors of 3 corridors and two floors of 1 corridor called corridor (2). To do conduct required experiments, all corridors are named as corridor (1), corridor (2), corridor (3) and corridor (4) as shown in Fig. 4. Among them, experimental results of proposed model and corridor (1) and (2) are shown in Fig. 7-10. When conducting experiments in closed type corridor, the department of Electrical Power Engineering and Hostel for postgraduate students are used to participate. These types of buildings are single floor and three floor types.

Fig. 4. Building layout of experimental regions

All building materials are constructed with brick wall and concrete type floors, and glass windows with wood frame doors are used. While conducting all experiments, all doors are closed, and people are forced to restrict walking in these experimental regions. So, opened and closed position of doors, and the effect of walking people between antennas are not considered in this proposed system.

V. EXPERIMENTAL SETUP

The experimental set up used for propagation measurements is briefly presented in this paper. LAPTOP with Microsoft windows based WINDOWS 7 operating system was used as a receiver. The Laptop with wireless signal analyser software called inSSIDer was used as a receiver and TP-Link TL-WR1043N router with 8dBi omnidirectional antenna, medium transmitted power level 10 dBm, and carrier frequency 2.4 GHz is used as a transmitter in all experiments. The experiment was carried out in the different corridors in the same floor and different corridors in different floors of the Mandalay Technological University.

The placement of transmitter was stable at the centre of each experimental corridor, and the heights of transmitter were varied as shown in experimental record photos of Figure. 5 and according to the experimental schedules shown in Fig. 6.There are four strategies of receiver's placements when conducting all experiments. The first two placements of receiver are at the centre of each corridor when the heights of transmitter and that of receiver were not equal and equal.

The second two placements of receiver are at one meter from the side wall of each corridor to the centre of that corridor as shown in Fig 6. At first, all experimental points are marked on each corridor floor as 1 meter from the transmitter until the end of specific corridor. To conduct all experiments for examining LOS signal attenuation, the movement of receiver is at the predefined marked point on the specific corridor. There are four values when conducting experiment with Laptop at each point with respect to the face sides of Laptop.

Fig. 5. The placements of transmitter and receiver

Moreover, to get the mean values of received signal strength under different temperature and humanity, all experiments were carried out at different days and times. After that, all data from different days and values are calculated as the average values.

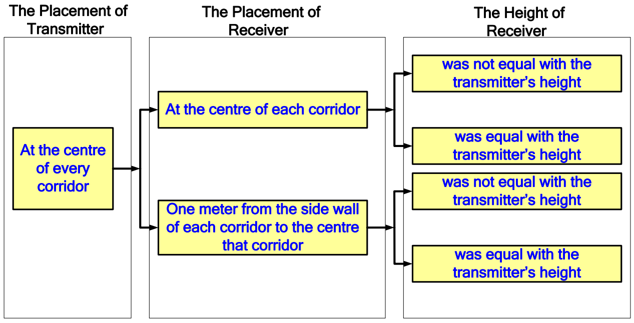


Fig. 6. The placements of transmitter and receiver

VI. EXPERIMENTAL RESULTS

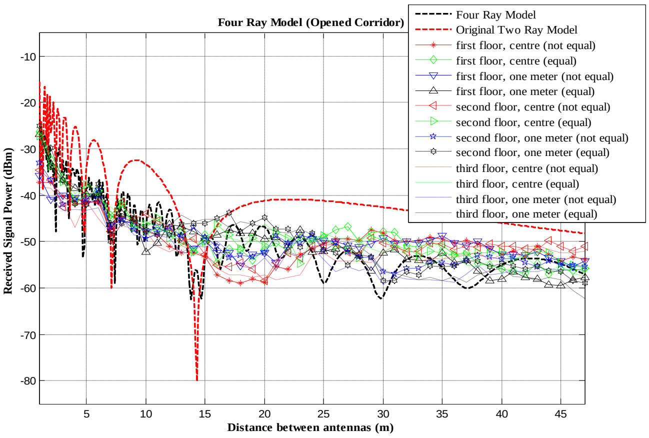


Fig. 7. The comparison results of proposed four ray model, original two ray model and experimental data when conducting at three floors of corridor (1), the width of corridor is 2.7m and the height of corridor is 4m

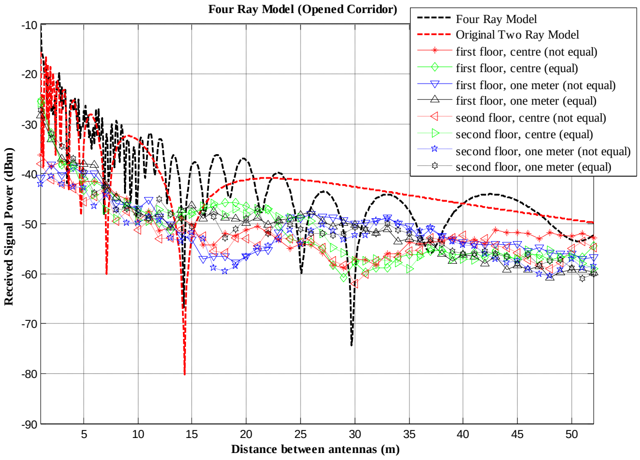


Fig. 8. The comparison results of proposed four ray model, original two ray model and experimental data when conducting at two floors of corridor (2) the width of corridor is 3.33m and the height of corridor is 4m

