COMPARATIVE ANALYSIS OF WIRELESS INDOOR RADIO PROPAGATION MODELS USING ULTRA-WIDEBAND (UWB) TECHNOLOGY

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Abstract - Over the coming decades, high-definition situation ally-aware networks have the potential to create revolutionary applications in the social, scientific, commercial, and military sectors. Ultra wide bandwidth (UWB) technology is a viable candidate for enabling accurate localization capabilities through time-of-arrival (TOA)-based ranging techniques. It is difficult to model indoor mobile radio channel because the channel parameters varies significantly. The indoor radio channel depends heavily on factors which include building structure, layout of rooms, and the type of construction materials used. In order to understand the effects of these factors on electromagnetic wave propagation, it is necessary to recall the three basic mechanisms of electromagnetic wave propagation -- reflection, diffraction, and scattering. In this paper three types of indoor radio propagation models are analyzed at ultra wideband frequency range and results are compared to select best suitable model for setting up indoor wireless connectivity and nodes in typical office, business and college environments and WPAN applications.

Keywords - Path loss exponent, Wireless radio propagation models, UWB technology, indoor environment, Blockage.

I. INTRODUCTION

The Federal Communications Commissions (FCC) Report and Order (R&O), issued in February2002 [6], allocated 7,500 MHz of spectrum for unlicensed use of UWB devices in the **3.1 to 10.6 GHz frequency band**. The UWB spectral allocation is the first step toward a new policy of open spectrum initiated by the FCC in the past few years. More spectral allocation for unlicensed use is likely to follow in the next few years [2]. The FCC defines UWB as any signal that occupies more than 500 MHz bandwidth in the 3.1 to 10.6 GHz band and that meets the spectrum mask shown in Fig 1. [1]

This is by far the largest spectrum allocation for unlicensed use the FCC has ever granted. It is even more relevant that the operating frequency is relatively low.

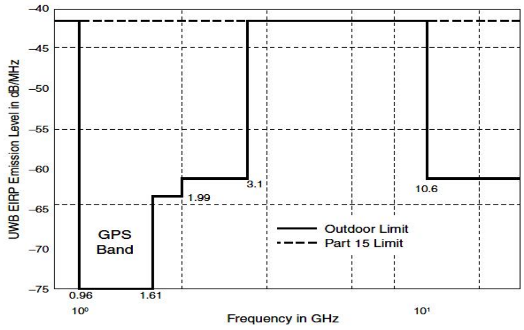


Fig.1: FCC spectrum mask for UWB [1]

UWB characteristics can be analyzed according to the Shannon capacity (C) formula. For an Additive White Gaussian Channel (AWGN) of bandwidth, the maximum data that can be transmitted can be expressed as, [21]

$$C = B\ log_2\,(1 + SNR)\ bit/second \qquad (1)$$

SNR is representing the signal-to-noise ratio. From (1) it is clear, if bandwidth (B) of the system is increased, the capacity of the channel will increase. In the context of UWB, the bandwidth is very high and very low power is required for transmission. So we can gain a very high channel capacity using UWB with lower power that can make batter life longer and reduce the interference with existing systems.

This paper analyses the effect of changing Path Loss based on distance in typical indoor environment. Path loss is the reduction in power density of an electromagnetic wave as it propagates through space. In simulator different position of transmitter and receiver nodes are used to estimate the free space path loss

The indoor mobile radio channel can be especially difficult to model because the channel varies significantly with the environment. The indoor radio channel depends heavily on factors which include building structure, layout of rooms, and the type of construction materials used. In order to understand the effects of these factors on electromagnetic wave propagation, it is necessary to recall the three basic mechanisms of electromagnetic wave propagation -- reflection, diffraction, and scattering.

One goal of our work is to characterize how the indoor radio channel affects the performance of the wireless nodes such as Personal Digital Assistant (PDA), Laptops, and other devices. In particular, we would like to determine the amount of attenuation that can be expected from walls, floors, and doors in a residential environment. Furthermore, we would like to be able to estimate the amount of path loss that can be expected for a given transmitter-receiver (T-R) separation within a home.

