International Journal of Computer
(IJC)
ISSN 2307-4523 (Print & Online)

http://ijcjournal.org/

Development of Radio Wave Propagation Model in Indoor Non-Line-of-Sight (NLOS) Scenario

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Abstract

To improve the performance of an indoor WLAN, it is very important to estimate specific received signal strength based on experimental and predicting data. As the design of building layouts and constructed building materials modernize and are complex, it is difficult to estimate the received signal strength values according to those building structure. For this reason, this research develops a new radio wave propagation model for indoor Non-Line-of-Sight (NLOS) scenarios with the help of TP-LINK router .In order to develop the proposed model, the free space model is modified by considering the influence of corridor conditions on each floor based on ray tracing technique at a carrier frequency range of 2.4GHz. Using this model, indoor received signal strength values can be estimated according to the geometrical plan in modeling of indoor radio wave propagation. The performance comparison of channel capacity is implemented with various frequency ranges using MATLAB programming language. The recommendation results from experimental data and proposed model will help wireless network system designers in optimization overall cost effect.

Keywords: WLAN; Non-Line-of-Sight (NLOS); free space model; ray tracing technique; received signal strength; channel capacity.

1. Introduction

With the continual improvement in IEEE 802.11 standards wireless networks are being deployed in ever increasing numbers. As technology advances the data rates and coverage of Wi-Fi increases and so the usage for different high bandwidth requirement applications increases. These enhancements to the technology do provide network design engineers with some significant problems when designing the network infrastructure.

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Radio wave propagation model is a set of mathematical expressions, diagrams, and algorithms used to represent the radio characteristics of a given environment. The characteristics of an indoor radio channel vary between different environments and must be considered when modeling the radio channel. Many have studied the propagation characteristics of the indoor 2.4 GHz channel [1, 2], for which current 802.11b implementations are designed. The WLAN primarily operates in an indoor environment having tremendous amount of impairment and variability. Indoor channels heavily depend on the placement of walls and partitions that dictate the signal path within the building. There are many different ways on how the signal coverage in buildings can be determined. In this paper, processing of measured values to predict received signal strength in the indoor NLOS area was concentrated in order to develop new indoor radio wave propagation model especially for NLOS environment based on free space model and modified reflection coefficient using ray tracing technique. The wireless signal analyzer software called inSSIDer is used to measure the signal strength per varying distances [3].

2. 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. With indoor radio communication, there is rarely a line of sight between the transmitter and receiver, and multiple signal propagation paths exist. The signals from these paths combine both constructively and destructively at the receiver to produce multipath fading. Depending on the building construction and layout, the signal usually propagates along corridors and into other open areas. In some cases, transmitted signals may have a Line-of-Site (LOS) to the receiver. When propagating of radio wave between transmitter and receiver takes place without any obstacles between them, such kind of propagation is called Line-of-Sight (LOS). LOS situation is often impossible to maintain while using mobile radio systems. It is obvious that there can always be many obstacles such as many objects, reflecting surfaces, furniture and building partitions in indoor environments. 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 [4].

2.1. 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 [5]. The model is given by equation (1) which represents the path loss as a positive quantity in dB:

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

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

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 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 *Gt = Gr = 1* [6].

2.2. Reflection Coefficient

The reflection coefficients for vertical and horizontal polarization, Rcv and Rch, respectively are presented in equation (3) and (4).

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

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

Where θ is grazing angle, $\varepsilon_c = \varepsilon_r - j60\sigma\lambda$ is complex dielectric constant, ε_r is the dielectric constant of reflection surface, σ is the conductivity of reflection surface and λ is wavelength. In this study the values of reflection factor were calculated depending on the type of reflective materials and various distances between transmitter and receiver. Table 1 shows the values of relative permittivity and conductivity depending on the type of materials working at 2.4GHz.