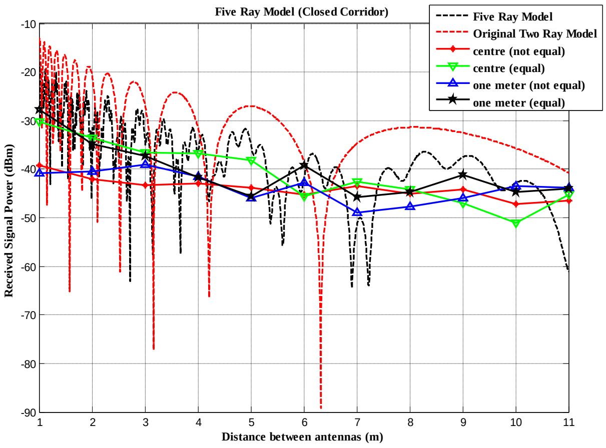


Fig. 9. The comparison results of proposed five ray model, original two ray model and experimental data when conducting at two floors of corridor (2) (EP dept), the width of corridor is 2.3m and the height of corridor is 3.33m

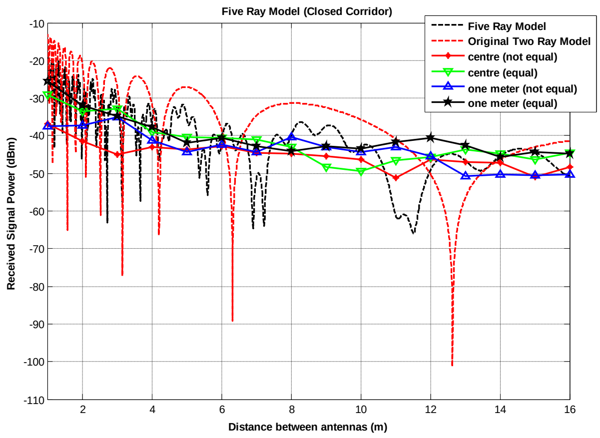


Fig. 10. The comparison results of proposed model, original two ray model and experimental data when conducting at two floors of corridor (2)(Hostel), the width of corridor is 1.7m and the height of corridor is 4m

All measurement values of received signal strength were collected, and then stored at the Matlab database. As the lengths of corridor vary, there are different measuring points at each corridor. When analysing experimental data, the collecting data from Matlab database are used to manipulate with the help of MatLab Programming Language. The different colours and line types show the different values of received signal strength, the different floors and the different corridors. In the exponential values of proposed model, all imaginary values are ignored when plotting the graphs. The experimental results and comparison results of experimental data from all corridors of all floors, data from proposed model, and the original data of two ray model are shown in Fig. 7-10. The vertical values of curve show the received signal strength level in dBm, and the horizontal values show the distance in meters between the transmitter and receiver. When analysing the received signal strength according to the height of transmitter and distance between them, the height of transmitter is varied from 1m to 10m with omnidirectional antenna.

VII. CONCLUSIONS

The two new proposed indoor radio wave propagation models based on two ray model are presented in this system. The original two ray model is constructed to be used in large scale propagation region called outdoor propagation environment. By optimizing it, the proposed model was developed, and can be used in indoor propagation environment. All possible reflective rays are considered, so the attenuation path loss values due to these reflective points are also considered in this proposed model. Therefore, total path losses according to the proposed two new models are more than that in original two ray model. In this system, there are two kinds of experiments are conducted in two categories. Many experiments according to the proposed models are conducted with different building types, lengths of corridor, and types of corridor, width of corridor and propagation parameter. In the results of proposed opened four ray model, the results from the experiments and predictive data from this model are well coincided each other. The received signal strength according to the four ray model is more accurate of 2-3 dB that the original two ray model. When conducting and analysing the proposed five ray model, the experimental results and predictive data according to the proposed are almost identical with each other. For estimating of received signal strength with the help of this ray tracing technique will be a useful tool to aid in manipulating the signal level not only in indoor environment but also in outdoor environment.

VIII. SYSTEM LIMITATION

Many experiments were conducted according to their different types of building and geometrical configurations. But, there may be some windows or doors in the region of experiments. So, the maximum heights of transmitter and receiver do not reach to the lower level of glass windows. The different types of wall at the different building are also used in conducting various experiments. All the values of reflection coefficients are assumed the same with the values of brick walls in this proposed system, so it is also needed to calculate depending on various types of wall. Other types of routers, or signal generator, or signal analyser machines, or analyser software will be used to compare with these results in next future works.

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