In visual studio the region of interest (ROI) is defined with in small range of distance up to 30m and transmitter and receiver nodes are placed in the defined ROI to calculate Free Space Path Loss (FSPL) and node distance. Also in visual studio standard environment is created to analyse the indoor radio propagation model and for each model parameters are defined and value of free space pass loss and receiver signal strength (RSS) is measured.

II. MAIN SOURCES OF ERRORS OF RANGE BASED TECHNIQUE

The range-based Time of Arrival (TOA) and Time Difference of Arrival (TDOA) approach are the most suitable approach for localization in UWB sensor networks, because it is proved to have a very good accuracy due to the high time resolution (large bandwidth) of UWB signals. However, there are many challenges in developing a real-time indoor UWB localization system. These challenges include clock synchronization, signal acquisition, multipath interference, sampling rate limitations etc. TOA systems need to setup a very precise timing reference between anchor nodes with target node. In TDOA estimation, all of the anchor nodes need to be synchronized [23].

Therefore, there are a number of error sources that may degrade the accuracy of the range estimation, such as thermal noise, multipath propagation, Direct Path (DP) blockage and DP excess delay [22]. In Fig.2, six different simple situations are displayed. In this section, these main sources of errors of the time-based ranging with UWB signal in realistic environment will be discussed.

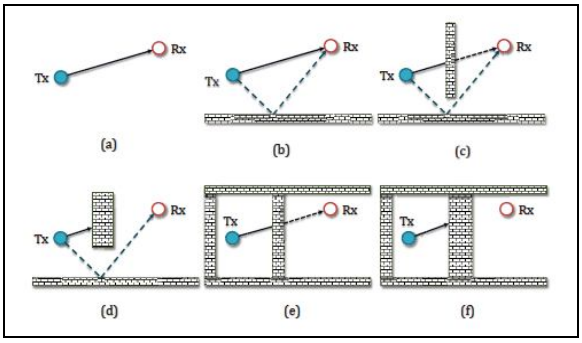


Fig.2 Possible simple situation from transmitter (Tx) to Receiver (Rx) (a) Direct path (b) Reflected path (c) Reflected and direct path (d) DP blockage (e) DP Excess delay (f) DP Blockage

2.1. Multipath Propagation

Multipath propagation is caused by the destructive and constructive interference of signals arriving at the receiver via different propagation paths [22]. In UWB systems, UWB signals have the distinct advantage of resolving multipath components, greatly reducing multipath fading, the multipath components (MPCs) could be resolved or be partially overlapped (not resolvable channel). However, a large number of MPCs in a dense multipath environment still make the DP detection challenging. As displayed in Figure-4.10, the multipath propagation is commonly existed in an urban or indoor environment. It makes detection of the direct path signal, if present, difficult. What's more, in practice, the strongest path may arrive much later than the direct path. It may be difficult to recognize the first path, especially at low and medium signal to noise ratios (SNR). Therefore, it introduces the ambiguities in direct path detection.

2.2. DP Blockage

In some areas of the environment, as displayed in Fig.2 (d) and (f), when the direct path between the Tx and Rx is obstructed, the direct path would be attenuated or even be completely obstructed such that the only received signals are from reflections and diffraction. In these cases, the resulting measured ranges are larger than the true distances, that means the TOA estimate will include a positive bias [22], [6]. The estimation performance is dominated by large errors (also called global errors) with magnitudes much larger than the width of the transmitted pulse.

2.3. DP Excess Delay

Another difficulty is due to DP excess delay incurred by propagation of the partially obstructed DP signal through different materials, such as walls, as displayed in Fig.2 (c) and (e). Because the propagation of signals is slower in some materials than in the air, the signal arrives with excess delay, yielding again a range estimate larger than the true one.