Table 1: Relative permittivity and conductivity of various materials [9]

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

2.3. Single Input Single Output (SISO) Systems

SISO systems or the single input single output communication systems is the simplest form of the communication system out of all four in which there is single transmitting antenna at the source and a single receiving antenna at the destination[7]. SISO systems are used in multiple systems like Bluetooth, Wi-Fi, radio broadcasting, TV etc. Figure 1 shows Slaude Shanon's SISO channel capacity. The capacity of a SISO link is specified in the number of bits that can be transmitted over it as measured by the very important metric, (b/s/Hz). The capacity of a SISO link is a function simply of the channel SNR as given by the equation (5).

This capacity relationship was of course established by Claude Shannon [8] and is also called the information-theoretic capacity. The SNR in this equation is defined as the total power divided by the noise power. The capacity of such systems is given by Shannon capacity theorem giving the mathematical form as

$$C = \log 2(1 + SNR) \quad (5)$$

Where, *C* is capacity and *SNR* is the signal to noise ratio. SISO are advantageous in terms of the simplicity. It does not require processing in terms of diversity schemes. The throughput of the system depends upon the channel bandwidth and signal to noise ratio. In some conditions, these systems are exposed to the issues like multipath effects. When an electromagnetic wave interacts with hills, buildings and other obstacles, waveform get scatter and takes many paths to reach the destination. Such issues are known as multipath. This causes several issues like fading, losses and attenuation also the reduction in data speed, packet loss and errors are increased.

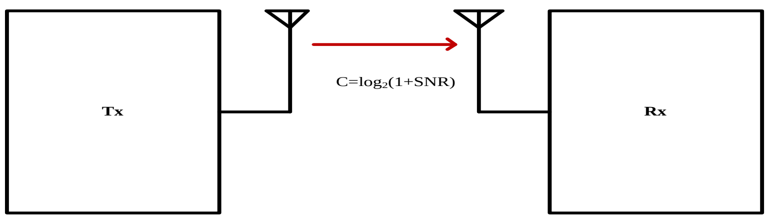

Figure1: Claude Shanon's SISO channel capacity

3. Optimization of Indoor Radio Wave Propagation Model

This research aims to optimize indoor radio wave propagation model based on free space model with consideration of the ray components along the L-shape corridor such as the reflective rays from the ground, roof and side walls. Figure.2 shows the system block diagram of proposed model.

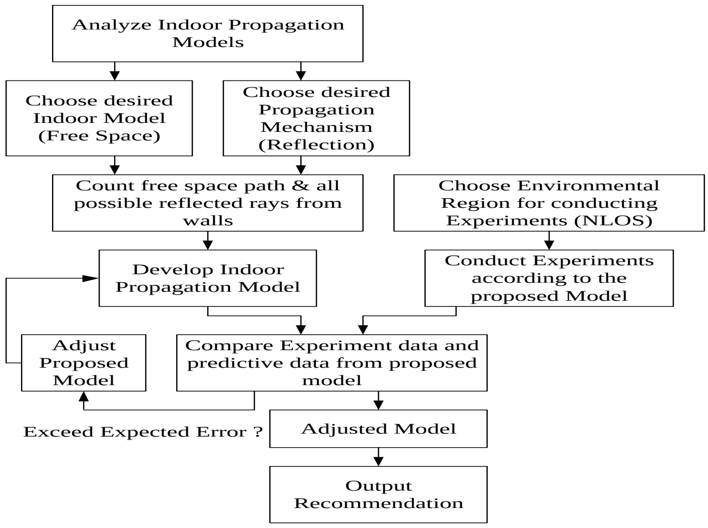

Figure 2: System Block Diagram of Proposed Mode

In free space propagation model, only the free space path is considered, but all possible reflective rays from the ground, roof, side walls and opposite walls are also needed to consider in the case of indoor radio wave propagation along the L-shape corridor.