III. BASIC METHODS OF PROPGATION

Reflection, diffraction and scattering are the three fundamental phenomena that cause signal propagation in a mobile communication system, apart from LOS communication. The most important parameter, predicted by propagation models based on above three phenomena, is the received power. The physics of the above phenomena may also be used to describe small scale fading and multipath propagation. The following subsections give an outline of these phenomena.

3. 1. Reflection

Reflection occurs when an electromagnetic wave falls on an object, which has very large dimensions as compared to the wavelength of the propagating wave. For example, such objects can be the earth, buildings and walls. When a radio wave falls on another medium having different electrical properties, a part of it is transmitted into it, while some energy is reflected back. Let us see some special cases. If the medium on which the E.M. wave is incident is a dielectric, some energy is reflected back and some energy is transmitted. If the medium is a perfect conductor, all energy is reflected back to the first medium. The amount of energy that is reflected back depends on the polarization of the E.M. wave.

3. 2. Diffraction

Diffraction is the phenomenon due to which an EM wave can propagate beyond the horizon, around the curved earth's surface and obstructions like tall buildings. As the user moves deeper into the shadowed region, the received field strength decreases. But the diffraction field still exists and it has enough strength to yield a good signal.

This phenomenon can be explained by the Huygens's principle, according to which, every point on a wavefront acts as point sources for the production of secondary wavelets, and they combine to produce a new wavefront in the direction of propagation. The propagation of secondary wavelets in the shadowed region results in diffraction. The field in the shadowed region is the vector sum of the electric field components of all the secondary wavelets that are received by the receiver. For e.g the sound can be heard in a room, where the source of the sound is another room without having any line of sight. The similar phenomenon occurs for light also but the diffracted light intensity is not noticeable. This is because the obstacle or slit need to be of the order of the wavelength of the wave to have a significant effect.

3.3. Scattering

The actual received power at the receiver is somewhat stronger than claimed by the models of reflection and diffraction. The cause is that the trees, buildings and lampposts scatter energy in all directions. This provides extra energy at the receiver. Roughness is tested by a Rayleigh criterion, which defines a critical height *hc* of surface protuberances for a given angle of incidence θ_i, given by,

$$h_c = \frac{\lambda}{8 \sin \theta_i} \qquad (1)$$

3.4. Free Space Path Loss (FSPL)

In telecommunication, free-space path loss (FSPL) is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space (usually air), with no obstacles nearby to cause reflection or diffraction. It does not include factors such as the gain of the antennas used at the transmitter and receiver, nor any loss associated with hardware imperfections

Free-space path loss is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal.

$$\mathrm{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (2)$$

$$\mathrm{FSPL} = \left(\frac{4\pi d f}{c}\right)^2 \qquad (3)$$

Where, d is distance between transmitter and receiver, f is frequency of operation, c is velocity of light, ƛ is wavelength.

As seen from the equation 2 and 3 the free space path loss of wireless communication is strongly dependent on frequency of the communication. Hence to calculate the path loss at the UWB frequency is very important which is working for indoor environment. Also indoor environment is subject to various losses and parameters as describe above. Our goal of this paper is to analyze the various radio propagation models at UWB frequency, calculate RSS for those models and estimate the exact path loss between wireless transmitter and receiver nodes.

IV. INDOOR RADIO PROPAGATION MODELS AT UWB FREQUENCY

An indoor propagation environment is more hostile than a typical outdoor propagation environment [22], [23]. The indoor propagation model estimates the path loss inside a room or a closed area inside a building delimited by walls of any form. Phenomena like lack of line-of-sight condition, multipath propagation, reflection, diffraction, shadow fading, heavy signal attenuation, close proximity of interference sources, and rapid fluctuations in the wireless channel characteristics have a significant influence on the received power in indoor propagation.

Reflection occurs when a wave impacts an object having larger dimensions than the wavelength. During reflection, part of the wave may be transmitted into the object with which the wave has collided. The remainder of the wave may be reflected back into the medium through which the wave was originally travelling. In an indoor environment, objects such as walls and floors can cause reflection [22].

When the path between transmitter and receiver is obstructed by a surface with sharp irregularities, the transmitted waves undergo diffraction. Diffraction allows waves to bend around the obstacle even when there is no line-of-sight (LOS) path between the transmitter and receiver. Objects in an indoor environment which can cause diffraction include furniture and large appliances.

Since the properties of an indoor radio channel are particular to a given environment, we have focused our efforts on deriving large scale propagation models. Sections 4.1-4.3 summarize some of the indoor radio propagation models that have been proposed for use in the home. The applicability of each of these models to the standard environment created in visual studio is investigated to decide best model applicable at UWB frequency from 3.1 GHz to 10.6 GHz. The created standard environment is as shown in Fig. 3 below.

In the Fig. 3 below transmitter node is indicated by green circle and there are three receiver nodes which are indicated by using red colour circle. To create multipath effect the black colour lines between transmitter and receiver nodes indicates the walls and flooring which has to be accounted when calculating path loss. The frequency is changed by the frequency dial provided within UWB frequency range. To change the distance between wireless transmitter node transit distance dial is provided. Also a drop down list is designed in the GUI to select various wireless models as seen from fig.3 below.

All the large scale path loss models require free space path loss to be calculated by using friss transmission equation calculated in section 3.4. To analyse the large scale path loss model the basic free space path loss is calculated from friss transmission equation.