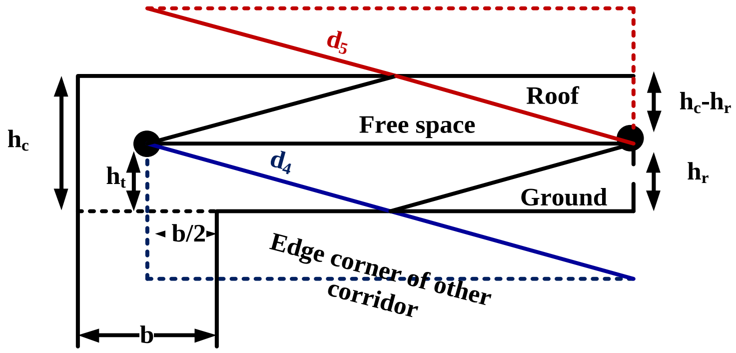

Figure 3: Free space and the reflective rays from the ground and roof

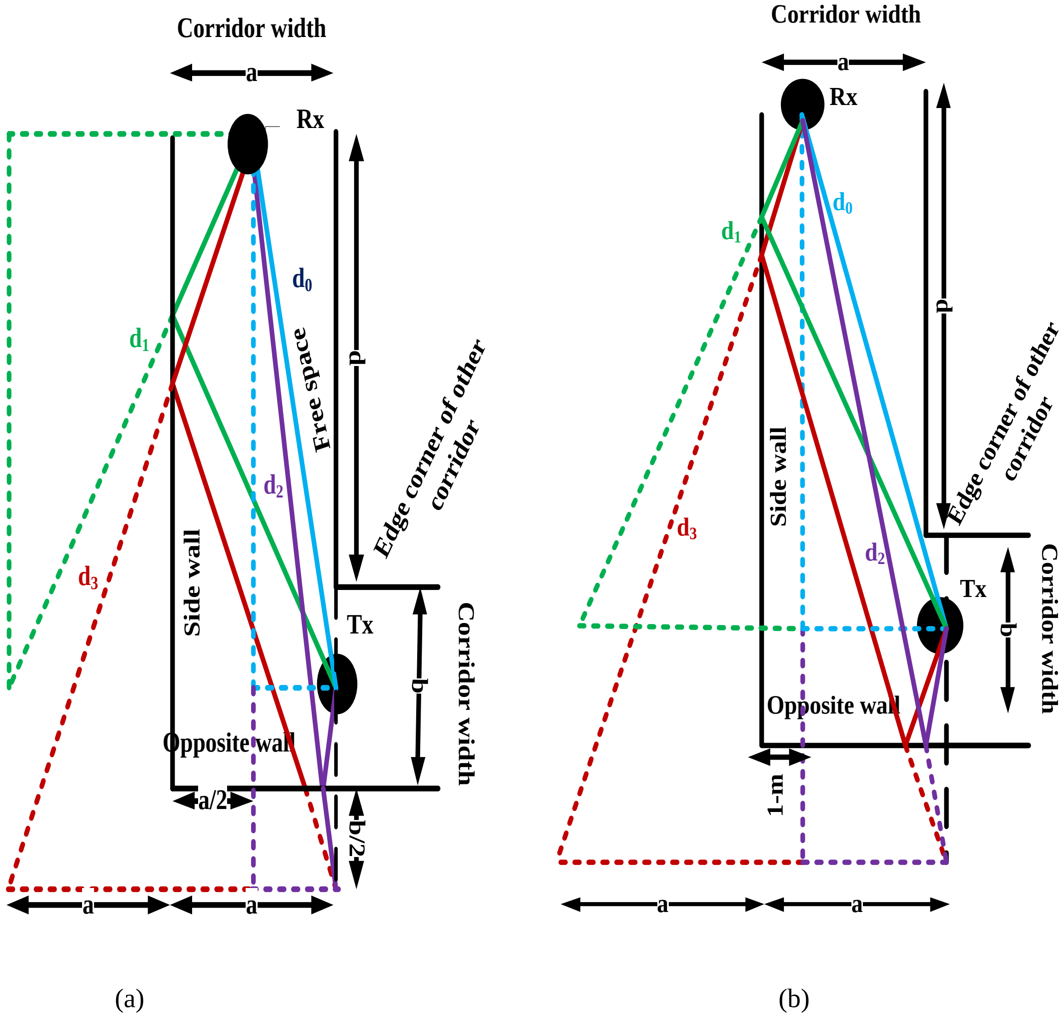

Figure 4: (a) The reflective rays from the side and opposite walls while the receiver located at center point (b) The reflective rays from the side walls and opposite walls while the receiver located one meter from side wall.