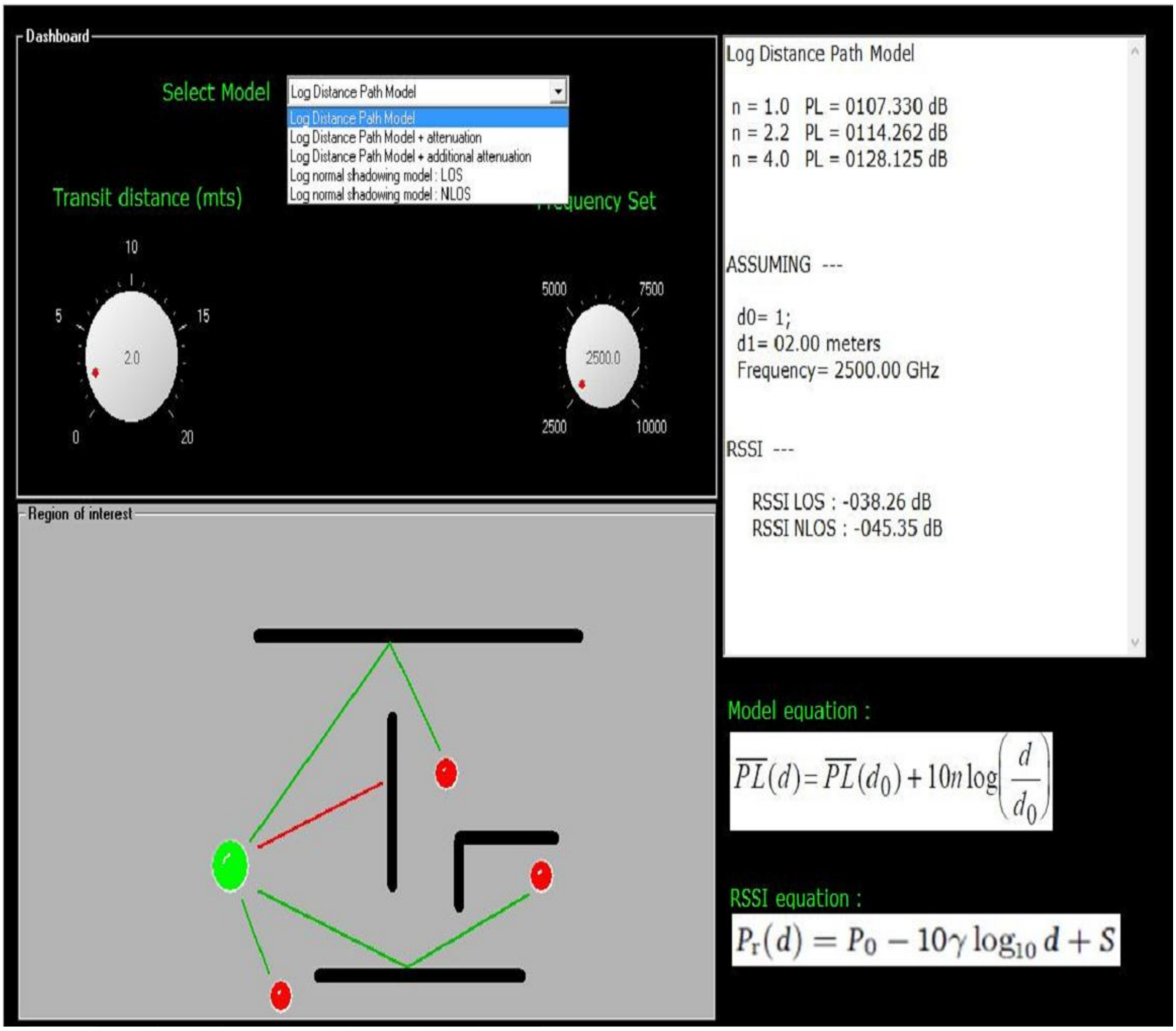
4.1. Log- distance propagation model

The log-distance path loss model is a radio propagation model that predicts the path loss which is encountered by a signal inside a building or densely populated areas over distance [22]. The model is applicable to indoor propagation modeling. Log distance path loss model is based on distance-power law, and is expressed as (4) below,

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) \qquad (4)$$

Where *n* is the path loss exponent, *d* is the T-R separation in meters, and d_o is the close-in reference distance in meters. *PL* (d_o) is computed using the free space path loss equation discussed in Section 3.4. The value d_o should be selected such that it is in the far-field of the transmitting antenna, but still small relative to any practical distance used in the mobile communication system.

Path loss in standard environment shown in Fig. 3 below can be calculated by taking d_0 as a close in reference distance as 1m, values of path loss exponent n as 1.0, 2.2 and 4.4 and changing frequency in the UWB range from 3.1 GHz to 10.6 GHz and distance from 1m to 20m for typical indoor environment.



Log Distance Path Model

n = 1.0 PL = 0107.330 dB
n = 2.2 PL = 0114.262 dB
n = 4.0 PL = 0128.125 dB

ASSUMING ---

d0= 1;
d1= 02.00 meters
Frequency= 2500.00 GHz

RSSI ---

RSSI LOS : -038.26 dB
RSSI NLOS : -045.35 dB

Model equation :

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right)$$

RSSI equation :

$$P_r(d) = P_0 - 10\gamma\log_{10} d + S$$

Fig. 3 Indoor wireless standard environment with obstruction in between to create multipath

Table 1: Calculation of path loss by using log distance path loss model (a) f=3.1 GHz, (b) f=5 GHz, (c) =7.5 GHz [31]

(a)

Frequency of 3.1GHz			
	Path loss (dB) using Log distance model		
Distance	n=1.0	n=2.2	n=4.4
1m	103.31	104.34	106.42
5m	118.27	134.27	166.28
10m	125.28	148.29	194.30
15m	129.37	156.46	210.66
20m	132.23	162.18	222.10

(b)

Frequency of 5 GHz			
	Path loss (dB) using Log distance model		
Distance	n=1.0	n=2.2	n=4.4
1m	106.71	106.92	107.36
5m	122.56	138.62	170.74
10m	129.48	152.48	198.46
15m	133.59	160.69	214.88
20m	136.45	166.41	226.32

(c)

Frequency of 7.5 GHz			
	Path loss (dB) using Log distance model		
Distance	n=1.0	n=2.2	n=4.4
1m	110.20	110.41	110.85
5m	126.06	142.02	174.06
10m	132.97	155.95	201.93
15m	137.07	164.15	218.32
20m	139.94	169.90	229.81

4.2 Attenuation factor path loss model

The attenuation factor path loss model is a radio propagation model that predicts the path loss which includes the effect of type of the building as well as the signal variations caused by partitions and obstacles present inside the building [23]. The attenuation factor model is expressed as,

$$PL(dB) = \overline{PL}(d_0) + 10n_{sf}\log\left(\frac{d}{d_0}\right) + FAF \quad (5)$$

Where, *nsf* is the path loss exponent for a same floor measurement and *FAF* is a floor attenuation factor based on the number of floors between transmitter and receiver. If the path loss is required to be determined for the indoor propagation in the same floor of the building, then the path loss exponent value for that floor should be known. Value of *nsf* varies from 1.6 to 3.3 in an indoor environment. The results are simulated with frequency of 3.1 GHz, 5 GHz and 10 GHz with *nsf* of 3.0 and changing distance between transmitter and receiver.

Table 2: Calculation of path loss by using attenuation factor path loss model (a) f=3.1 GHz, (b) f=5 GHz, (c) =10 GHz [31]

(a)

Frequency of 3.1GHz, n_{sf}=3.0				
	Path loss (dB) using attenuation factor path loss model			
Distance	FAF=0	FAF=12.9	FAF=18.7	FAF=24.4
1m	103.38	116.38	122.38	127.38
5m	150.57	163.57	169.57	174.57
10m	171.61	184.61	190.61	195.61
15m	183.54	196.54	202.54	207.54
20m	192.25	205.25	211.25	216.25

(b)

Frequency of 5 GHz, n_{sf}=3.0				
	Path loss (dB) using attenuation factor path loss model			
Distance	FAF=0	FAF=12.9	FAF=18.7	FAF=24.4
1m	105.43	118.43	124.43	129.43
5m	154.72	167.72	173.72	178.72
10m	175.63	188.63	194.63	199.63
15m	187.76	200.76	206.76	211.76
20m	196.42	209.42	215.42	220.42

(c)

Frequency of 10 GHz, n_{sf}=3.0				
	Path loss (dB) using attenuation factor path loss model			
Distance	FAF=0	FAF=12.9	FAF=18.7	FAF=24.4
1m	111.31	124.31	130.31	135.31
5m	160.67	173.67	179.67	184.67
10m	181.7	194.7	200.7	205.7
15m	193.68	206.68	212.68	217.68
20m	202.31	215.31	221.31	226.31

4.3 Additional Attenuation factor path loss model

A third model incorporates additional attenuation factors. This model was developed by Motley and Keenan [22] and is of the form shown in equation

$$PL(d) = PL(d_0) + 10n\log(d) + kF \quad (6)$$

Where *k* is the number of floors between the transmitter and receiver and *F* is the individual floor loss factor.

Table 3: Calculation of path loss by using additional attenuation factor path loss model (a) f=3.1 GHz, (b) f=5 GHz [31]

(a)

Frequency of 3.1 GHz, n=2.63			
	Path loss (dB) using additional attenuation factor path loss model		
Distance	kf=0	kf=12.9	kf=27.0
1m	101.79	114.79	128.79
5m	150.83	163.83	177.83
10m	171.45	184.45	198.45
15m	183.50	196.50	210.50
20m	192.21	205.21	219.21
Frequency of 5 GHz, n=2.63			
	Path loss (dB) using additional attenuation factor path loss model		
Distance	kf=0	kf=12.9	kf=27.0
1m	105.95	118.95	132.95
5m	155.06	168.06	182.06
10m	175.55	188.55	202.55
15m	187.72	200.72	214.72
20m	196.37	209.37	223.37

4.4. Log-normal shadowing path loss model

One downfall of the log-distance path loss model is that it does not account for shadowing effects that can be caused by varying degrees of clutter between the transmitter and receiver [22]. The log-normal shadowing model attempts to compensate for this.