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 Figure 3 and Figure 4. Moreover, maximum six reflective waves are also considered in ground and roof waves for this research work. Therefore, the effective distance values for all possible rays along L-shape corridor are calculated for this proposed system. The Table 2 shows the calculated distance values between antennas depending on six rays occurred in L-shape hallway.

Table 2: Comparison table of effective distance values between antennas

No	Dis: Index	Mathematical Expression	
		Center Point	1-meter from wall
1	d_0	$\sqrt{(a/2)^2+(d+b/2)^2}$	$\sqrt{(a-1)^2+(d+b/2)^2}$
2	d_1	$\sqrt{(3a/2)^2+(d+b/2)^2}$	$\sqrt{(a+1)^2+(d+b/2)^2}$
3	d_2	$\sqrt{(a/2)^2+(d+3b/2)^2}$	$\sqrt{(a-1)^2+(d+3b/2)^2}$
4	d_3	$\sqrt{(3a/2)^2+(d+3b/2)^2}$	$\sqrt{(a+1)^2+(d+3b/2)^2}$
5	d_4	$\left[\begin{array}{l}\sqrt{(2h_c-2h_t)^2+(d_0)^2}+\sqrt{(2h_c)^2+d_0^{\,2}}\\+\sqrt{(4h_c-2h_t)^2+(d_0)^2}+\sqrt{(4h_c)^2+d_0^{\,2}}\\+\sqrt{(6h_c-2h_t)^2+(d_0)^2}+\sqrt{(6h_c)^2+d_0^{\,2}}\end{array}\right]= \sum_{m=1}^{3}\left[\sqrt{(2mh_c-2h_t)^2+d_0^{\,2}}+\sqrt{(2mh_c)^2+d_0^{\,2}}\right]$	$\left[\begin{array}{l}\sqrt{(2h_c-2h_t)^2+(d_0)^2}+\sqrt{(2h_c)^2+d_0^{\,2}}\\+\sqrt{(4h_c-2h_t)^2+(d_0)^2}+\sqrt{(4h_c)^2+d_0^{\,2}}\\+\sqrt{(6h_c-2h_t)^2+(d_0)^2}+\sqrt{(6h_c)^2+d_0^{\,2}}\end{array}\right]= \sum_{m=1}^{3}\left[\sqrt{(2mh_c-2h_t)^2+d_0^{\,2}}+\sqrt{(2mh_c)^2+d_0^{\,2}}\right]$
6	d_5	$\left[\begin{array}{l}\sqrt{(2h_c-2h_r)^2+(d_0)^2}+\sqrt{(2h_c)^2+d_0^{\,2}}\\+\sqrt{(4h_c-2h_r)^2+(d_0)^2}+\sqrt{(4h_c)^2+d_0^{\,2}}\\+\sqrt{(6h_c-2h_r)^2+(d_0)^2}\end{array}\right]= \sum_{p=1}^{n}\left[\sqrt{(2ph_c-2h_r)^2+d_0^{\,2}}+\sqrt{(2ph_c)^2+d_0^{\,2}}\right]$	$\left[\begin{array}{l}\sqrt{(2h_c-2h_r)^2+(d_0)^2}+\sqrt{(2h_c)^2+d_0^{\,2}}\\+\sqrt{(4h_c-2h_r)^2+(d_0)^2}+\sqrt{(4h_c)^2+d_0^{\,2}}\\+\sqrt{(6h_c-2h_r)^2+(d_0)^2}\end{array}\right]= \sum_{p=1}^{n}\left[\sqrt{(2ph_c-2h_r)^2+d_0^{\,2}}+\sqrt{(2ph_c)^2+d_0^{\,2}}\right]$

Where,

d_0 is distance between antennas for the free space

d_1 is distance between antennas for the ray from T_x to R_x by hitting 1-reflected ray from side wall

d_2 is distance between antennas for the ray from T_x to R_x by hitting 1-reflected ray from the opposite wall

d_3 is distance between antennas for the ray from T_x to R_x by hitting 1-reflected ray from both side and opposite wall

d_4 is distance between antennas for the ray from T_x to R_x by hitting all possible reflected rays from the ground (maximum six reflective waves)

d_5 is distance between antennas for the ray from T_x to R_x by hitting all possible reflected rays from the roof (maximum six reflective waves).

Although one type of distance is considered in original free space model according to equation (1), this research work concentrated on all possible distances between transmitter and receiver taking into consideration of different directions. All possible distances are defined as effective distance values (d_f) for this system. Finally, the mathematical formula for the proposed radio wave propagation model based on free space model can be shown in equation (6):

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 (d_f)^2} \tag{6}$$

Where, d_f is the effective distance values with modified reflection coefficient and which is shown in equation (7). After replacing the various distance values from table II, equation (7) can be simplified by equation (8). In this research work, the value of reflection factor R_f varies according to the equation (9).

$$d_f = (d_0 \times R_{f_0}) + (d_1 \times R_f) + (d_2 \times R_f) + (d_3 \times R_f) + (d_4 \times R_f) + (d_5 \times R_f) \tag{7}$$

$$\begin{aligned} d_f = {} & d_0 \times R_{f_0} + \sum_{l=1}^{3} n d_l R_f \; + \\ & \sum_{m=1}^{3} \left[(2m-1) R_f \sqrt{(2mh_c - 2h_t)^2 + d_0^{\,2}} + 2mR_f \sqrt{(2mh_c)^2 + d_0^{\,2}} \right] + \\ & \sum_{p=1}^{3} \left[(2p-1) R_f \sqrt{(2ph_c - 2h_r)^2 + d_0^{\,2}} + 2pR_f \sqrt{(2ph_c)^2 + d_0^{\,2}} \right] \end{aligned} \tag{8}$$

$$R_f = Rc_h \times \frac{\sqrt{h_t \times h_r}}{\sqrt{h_c \times a}} \tag{9}$$

Where, R_f is the reflection factor value for all reflected rays, n=2 is the numbers of reflection time to side wall and opposite wall for distance d_3, d_i is distance where signal travels along from transmitter to receiver, R_{f0} is 1 (reflection factor for free space), Rc_h is reflection coefficient for horizontal polarization, a is width of corridor (1) and corridor (3).

h_t and h_r are heights of transmitter and receiver respectively and h_c is the height of each corridor. Moreover, the equation for channel capacity can also be calculated according to the equation (9) based on the proposed radio wave propagation model.

$$C = \log 2(1 + SNR) bps / Hz \tag{10}$$

$$SNR = P_r(d_f)/N \tag{11}$$

Where P_r is the received signal power, N = K T B is the thermal noise, K (Boltzmann's constant) is 1.3803×10^{-23} [J/K], T is Temperature [K] (Standard Temperature = 290 K) and B is the bandwidth.

4. Experimental region

All experiments were conducted at the main building of Mandalay Technological University, the Republic of the Union of Myanmar. 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 one 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 Figure 5.