The log-normal shadowing model predicts path loss as a function of T-R separation using:

$$PL(d) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \qquad (7)$$

Where, *X*σ is a zero-mean Gaussian random variable with standard deviation s. Both *X*σ and σ are given in dB. The random variable *X*σ attempts to compensate for random shadowing effects that can result from clutter. The value of n is taken as 1.6 for LOS condition and 2.63 for NLOS condition and value of Xσ is taken as 3.9 and path loss is calculated with different distance.

4.3.1 Log-normal shadowing (Line of Sight)

Table 4: Calculation of path loss by using Log-normal shadowing path loss model (a) f=3.1 GHz, (b) f=5 GHz [31]

(a)

Frequency of 3.1 GHz, Xσ=3.9 n=1.63 (LOS)	
Distance	Path loss (dB) using Log-normal shadowing model
1m	104.28
5m	136.68
10m	150.33
15m	158.51
20m	164.28

(b)

Frequency of 5 GHz, Xσ=3.9 n=1.63 (LOS)	
Distance	Path loss (dB) using Log-normal shadowing model
1m	108.41
5m	140.83
10m	154.63
15m	162.68
20m	168.41

4.3.2 Log-normal shadowing (Non-Line of Sight)

Table 5: Calculation of path loss by using Log-normal shadowing path loss model (a) f=3.1 GHz, (b) f=5 GHz [31]

(a)

Frequency of 3.1 GHz, Xσ=3.9 n=2.63 (NLOS)	
Distance	Path loss (dB) using Log-normal shadowing model
1m	107.73
5m	154.37
10m	175.39
15m	187.62
20m	196.23

(b)

Frequency of 5 GHz, Xσ=3.9 n=2.63 (NLOS)	
Distance	Path loss (dB) using Log-normal shadowing model
1m	111.88
5m	158.77
10m	179.61
15m	191.78
20m	200.38

4.5. Received Signal Strength (RSS)

RSS ranging is based on the principle that the greater the distance between two nodes, the weaker their relative received signals. This technique is commonly used in low-cost systems such as WSNs because hardware requirements and costs can be more favourable compared to time-based techniques. In RSS-based systems, a receiving node B estimates the distance to a transmitting node A by measuring the RSS from A and then using theoretical and/or empirical path-loss models to translate the RSS into a distance estimate. These models strongly affect ranging accuracy [30].

A widely used model to characterize the RSS at node B from node A's transmission is given by [23]

$$P_r(d) = P_0 - 10\gamma \log_{10} d + S \qquad (8)$$

Where $P_r(d)$ (dBm) is the received signal power, P_0 is the received power (dBm) at a reference distance of 1 m (which depends on the radio characteristics as well as the signal wavelength), d (meters) is the separation between A and B, and S (dB) represents the large-scale fading variations (i.e., shadowing). It is common to model S (dB) as a Gaussian random variable (RV) with zero mean and standard deviation σ_s. [23].

Table 6: Calculation of Received signal strength (RSS) with LOS and NLOS condition [31]

Received Signal Strength (RSS)		
Distance	LOS (dB)	NLOS (dB)
1m	-15.34	-13.74
5m	-66.94	-84.85
10m	-88.78	-115.41
15m	-101.39	-132.89
20m	-110.41	-145.40

V. COMPARATIVE ANALYSIS AND DISCUSSION

With log distance path model analyzed in section 2.1 we got path loss value of around 103 dB at frequency of 3.1 GHz as seen from table 1. We observed that path loss value does not change even with increase in path loss exponent value when distance between transmitter and receiver is less at 1m. But as the distance between transmitter and receiver is increased with change in path loss exponent n there was a significant change was found in the value of path loss. This is because as the distance between transmitter and receiver is increased there is more reflection obtained from the obstruction present and because of this path loss values will change drastically. Also the observations were made at different frequency of 5 GHz and 7.5 GHz and with increase in frequency and distance value of path loss were found to be increased. Also it was observed that drawback of the log-distance path loss model is that it does not account for obstacles separating transmitter and receiver. In Section 2 it was discussed that obstacles are an important consideration in predicting path loss within homes.

The next model discussed in section 4.2 considers the floor attenuation factor (FAF) based on number of floors between transmitter and receiver. Results are tabulated in table 2. We observed that with the addition of attenuation factor FAF the path loss is increased as compared to path loss measured with log distance model with same frequency and same path loss exponent value. Hence it can be commented that within indoor environment to set up exact number of transmitter and receiver for creating wireless environment exact values of floor attenuation factors and number of floors has to be added to the value of path loss obtained.

In section 4.3 additional attenuation factor path loss model is discussed. Results are tabulated in table 3. The main difference of this model with the attenuation factor path loss model is that these models provide an individual floor loss factor which is then multiplied by the number of floors separating transmitter and receiver. Whereas former model provide a table of floor attenuation factors which vary based upon the number of floors separating the transmitter and receiver. Table 3 shows summary of results obtained from this path loss model.

In section 4.4 another model which considers effect of shadowing effect that is caused by varying degrees of clutter between transmitter and receiver. This model includes addition of random variable X_σ to account for shadowing effect. The simulation is done for this model by considering both LOS and NLOS condition by considering different values of path loss exponent for each case. It was observed that for the same frequency value the LOS path loss is less as compared to NLOS condition. Since NLOS path is more affected by fading of the signal the value of path loss is increased as given in table 4 and 5.

In section 4.5 received signal strength (RSS) based ranging is analyzed for both LOS and NLOS condition between transmitter and receiver. With increased in distance between transmitter and receiver the value of RSS decreases. Also we observed that in table 6 value of RSS is lower for NLOS condition since it is indirect path between transmitter and receiver and signal gets more faded when reach to receiver.

VI. SELECTION OF MODEL FOR WIRELESS SYSTEM

As seen in the result from section 4.1-4.5 all the models are analyzed by considering various condition, path loss exponent, floor loss factors, attenuation factors. These models are subject to the UWB frequency range from 3.1GHz to 10.6GHz. We observed that from table 3 calculation of path loss by additional attenuation factor path loss model gives less path loss between transmitter and receiver in typical indoor environment

This path loss model is better to be selected as a wireless model for the indoor environment because it counts for the loss for the individual floor loss factor and multiplication of that factor is taken. Hence this model becomes floor dependent path loss model. As typical indoor environment is changing depending on the construction, material used number of doors, walls. Hence this model gives the best result as it adopts the changes taking place in the location sight and path loss observed is less.

Thus, the log-distance model is a combination of a modified power-distance law and a log normal fading model. The attenuation factor path loss model provides 4 dB standard deviation between the measured and predicted path-loss as compared to 13 dB given by log-distance model. Thus this model provides flexibility and excellent accuracy.

Also it was observed from the results of the received signal strength the value calculated of RSS by considering line of sight calculation is more as compared to non line of sight conditions. Since for the LOS condition there will be less free space losses discussed in section 3.1-3.3.

CONCLUSION

The obvious observation is that indoor propagation within homes appears to be site-specific. Results of these measurements can provide a worst-case path loss model within homes. This information can guide the installation procedure for the wireless system. Data calculated in this analysis indicate that the model should be based on the log distance path loss model with the addition of a distance-dependent floor loss factor. Furthermore, doors within the home do not contribute significantly to path loss. In this paper, the free space path loss of UWB communications is studied. From the analysis results, the UWB free space path loss at the frequency bandwidth about 500 MHz is almost the same with that obtained from Friss' formula

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