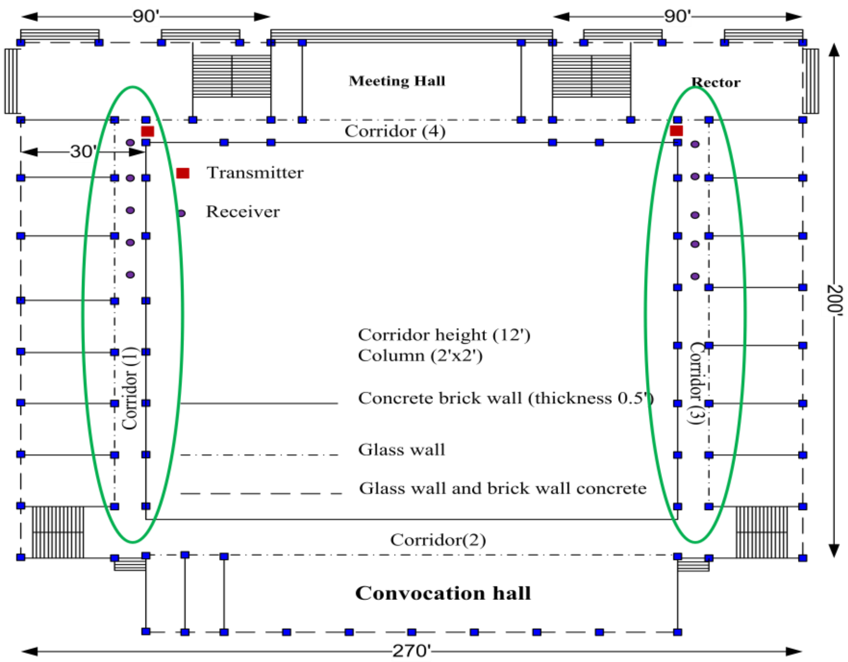

Figure 5: Building Layout of experimental region

5. Experimental Procedure

This section briefly outlines the experimental set up used for our propagation measurement. 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 Technology University, the Republic of the Union of Myanmar. In all measurements, TP-Link TL-WR1043N router with 8dbi omnidirectional antenna was used for wireless transmitter and LAPTOP (3dBi) with Microsoft WINDOWS 7 operating system was used for receiver. To survey received signal strength, the wireless signal analyzer software called inSSIDer was installed in this laptop. Carrier frequency was 2.4GHz with 20dBm transmitted power. At first, TP-Link TL-WR1043N router is located in a fixed centre position of corridor (4). The placement of transmitter was constant, 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. There are two positions of receiver's placement when conducting all experiments. The first placement of receiver is at the centre of each corridor and the other is 1 meter from the side wall of each corridor to the centre of that corridor. All experimental points are marks as 1 meter from the transmitter along L-shape form of hallway and moved the receiver to each experimental point along the corridor to the end of it. 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.

6. Experimental Results

After performing all measurements, all experimental data were used to draw received signal power with the aid of Matlab programming language. Figure 6-9 shows the comparison of the experimental data and theoretical data curves based on free space model .The horizontal increment values are used to describe the distance from the transmitter to the receiver, always one meter gradually increasing away from the transmitter and the vertical increment values are used to describe the received signal power level in dBm at the received point. The different colors and line types show the different values of received signal strength, the different floors and the different corridors.

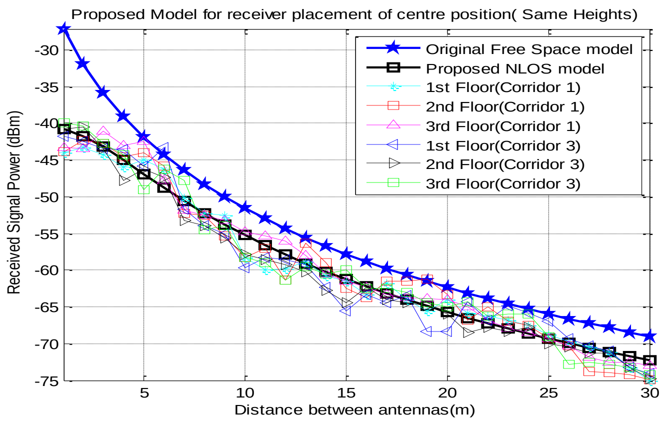

Figure 6: The comparison results of proposed model, original free space model and experimental data for corridor (1) and (3)

The free space model is well known model for radio wave propagation between antennas especially in Line-of-Sight (LOS) environment. But those model can be used not only LOS environment but also NLOS environment. This research submitted all possible ways to use those models in order to be useful in indoor environments using parameters of experimental region. The mention model can well be used in indoor environment after some adjusting to them depending on parameters of the experimental building.Figure 6 shows received signal power, in dBm versus distance between transmitter and receiver, in meters 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.

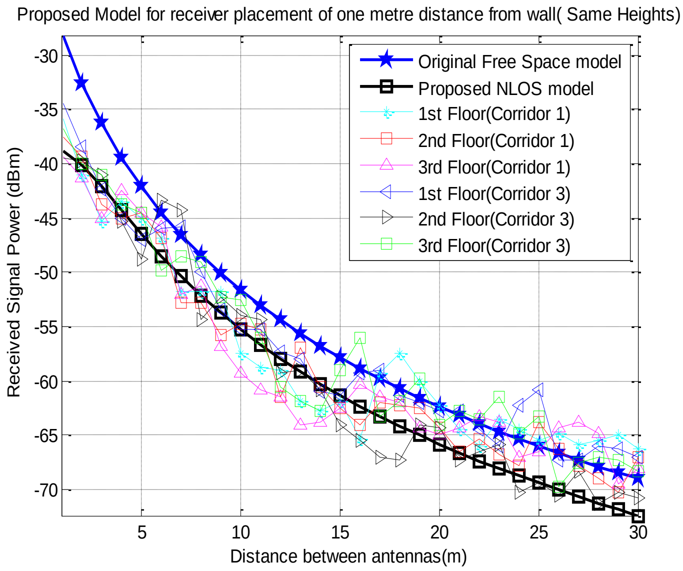

Figure 7: The comparison results of proposed model, original free space model and experimental data for corridor (1) and (3)

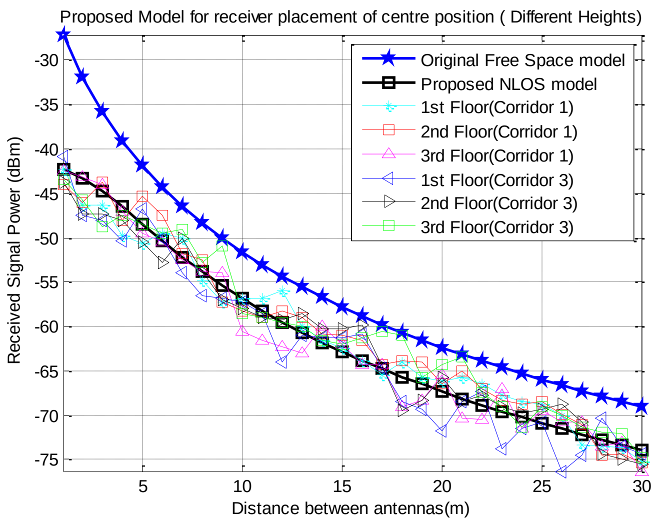

Figure 8: The comparison results of proposed model, original free space model and experimental data for corridor (1) and (3)

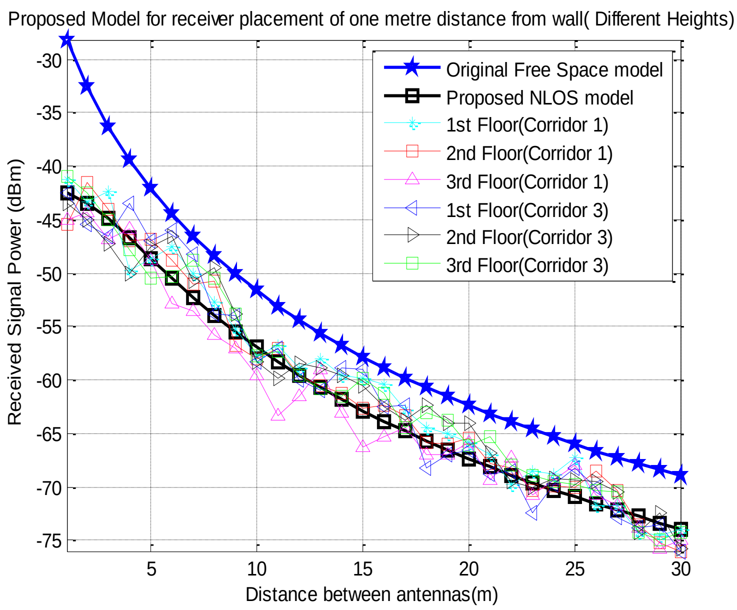

Figure 9: The comparison results of proposed model, original free space model and experimental data for corridor (1) and (3)

Figure 7 shows received signal power, in dBm versus distance between transmitter and receiver, in meters for all floors of corridor (1) and (3) of the experimental region when conducting the experiment with same heights of transmitter and receiver located one metre distance from wall.Figure 8 shows received signal power, in dBm versus distance between transmitter and receiver, in meters 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.

Figure 9 shows received signal power, in dBm versus distance between transmitter and receiver, in meters for all floors of corridor (1) and (3) of the experimental region when conducting the experiment with different heights of transmitter and receiver located one metre distance from wall.

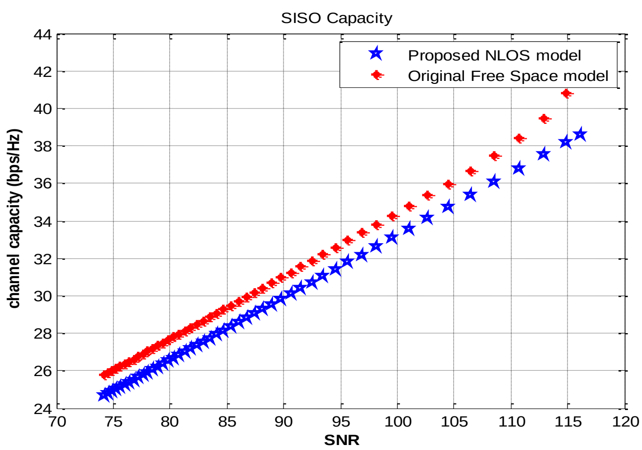

Figure 10: SISO Channel Capacity for free space and proposed model

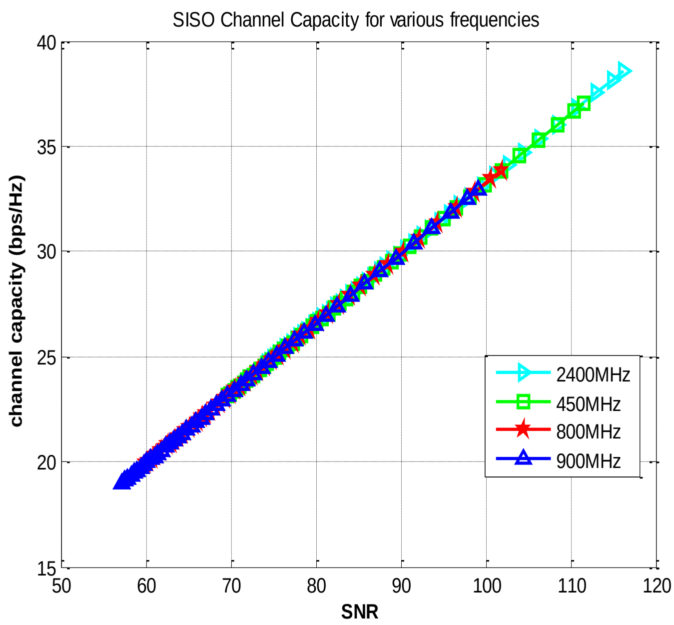

Figure 11: The channel capacity values for four types of frequencies

After conducting some experiments according to the proposed model, the comparison results are illustrated in Figure 6 to Figure 9. 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 until the last point. It shows that the proposed model can be recommended to the distance value of 30-meters from the corner of the other corridor. Moreover, comparison results for SISO channel capacity are also illustrated. Figure 10 shows SISO channel capacity based on free space model and proposed model. . The channel capacity values for four types of frequencies are evaluated and compared based on proposed model as shown in Figure 11. According to these results, it is also clear that the capacity grows when the value of SNR becomes higher with different types of frequencies.

7. Conclusions

The new indoor radio wave propagation models based on free space model are presented in this paper that can be used to predict received signal strength of planning wireless network. 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. In optimizing the channel capacity of SISO system, it is can be seen that the channel capacity grows as high as the value of SNR with different types of frequencies ranges. The capacity of SISO system with frequencies ranges of 2400 MHz is better than other frequencies ranges. All reflective walls are assumed as the brick wall of building.

8. Recommendations

As the recommendation results, experimental data with various heights and positions of receiver are accurate from the start point until the last point. It shows that the proposed model can be recommended to the distance values of 30-meter from the corner of the other corridor. 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, the heights of transmitter and the placements of receivers. As for further works, the difference frequencies ranges and the different types of wall at the different building are also needed to conduct in various experiments.

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